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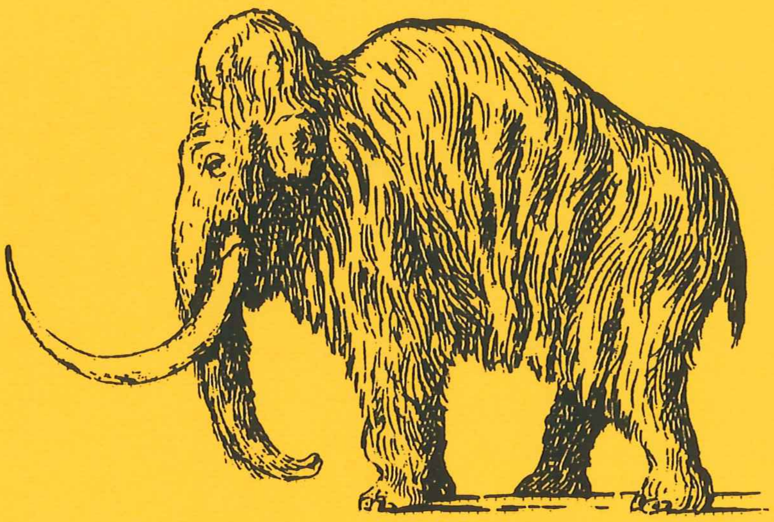

Pollen-stratigraphic position of the last Baltic Ice Lake drainage

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Nr 91

CODEN: SE-LUNBDS/NBGO-97/5091+27S

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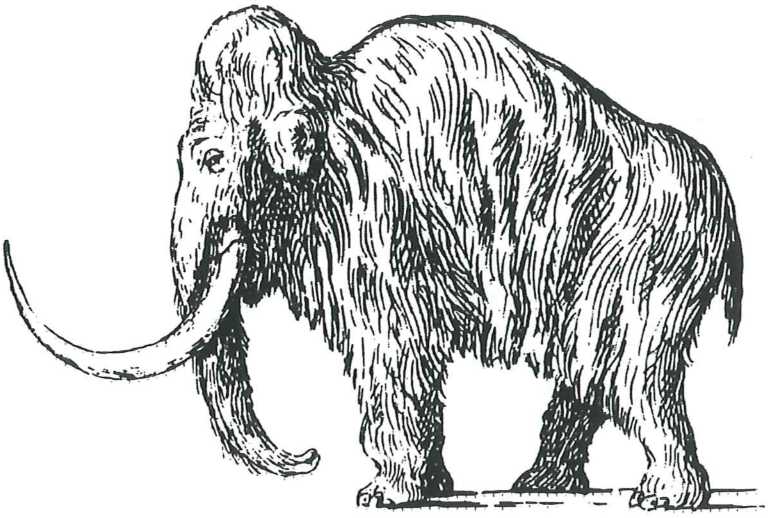

Pollen-stratigraphic position of the last Baltic Ice Lake drainage

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Lund 1997 Examensarbete, 20 p Nr 91
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ABSTRACT: High-resolution analyses of sediments from two sites in Blekinge, south-eastern Sweden (the former Lake Togölen and Lake Bredsjön), were evaluated in order to establish the pollenstratigraphical position of the second and final drainage sof the Baltic Ice Lake in relation to the Younger Dryas-Preboreal pollen zone transition. Remanent magnetisation and magnetic susceptibility were used to correlate between parallel cores and to evaluate the amount of inorganic allochthonous material. Total carbon content was analysed to determine the isolation. Detailed pollen made it possible to correlate the local pollen assemblage zones to the regional pollen assemblage zones in Blekinge. Macrofossils analyses helped to assess the surrounding vegetation during, before and after the last Baltic Ice Lake drainage. The second drainage of the Baltic Ice Lake seems to have occurred immediately before the Younger Dryas-Preboreal transition zone and as one single event.

KEYWORDS: Baltic Ice Lake, second drainage, Preboreal, Younger Dryas, pollen stratigraphy, mineral magnetic content, total carbon content, Blekinge, Sweden.

1. Introduction

The different stages of the Late Weichselian and Holocene development of the Baltic have been extensively discussed amongst geologists in the surrounding countries over the last 100 years. During the Late Weichselian deglaciation, the Baltic Ice Lake (BIL) expanded south of the retreating Scandinavian ice sheet. This first fresh-water stage was later followed successively by the marine Yoldia Sea (10,300-9,500 ^{14}C yr. BP), the Ancylus Lake (9,500-8,000 ^{14}C yr. BP) and the Littorina Sea (Björck 1995, Berglund and Björck 1994, Svensson 1989).

During the Baltic Ice Lake stage, two important drainages occurred. The first was during the late Alleröd (AL) (at c. 11,200 ^{14}C yr. BP) and the second was at the end of Younger Dryas (YD); i.e. at the transition to the Yoldia Sea (Björck 1995). Although the first drainage is still partly a topic of discussion, the last drainage is clearly recorded in marine sediments (Bergsten 1994, Jiang and Klingberg 1996, Bodén et al. 1997), in varved clays (Brunnberg 1996, Strömberg 1994) and in lake and peat bog sediments, which then became isolated from the Baltic Ice Lake (see e. g. Björck 1995, Svensson 1989). This final drainage was caused by the warming at the Younger Dryas-Preboreal (YD-PB) transition which made the ice sheet melt rapidly. As a result, the lowlands in south-central Sweden became ice free and the Baltic Ice Lake was able to drain through central Sweden into the Skagerrak-Kattegatt of the North Sea. This drainage which resulted in a lowering of the Baltic Ice Lake by c. 25 m is dated by conventional bulk radiocarbon dates to c. 10,300 ^{14}C yr. BP.

The exact timing of the last BIL drainage has been a matter of debate for many decades. Based on pollen stratigraphy and shore displacement curves in Blekinge, Berglund (1966) placed the BIL drainage during the upper part of the so-called "Younger Dryas-Preboreal transition period". Björck's (1979) investigations in Blekinge, which included pollen stratigraphy, radiocarbon dates, loss of ignition and susceptibility, showed that the drainage of the BIL occurred before the "Younger Dryas-Preboreal transition period" which he placed in the upper part of the Younger Dryas chronozone. Bulk ^{14}C dates allowed to frame the drainage to between 10,300-10,200 ^{14}C yr. BP. Björck and Digerfeldt (1984), however, based on pollen, oxygen isotopes, diatoms and radiocarbon dates argued that the drainage of the BIL occurred at 10,400 ^{14}C yr. BP, i.e. before the beginning of the YD-PB transition period (10,000-10,200 ^{14}C yr. BP). These conclusions where supported by more detailed studies performed by Björck and Möller (1987). Svensson's (1989) investigations in S Småland arrived at similar results and placed the BIL drainage at c. 10,300 ^{14}C yr. BP, at the transition between YD and the YD-PB transition zone. Based on diatom, foraminiferal, mollusc, lithological data and sediment accumulation rates, Jiang and Klingberg (1996) argued for a meltwater peak (corresponding to the BIL second drainage) at c. 10,300 ^{14}C yr. BP, which was followed by a two-step climatic warming during the YD-PB transition. Bodén et al. (1997), on the other hand, interpreted two d^{18}O spikes in foraminifera from marine sediments on the Swedish west coast as reflecting a two-step drainage of the BIL, which they placed in the early PB.

The absolute assignment of the event was, however, hampered by the fact that a long radiocarbon plateau covers the transition between YD and PB.

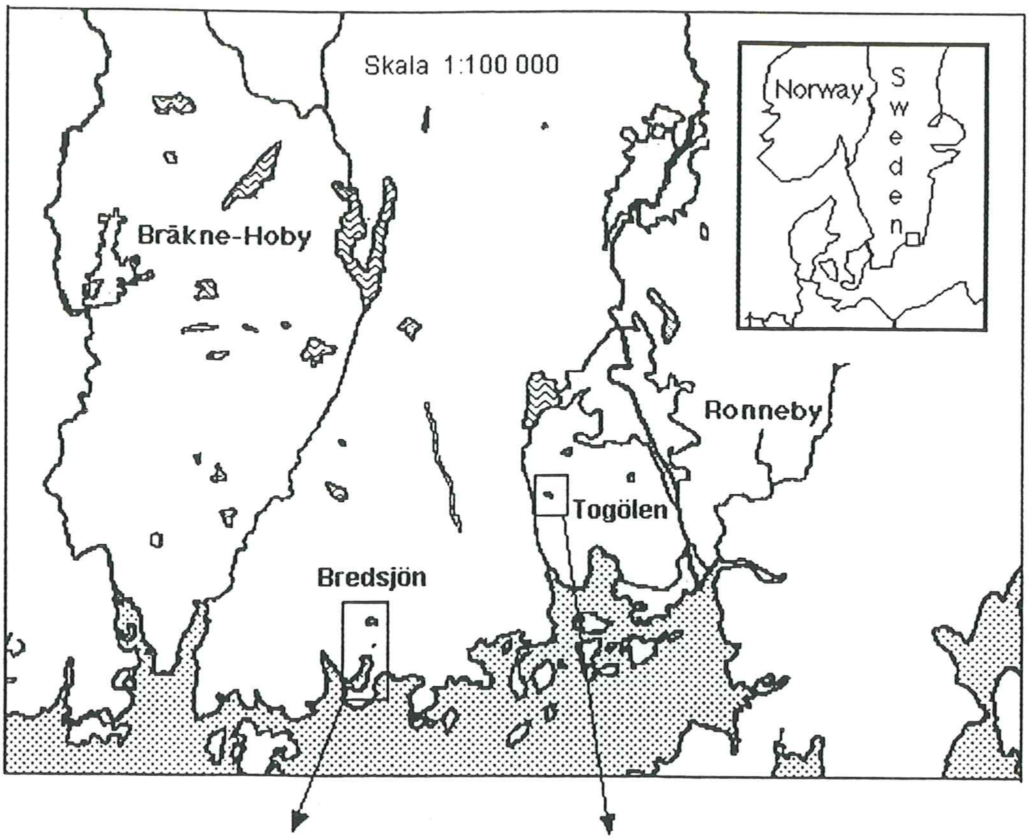

Fig. 1. Map of the investigation area showing the position of Lake Bredsjön and Togölen.

Recently, Björck et al. (1996) performed a large number of AMS ^{14}C dates which covered the YD and earlier part of the PB. By calibrating these dates to the tree ring calibration curve, they arrived at a calendar year age of 11,390-11,450 yr. BP for the beginning of the YD-PB transition zone. Furthermore, they emphasised that the beginning of the transition zone coincides with the beginning of the Holocene as seen in ice core and tree ring data. Consequently, the last drainage of the Baltic Ice Lake should then have occurred during the very end of YD, but before the end of the 10,000 ^{14}C yr. plateau. Thus, the discussion about the 'exact' position of the Last BIL drainage in relation to the YD-PB transition zone is still an open question.

The large body of meltwater discharged into the Kattegatt/Skagerak of the North Sea (Bergsten 1994, Jiang and Klingberg 1996, Bodén et al. 1997) at the YD-PB transition, must have had a large influence on the circulation in the North Atlantic. Lately, Björck et al. (1996), suggested that this melt-water injection may have disturbed the North Atlantic thermohaline circulation, which in turn may have led to the short-term cooling event, registered during the early PB, called the PB Oscillation.

The aim of the present study, is to detect from pollen stratigraphical analyses, when exactly the final Baltic Ice Lake drainage occurred in relation to the YD-PB transition in Blekinge, south-eastern Sweden. This area has a well-defined regional and local pollen stratigraphy. The shore displacement curve established for Blekinge by Björck (1979) displays the sudden drop in water level caused by the last Baltic Ice Lake drainage. Two sites which became isolated from the Baltic Ice Lake at the YD-PB pollen zone transition were chosen for the present study: the former Lake Togölen and Lake Bredsjön (Björck 1979). High-resolution analyses of pollen, macrofossils, carbon and mineral magnetic content provide a detailed record of climatic and environmental changes during the transition from YD to PB.

2. Description of the study area

2.1. Topography and geology

The province of Blekinge, situated in south-eastern Sweden (Fig. 1), consists of a coastal plain with NNW-SSE oriented river valleys, an island archipelago to the south, and the area above the Highest Shore Line to the north. Blekinge is part of the marginal area of the south Swedish upland and is composed of a mosaic landscape with rocky hills which reaches 100-150 m a.s.l. and sediment filled

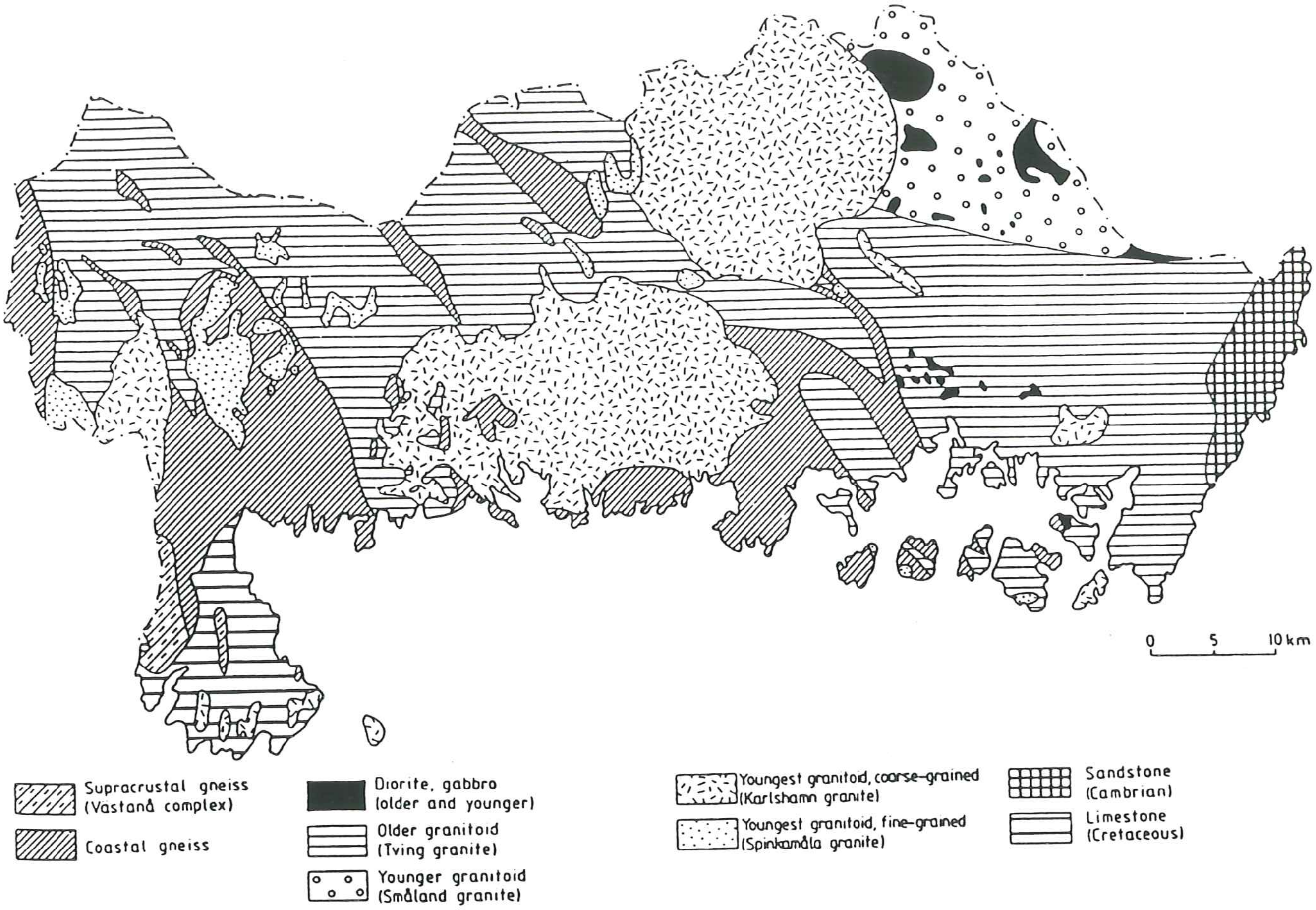

Fig. 2. Bedrock map of Blekinge, compiled by Fodgestam (1982).

valleys in the northern part. The southern surface relief is normally below 30 to 40 m a.s.l., while most of the archipelago is situated around 20 m a.s.l..

The bedrock of Blekinge is part of the Precambrian region consisting mainly of old granites and gneiss (Kornfeldt and Bergström, 1991). Blekinge "Coastal Gneiss" occurs in the western and south-central part; Karlshamn granite in the central and south-central part of the province and gneissic granite in the north-west and south-east. Greenstone has been mapped in the far east and volcanic rocks of the Västanå group in the western part (Fig. 2) (Lindström et al., 1991). The western part of Blekinge is relatively rich in diabase dikes which are usually orientated in a NNE-SSW direction (Kornfeldt and Bergström, 1991; Lindström et al., 1991). Cambrian sandstones and arcoses occur in the far east and Cretaceous limestones and arenaceous limestones in the south-east (Kornfeldt and Bergström, 1991).

2.2. Deglaciation history and Highest Shore Line

Four main ice stream directions seem to have existed during the Late Weichselian. The oldest, the Old Baltic ice stream, moved from east to west (N60°-65°E) and was succeeded by a younger stream from NNW (N30°-60°W). Following this, the next ice movement was from northeast (N20°-40°E). The youngest and last ice movement in the area came from the north (N5°-10°W) and was not influenced by local topography (Ringberg, 1971).

Deglaciation in Blekinge seems to have occurred around the beginning of the Bölling warming peak (Björck and Möller, 1987). The traditional view that deglaciation occurred as a more or less frontal deglaciation of the thick ice (Ringberg, 1971) has been challenged by Berglund (1976), who suggested an areal ice-wasting of the inland ice producing thinner ice-thickness. Björck and Möller (1987) presented two possible deglaciation models along south-north profiles across the area with different ice-flow characteristics and different basal thermal regimes: (1) Permafrost at and outside the ice margin as well as topographic conditions beneath the ice may have led to a build-up of a large zone of debris-rich basal till. (2) Surface ablation or increasing rigidity due to increased concentration of basal debris may have caused a stagnation of the ice resulting in deposition of hummocky moraine in areas above the Highest Shore Line in the northern part of Blekinge.

The Highest Shore Line of the Baltic Ice Lake was situated at c. 63.5-67.5 m a.s.l. and is considered to be synchronous over the whole area (Ringberg, 1991). Below the Highest Shore Line, varved clays deposited in the Baltic Ice Lake during the deglaciation. Ringberg (1991) calculated an initial ice recession of 100 m/year based on the regional clay-varve chronology, which decreased to 80 m/year only 20 varve years later. This was considered to be due to reduced calving intensity of the ice. The gradual isostatic uplift of the newly deglaciated areas, lowered the coastline of the Baltic Ice Lake. Deltas formed at c. 50-55 m a.s.l. at the mouth of all major river valleys, 100 to 200 years after the beginning of the deglaciation (Björck, 1981; Björck and Möller, 1987). The varved clays which were deposited during this time period are characterised by thick clayey summer and winter layers, and reflect an increase in meltwater discharge (Ringberg, 1991). According to pollen stratigraphy (Wohlfarth et al., 1994; Björck and Möller, 1987), these varved clays were deposited during the Bölling warming peak, when the stagnant ice above the Highest Shore Line began to melt rapidly.

During the initial stages of Older Dryas, varved clays were deposited below 30 m a.s.l. (Björck, 1979; Ringberg, 1979). However, due to the melting of the remaining ice and due to the continuous land uplift, varved clay deposition gradually ceased during Older Dryas. The first up-dammed stage of the Baltic Ice Lake began at c. 12,000 ^{14}C yr. BP (Björck, 1995) with the Öresund Strait acting as an outlet (Fig. 3). During the Alleröd, the shore line of the Baltic Ice Lake was situated at c. 45 m a.s.l. A first drainage of the Baltic Ice Lake is recognised at c. 11,300 ^{14}C yr. BP at the end of Alleröd (Fig. 4). This caused a regression of about 5-10 m (Björck, 1979; Berglund and Björck, 1994; Björck, 1995).

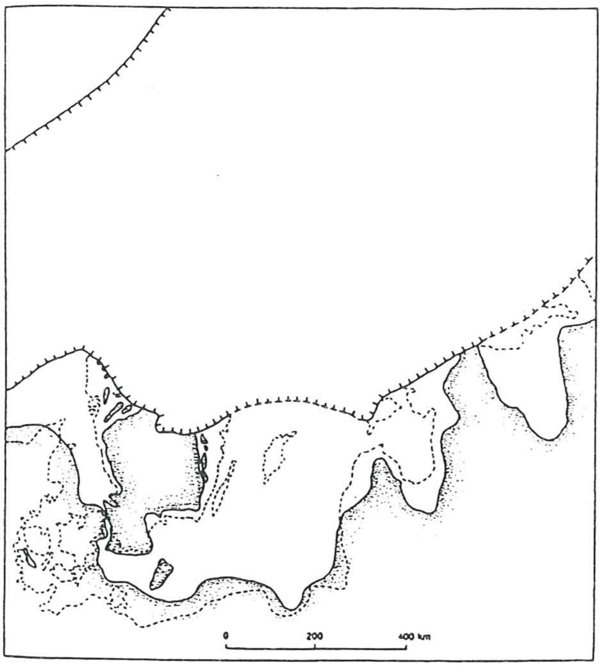

Fig. 3. The first up-dammed stage of the Baltic Ice Lake at 12,000 ^{14}C BP. From Björck (1995).

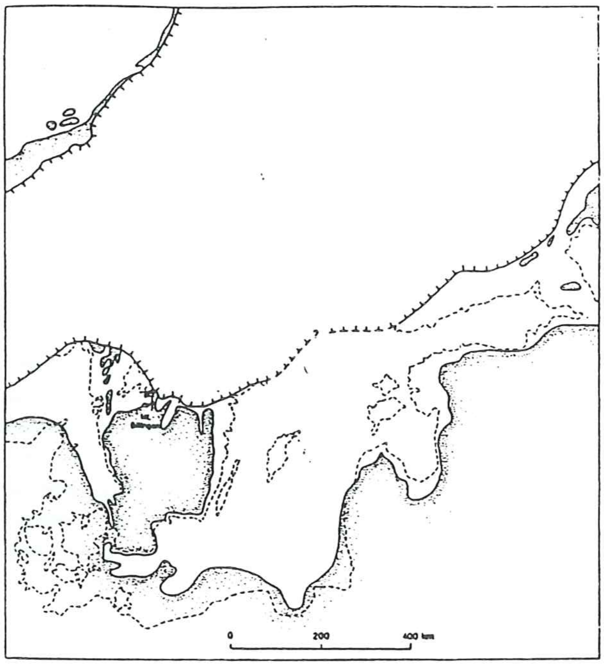

Fig. 4. The first drainage of the Baltic Ice Lake at 11,200 ^{14}C BP (the end of Alleröd). From Björck (1995).

At the beginning of YD, the readvance of the ice sheet south of Billingen resulted in a renewed damming of the Baltic Ice Lake (Fig. 5) which seems to have begun around 10,800 ^{14}C yr. BP (Berglund and Björck, 1994). The shore line in Blekinge was situated approximately at c. 30 m a.s.l.. During the middle part of YD (c. 10,500 -10,400 ^{14}C yr. BP according to Björck and Digerfeldt (1989)), the ice started to melt again culminating in the last drainage of the Baltic Ice Lake at Mt. Billingen (Fig. 6), which marked the termination of the Baltic Ice Lake stage (Björck, 1979; Björck and Digerfeldt 1984,1986,1989; Lagerlund and Björck, 1979; Svensson, 1989; Strömberg 1992,1994). As a result, a regression of at least 25 m is recorded in lake sediments in Blekinge (Björck, 1979; Björck, 1995).

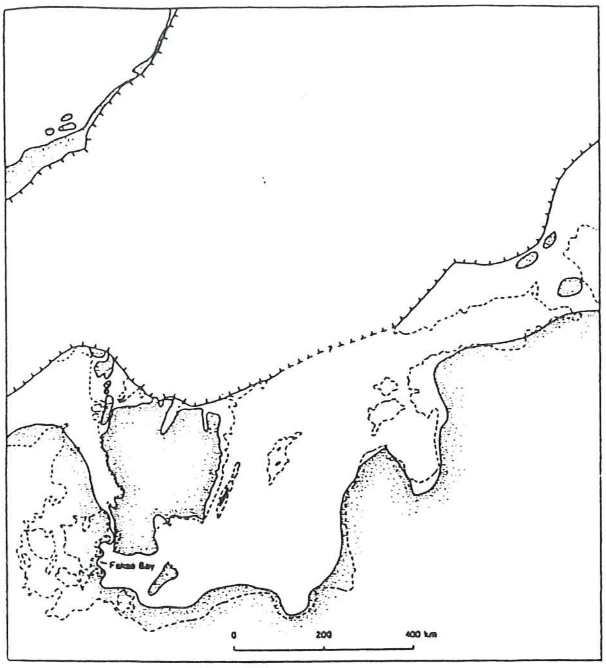

Fig. 5. The renewed damming of the Baltic Ice Lake at the beginning of Younger Dryas. From Björck (1995).

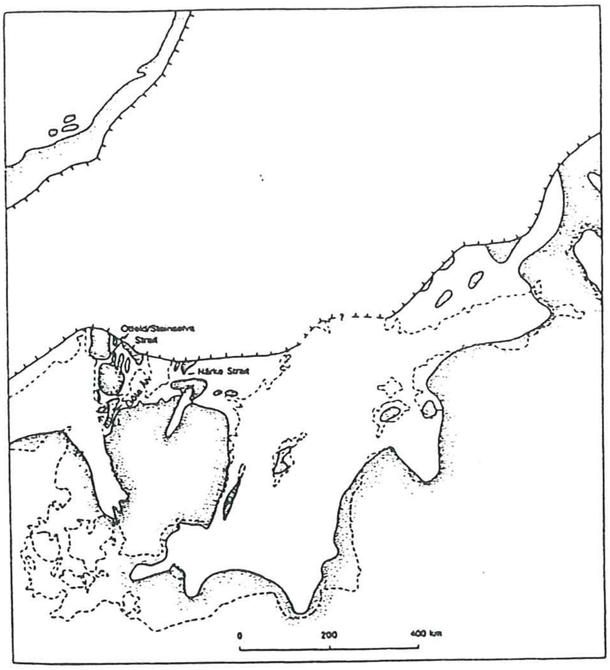

Fig. 6. The extension of the Baltic Ice Lake after the final drainage. From Björck (1995).

^{14}C yr BP	Berglund, 1966	Björck, 1979	Björck and Möller, 1987	Björck et al. 1996
	PB	**Betula-Pinus**	PB	PB
10,000	* DR 3-PB	**Juniperus-Empetrum-Pinus-Betula**	YD III	
10,200	DR 3	***Betula nana-Cyperaceae-Pinus-Artemisia**	YD II *	YD
10,500		**Artemisia-Juniperus-Gramineae-Chenopodiaceae**	YD I	
11,000				

*Table 1. Synthesis of previous investigations in Blekinge: the regional pollen assemblage zones. * marks where different authors place the isolation =BIL drainage.*

2.4. Late Weichselian pollen stratigraphy and ^{14}C chronology[1]

The immigration of plants into Blekinge rapidly followed the deglaciation. A shrub tundra with scattered stands of tree birch characterises the Bölling period (Björck and Möller, 1987). Increasing pollen influx values between 12,400 and 12,200 ^{14}C yr. BP suggest a climatic peak. During the succeeding 150 ^{14}C years (correlated to the Older Dryas stadial), arid and cold tolerant species expanded again (Björck and Möller, 1987). The following 700 ^{14}C years of the Alleröd, a characterised by a half-open woodland dominated by birch and in some cases pine. *Empetrum* became common as the woodland opened, at c. 11,300 ^{14}C yr. BP suggesting a slow but progressive climatic deterioration (Björck and Möller, 1987).

During the YD stadial, pollen influx values decreased and, the proportion of NAP (non arboreal pollen; i.e. shrubs and herbs) increased, especially *Artemisia*, Chenopodiaceae and Poaceae. *Empetrum* became probably disfavoured by soil disturbance (Björck and Möller, 1987). Warmer conditions are indicated by the abundance of *Empetrum* at c. 10,200 ^{14}C yr. BP and the reimmigration of *Pinus* between c. 10,200-10,100 ^{14}C yr. BP (Björck and Möller, 1987).

The end of the YD stadial in lake sediments in Blekinge, as well as in other areas in S Sweden is characterised by a lithological change from mainly minerogenic to more organic sediments. This transition coincides with the increase in *Empetrum* (~10,200 ^{14}C yr. BP), which marks the beginning of the YD-PB transition zone (Berglund, 1966; Björck, 1979). Following Björck et al. (1996) this pollen zone is now attributed to the beginning of the PB.

The PB in Blekinge was characterised by birch and pine forests, with minor *Artemisia* and grass communities, suggesting a cool-temperate climate (Berglund, 1966). A synthesis of previous works on pollen stratigraphy in Blekinge is presented in Table 1.

3. Site descriptions

3.1. Togölen

Togölen is an overgrown lake (c. 175 m x 75 m). It is situated 2.5 km SSW of Ronneby and 3 km from the coast (N 56°11´27´´, E 15 °15´26´´), at an altitude of 15 m a.s.l. (Fig. 7). Before the artificial lowering (Björck, 1979), the original level of the former lake was probably c. 20 m a.s.l. Togölen is surrounded by till. A fissure valley lies west of the basin and is covered by clayey and silty deposits.

The vegetation around the bog (Fig. 8) consists mainly of pine forest with some birch, with a ground cover of bramble (*Rubus chamaemorus*) and cowberry (*Vaccinium vitis-idaea*). Togölen´s surface vegetation is dominated by herbaceous perennials such as cotton-grass (*Eriophorum vaginatum*), sedge vegetation (*Cyperus flavescens* and *Cyperus fuscus*) and aquatic and swamp species of the Bur-Reed Family (*Sparganium angustifolium* and *Sparganium erectum*).

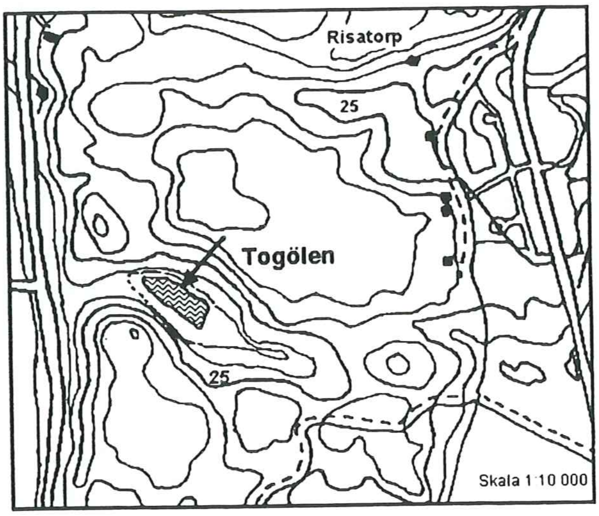

Fig. 7. The local topographic position of the peat bog Togölen. The arrow marks the coring point.

3.2. Bredsjön

Bredsjön is c. 225 m long and 125 m wide. It is located 6 km south-west of Ronneby and just north of the coast (N 15°12´3´´, E 56°10´4´´) (Fig. 9). The water level of the lake is now situated at 9 m a.s.l., but according to Björck (1979), the lake has been lowered by about 3 m. The basin is located at the very southern part of the bedrock plateau between Bräkne-Hoby and Ronneby (Gustavsson, 1977). Bredsjön is surrounded by bedrock and till. The vegetation around the lake (Fig. 10) is made up of deciduous forest which includes some pine. The lake side vegetation is dominated by aquatic and swamp perennials up to 2.5 m high, such as reedmace (*Typha latifolia* and *Typha angustifolia*), while e.g. lilies (*Nuphar lutea* and *Nymphea alba*) are common in open water.

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[1] Based on bulk ^{14}C dates.

Fig. 8. Togölen at the time of coring in June, 1996.

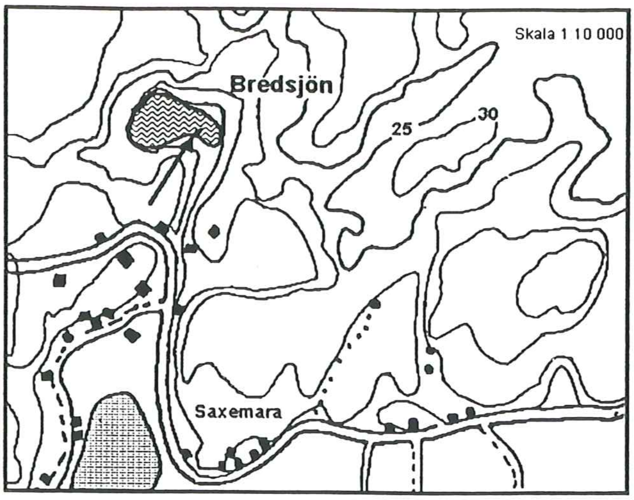

Fig. 9. The local topographic position of Lake Bredsjön. The arrow marks the coring point.

4. Methods

4.1. Field work

Both sites were cored during June 1996, as close to the deepest part of the basin as possible. At Togölen five parallel profiles were cored (in order to obtain enough plant material for AMS ^{14}C measurements), whereas at Bredsjön only two profiles were collected. Coring was carried out using a Russian sampler (Jowsey, 1966; Aaby and Digerfeldt, 1986) with an inside diameter of 100 mm and a length of 1 m. The location of the sampling sites is indicated in Figs. 7 and 9. A preliminary description of the lithostratigraphy of the sediments was carried out in the field. The cores were photographed, carefully wrapped in plastic, and placed in half PVC tubes prior to transport. The sediments were then stored at temperatures around 5°C in the cold room for one night.

4. 2. Laboratory work

4.2.1. Description and sampling of the cores

All cores were again described in the laboratory. The lithostratigraphy is presented in Tables 2 and 3. As the core surface became oxidised soon after exposure to air, the colour of the unoxidised sediment, described in the field, was used in the colour description. The sediment cores were correlated to each other according to their lithostratigraphy. Out of the five cores in Togölen (one at level 4.60-5.60 m, three at 4.50-5.50 m and one at 4.30-5.30 m) and two cores in Bredsjön (4.65-5.65 m and 4.75-5.75 m), a single profile from each locality was chosen as a reference core (at Togölen the core 4.60-5.60 m and for Bredsjön the core 4.65-5.65 m). In these cores the visual sediment stratigraphy seemed to be most complete. These were therefore sampled in detail, for magnetic, carbon and pollen analyses. In addition to this and, in order to verify the lithostratigraphic correlation, an additional core from Togölen out of three at the same level (4.50-5.50 m A-C) named core B, and the second core from Bredsjön (5.75-4.75 m) were sub-sampled for magnetic analyses. In Togölen, all cores except for the reference core were also sampled for macrofossils. Before sampling, the core surfaces were carefully cleaned. After sampling, the reference cores were wrapped in plastic and once again stored at 5° C in the cold room.

4.2.2. Mineral magnetic measurements

Mineral magnetic measurements, (SIRM and susceptibility), were carried out in order to correlate between the cores and to determine the level at which the isolation occurred. SIRM (Saturation Isothermal Remanent Magnetisation) reflects the rough concentration of magnetic particles in a lake sediment or peat (Thompson and Oldfield, 1986). The measurement is taken once the sample has been magnetically saturated. Saturation is acquired by inducing a strong magnetic field of 1 Tesla with a Redcliff pulse magnetiser. The induced magnetisation was measured on the fresh samples (Stober and Thompson, 1979). Magnetic susceptibility, according to Thompson and Oldfield (1986), is the ratio of induced magnetisation to applied field. Variations in the amount of in-washed inorganic allochthonous material in the area can be correlated to the changing susceptibility in lake sediments. Subsamples for magnetic measurements were taken in contiguous plastic boxes (2x2x2 cm) along the entire core except for over a lithostratigraphic boundary. The same samples were used for both SIRM and susceptibility. The samples were dried at 45° C to calculate mass specific SI units. The remnant magnetism was measured with a Molspin "Minispin" magnetometer and the results are expressed in mAm^{-1}. The susceptibility measurements were made by using a Digitalt Voltmeter Kopparbridge, KLY-2 and the results are expressed in 10^{-6} S.I. units.

4.2.3. Carbon analysis

Both organic and inorganic carbon can be determined by stepwise heating in a multiphase carbon/hydrogen/moisture determinator of model 787-900-300 (Leco RC-412). This is a

Fig. 10. Lake Bredsjön in June 1996, seen from the highest level on the east side of the lake.

microprocessor-based instrument with defined functions, controlled by a computer program. It allows the user to determine the source of several types of C. All forms of carbon are converted to CO_2 by analysing the samples in an oxidising atmosphere. The presence of organic carbon may, therefore, be verified by finding coincident peaks in H_2O and CO_2. The Leco RC-412 employs a state-of-the-art furnace control system which allows the temperature of the furnace to be stepped and ramped. Concentrations are reported as % C of the dry weight. The heating is stepwise up to 950 °C and the errors can be in the order of 0.3%. The total carbon content in a lake sediment is the product of the total stable organic material present in the sediment at 450-550 °C. Carbon derived from bedrock as coal is thermally stable up to temperatures of c. 750 °C.

Samples for carbon analysis in Togölen were taken at 2.5 cm intervals at the bottom of the cores and at 0.5 cm intervals further up. Sub-sampling in Bredsjön was made at 5 to 10 cm intervals above and below the presumed isolation level, and at 2 cm intervals around the level itself. The samples were dried overnight at 105 °C and then crushed to powder. 0.3 g of the material was removed and burnt from each sample and measured with an electrical balance (Precisa 100A-300M).

Layer No	Core depth (m)	Lithological description
T 6	4.60 - 4.69	Brown fine detritus gyttja, gradual LB.
T 5	4.69 - 4.775	Light brown fine detritus gyttja, sharp LB.
T 4	4.775 - 4.805	Light brownish grey gyttja clay with deformation structures, diffuse LB.
T 3	4.805 - 4.87	Bluish grey silty clay with some moss remains, FeS stains and high water content, gradual LB.
T 2	4.87 - 5.01	Reddish grey sandy silty clay with very high water content and FeS stains, gradual LB.
T 1	501 - 560	Bluish grey clayey silt, turns to yellowish due to oxidation. Fairly compact with FeS laminae at: 5.08; 5.20; 5.36; 5.51m.

Table 2. Lithostratigraphy of the reference core from Togölen. LB = lower boundary.

Layer No	Core depth (m)	Lithological description
B 9	4.65 - 5.04	Greenish brown fine detritus gyttja, gradual LB.
B 8	5.04 . - 5.125	Green yellowish brown clayey fine detritus gyttja, extremely rapid oxidising, sharp LB.
B 7	5.125 - 5.15	Greyish brown gyttja clay, with deformation structures and FeS stains, diffuse to gradual LB.
B 6	5.15 - 5.23	Light grey silty clay, rather loose in consistence, with a lot of FeS stains and probably moss remains, diffuse LB, differs in consistence and colour from the next layer.
B 5	5.23 - 5.31	Reddish grey clayey silt, more compact than the next layer, with some FeS stains and a gradual to sharp LB.
B 4	5.31 - 5.39	Reddish grey silty fine sand, very loose, FeS spots few droplets and sharp to gradual LB, gravel at 5.23 m.
B 3	5.39 - 5.41	Bluish grey silty fine sand layers about 0.5 cm thick with a reddish layer in the middle, diffuse LB.
B 2	5.41 - 5.50	Reddish grey clayey silt, with a lot of FeS stains and two 0.4 cm layers of sand at 5.47 and 5.48 m, gradual to sharp LB.
B 1	5.50 - 5.65	Yellowish grey silty fine sand with FeS stains.

Table 3. Lithostratigraphy of the reference core from Lake Bredsjön. LB = lower boundary.

4.2.4. Pollen analysis

Sub-samples for pollen analysis (3-4 cm^3 in the minerogenic material and 1 cm^3 in the organic material) were taken with a cut syringe. At Togölen, the sample interval varied between 1 cm at the base and 0.5 cm at the top of the core. At Bredsjön, the sampling interval was between 4 to 5 cm at the bottom and 1 to 2 cm at the top of the core. To enable the calculation of pollen concentrations, 1 or 2 Lycopodium tablets containing 11,267 Lycopodium spores, were added to each sample. The preparation of the pollen samples follows the description in Berglund and Ralska-Jasiewiczowa (1986), apart from the following modifications: the addition of HNO_3 was excluded, as pyrite was not visible in the sediment. The HF treatment together with HCl (to avoid petrifaction), gave best results when the samples were left in cold 40% HF. However, in most of the samples, a repeated HF treatment was necessary. Samples with a volume of 3-4 cm^3 and a high amount of coarse minerogenic material were left in cold 40% HF for 6 weeks and stirred 2-3 times a week. The HF solution was changed 3 times during this period, because fresh acid notably improved the preparation.

In order to avoid any errors associated with random pollen distributions, the tubes were stirred for 3 minutes before preparing the slides. A Zeiss Opton microscope with 40x Zeiss fluorite objective was used for routine analysis and a 100x Zeiss achromatic oil-immersion objective for critical analysis. Equally spaced traverses on the slides were analysed. A reticule with a measuring scale was used to determine pollen size. Pollen and spore identification was carried out using pollen keys and photographs by Moore & Webb (1978), Reille (1992) and Erdtman et al (1961) and by comparison with pollen-reference slides from the collection at the Dept. of Quaternary Geology in Lund. In order to distinguish between *Betula nana* and *Betula alba*, the detailed description in Terasäe (1951) and Praglowski (1962) were used. Pollen percentage diagrams were constructed using a calculation sum composed of all terrestrial pollen. The pollen profiles are presented as %'s of total terrestrial pollen.

4.2.5. Macrofossil analysis

Uncarbonized fruits, seeds, leaves, budscales and mosses were extracted to add information on the surrounding vegetation. For the macrofossil analyses, 13 different sampling levels were chosen as follows: 5 samples of 10 cm each in the clayey silt (see Table 2 for lithology); 2 samples of 7 cm each in the sandy silty clay; 2 samples of 3 cm each in the silty clay; 2 samples of 1.75 cm each in the transition zone; and finally 3 samples of 3.3 cm each in the clayey gyttja. Samples rich in clay and silt were placed in a solution with 1 part 5% $Na_4P_2O_7$ and three parts distilled water to aid dispersion of the clay particles. Organic rich samples were kept in a solution with one part 10% NaOH and three parts distilled water. This treatment was carried out immediately after sub-sampling and the samples remained in solution for 1-2 nights.

They were then sieved through a 0.5 mm sieve under running water. The extracted macrofossils were stored in a solution of distilled water with one drop of 5% HCl. The macrofossils were determined under a binocular microscope. Identification was carried out by comparison with modern reference material from the Dept. of Quaternary Geology in Lund, with plates in Grosse-Brauckmann (1986) and in Huysmans and Allemeersch (1991).s

4.2.6. AMS (accelerator mass spectrometry) ^{14}C measurements

Terrestrial macrofossils selected for AMS ^{14}C dating were immediately dried on aluminium foil (at 50°C over night). The samples contained between 1.05 and 2.70 mg dried material. They were then stored in sterilised glass bottles and sent to the Tandem Laboratory in Uppsala where the usual pre-treatment was applied with 1% HCl and 0.5% NaOH.

5. Results

5.1. Lithostratigraphy, mineral magnetic and carbon analyses

5.1.1. Togölen

The sediments were divided into six lithostratigraphic layers based on sediment colour, grain size and organic content (Table 2 and 3). The bottom layer T1, between 5.60-5.01 m, is characterised by a bluish-grey, fairly compact clayey silt with laminae of FeS. As shown in Fig. 11, bulk SIRM values fluctuate between 2 and 6 mAm^2kg^{-1} below 5.36 m, but remain constant at 4 mAm^2kg^{-1} between 5.36-5.07 m. At 5.045 m the values shows a distinct decrease (observed in one sample), after which there is a return to the same values as before. Bulk susceptibility fluctuates approximately between 0.3-0.8 S.I. units. A similar development can be observed in core 5.50-4.50 m (core B) (Fig. 11). However, the bulk SIRM values here are more constant throughout layer T1. The distinct decline in SIRM values, seen at 5.045 m (in core 5.60-4.60 m) occurs here at 5.095 m. Total carbon remains constant below 0.5%.

A loose reddish-grey, sandy silty clay with FeS stains (layer T2 between 5.01-4.87 m) follows with a diffuse to gradual lower boundary. The sediment was almost lost during sub-sampling because of its high water content. A continuous decrease of the bulk SIRM values from 5 to 1.5 mAm^2kg^{-1} can be observed (Fig. 11). The abrupt decrease in bulk susceptibility from 0.8 to 0.3 S.I. units between 5.00-4.93 m is followed by a more gradual decline to 0.15 S.I. units between 4.93-4.87 m. In core B, the bulk susceptibility in layer T2 (between 4.97-4.91 m) decreases from 0.8 to 0.05 S.I. units, but is followed by a slight increase to 0.15 S.I. units up to 4.87 m. Bulk SIRM in core B follows the same pattern as in the reference core, constantly decreasing between 4-2 mAm^2kg^{-1} (Fig. 11). Although a weak increase in total carbon content can be observed, the values remain below 1% (Fig. 12).

Layer T3 (4.87-4.805 m) consists of a bluish-grey silty clay with some moss remains and FeS stains and has a gradual lower boundary. No important change is seen in the bulk SIRM values, which show an insignificant decrease from 0.15 to 0.1 mAm^2kg^{-1} in the reference core, and between 2-1 mAm^2kg^{-1} in core B (Fig. 11). A similar pattern can be observed in the susceptibility values which drop from 0.3 to 0.2 S.I. units. The bulk susceptibility in core B remains constant at around 0.2 S.I. units. The total carbon content increases steadily, reaching 1.7% in the upper part of this layer (Fig. 12).

In layer T4 (4.805-4.775 m), the sediments change to a light brownish-grey gyttja clay with a diffuse lower boundary. This layer represents a peculiar depositional structure composed of several more or less globular protrusions of light brownish gyttja. These later appear to float in light grey clay, which gives the sediment a disturbed ´slurried` texture. Upward-pointing wedges of gyttja occur in the clay and isolated nodules of clay float in the gyttja which suggest load casts and flame structures (Fig. 13). Bulk SIRM and bulk susceptibility decrease only slightly in both cores, while the total carbon content increases dramatically from 1.7% to 8% (Fig. 11).

The transition to unit T5 (4.775-4.69 m) is sharp, and characterised by a distinct increase in organic matter. The light brown clayey gyttja shows an insignificant decrease in bulk SIRM values from 1.5 to 1.0 mAm^2kg^{-1} in the reference core, whilst the values stay around 0.8 mAm^2kg^{-1} in core B (Fig. 11). This decline is clearer in the bulk susceptibility values, which decrease slightly to 0.5 S.I. units in the reference core and to 0.4 S.I. units in core B (Fig. 11). Layer T5 contains the uppermost samples analysed for total carbon content, which here increase from 8 to 12.5% (Fig. 11). This change is due to the increase in organic matter.

The top layer in Togölen, T6 (4.69-4.50 m), is a brown fine detritus gyttja with a gradual lower boundary. Bulk SIRM and susceptibility values in both cores are reduced and stabilised very close to zero (Fig. 11).

The lithostratigraphy of the sediments in Togölen presented by Björck (1979), included from bottom to top: a grey, slightly muddy clay (layer 1), a grey muddy clay (layer 2), a brown-grey clay gyttja (layer 3) and a brown fine detritus gyttja (layer 4).

The lithostratigraphic subdivision described here (T1-T6) compares well to Björck's (1979) stratigraphy: T1 and T2 correspond to layer 1, T3 to layer 2 and T5 and T6 to layers 3 and 4, respectively. The transition between minerogenic and organic layers represented in T4 has however, not been

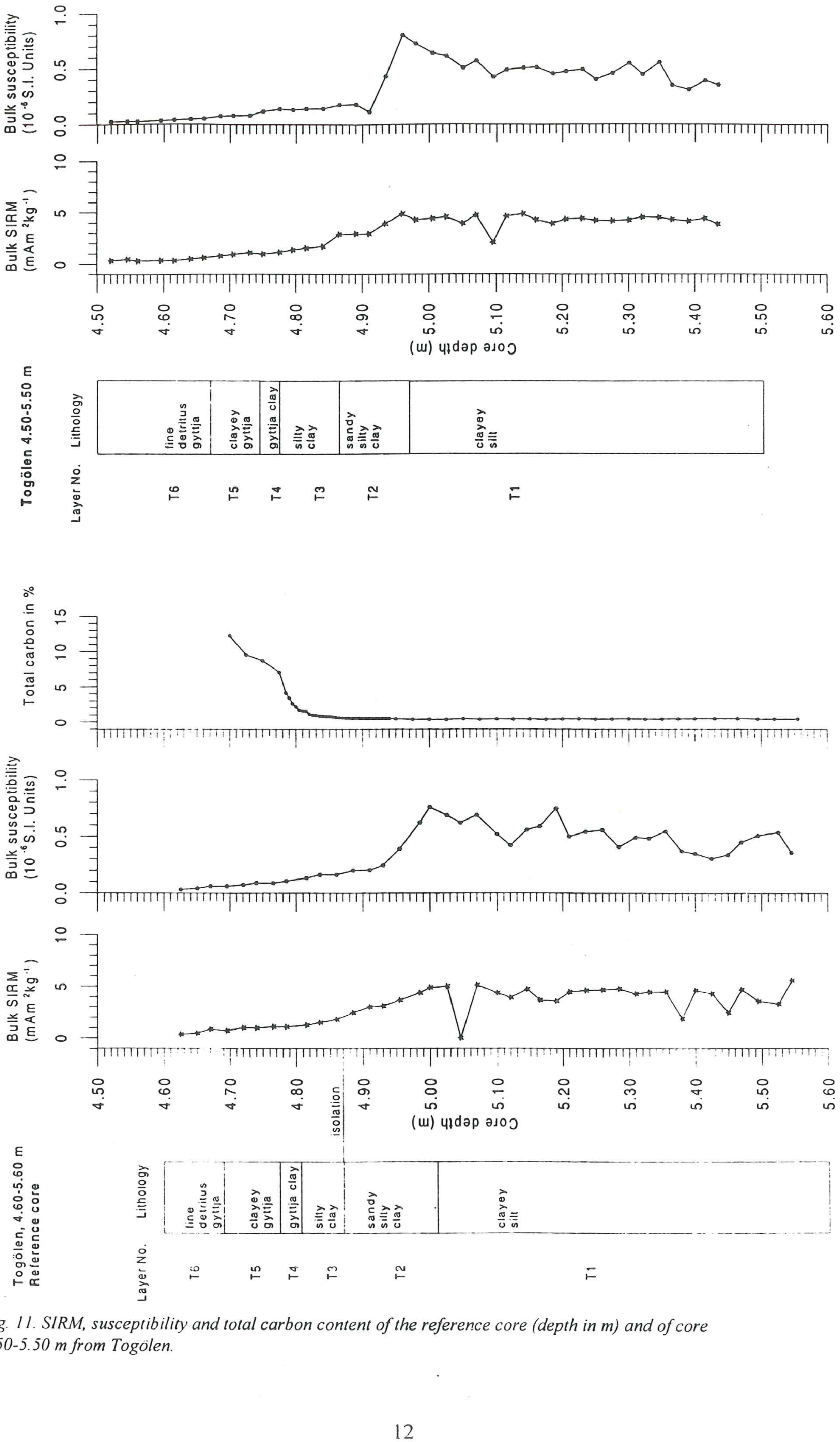

Fig. 11. SIRM, susceptibility and total carbon content of the reference core (depth in m) and of core 4.50-5.50 m from Togölen.

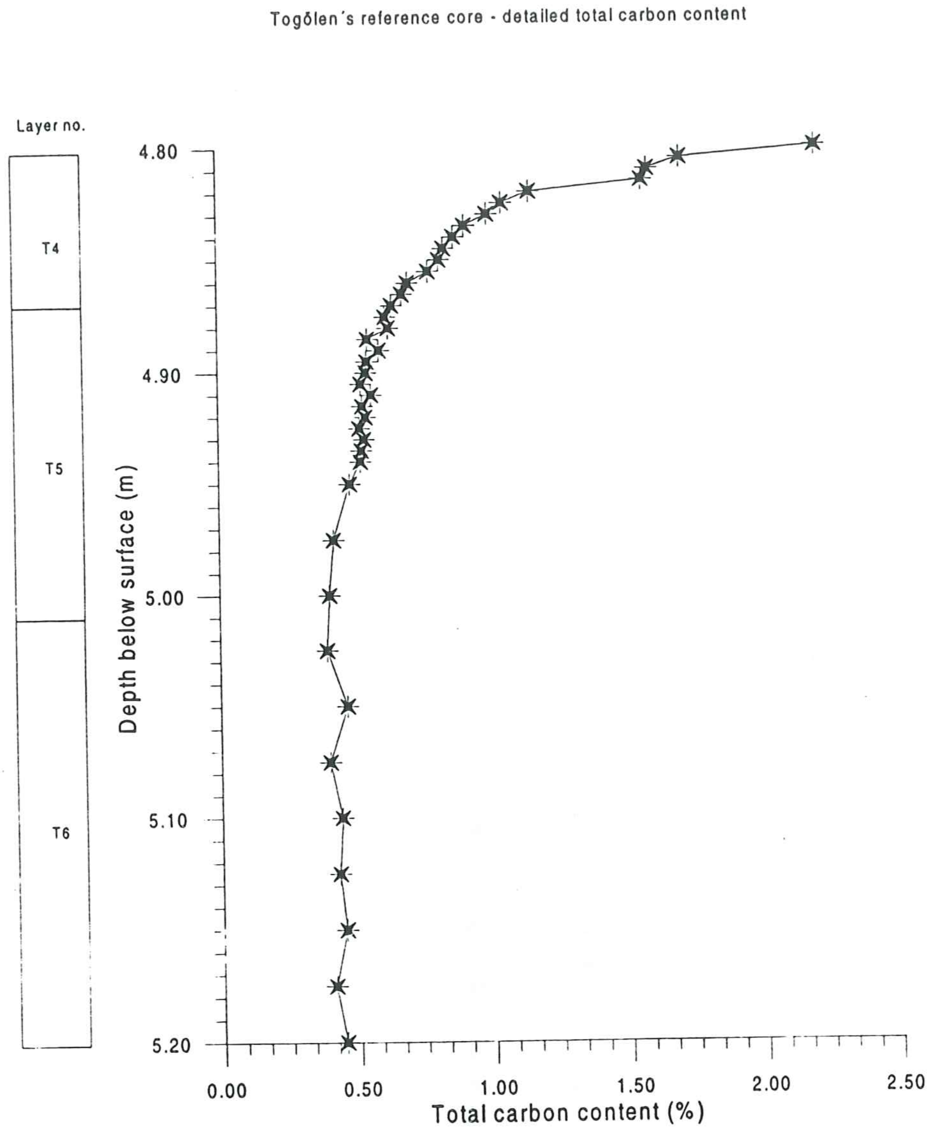

Fig. 12. Total carbon content of the reference core from Togölen between 4.80 and 5.20 m.s

Local pollen assemblage zone in this work		Local pollen assemblage zones according to Björck (1979)	
T4	Betula-Empetrum-Hippophaë	T8	Betula-Empetrum-Hippophaë
T3	Juniperus-Cyperaceae-Empetrum	T7	Juniperus-Cyperaceae-Empetrum
T2	Salix-Cyperaceae	T6	Salix-Artemisia-Cyperaceae
T1	Pinus-Betula nana-Juniperus	T5	Pinus-Betula nana-Juniperus

Isolation

*isolation according to Björck (1979)

Table 4. Correlation between the local pollen assemblages at Togölen presented by Björck (1979) and the diagram presented here.

observed by Björck. The lithostratigraphic subdivision described here (T1-T6) compares well toBjörck's (1979) stratigraphy: T1 and T2 correspond to layer 1, T3 to layer 2 and T5 and T6 to layers 3 and 4, respectively. The transition between minerogenic and organic layers represented in T4 has however, not been observed by Björck.

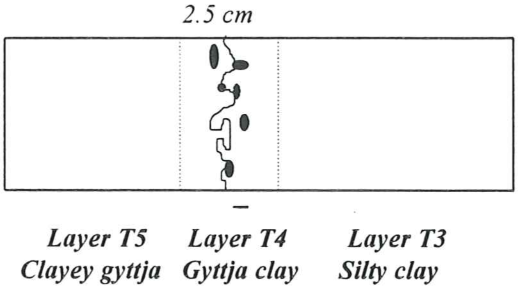

Fig. 13. Depositional structure showing wedges of gyttja floating in clay and nodules of clay in gyttja.

5.1.2. Bredsjön

The lowermost minerogenic sediment layer in Bredsjön is B1 (5.75-5.60 m), a yellowish-grey silty fine sand with FeS stains. A slight increase in the bulk SIRM values from 5 to 8 mAm^{2}kg^{-1} is visible up to 5.55 m in the next layer (Fig. 14), while bulk susceptibility decreases from 1.5 to 0.8 S.I. units. No magnetic measurements were made in the bottom layer of Bredsjön's core 5.75-4.75 m, between 5.75-5.70 m.

A reddish-grey clayey silt follows, which has a sharp to gradual lower boundary (B2, 5.60-5.41 m). It contains two sand layers at 5.48 m and 5.47 m, with many FeS stains. A two-step alternation of the SIRM values can be observed: from 8.75 m Am^{2}kg^{-1} at 5.54 m down to 6.26 mAm^{2}kg^{-1} at 5.49 m (Fig. 14). In the next sample (5.46 m), SIRM reach a value of 7.5 mAm^{2}kg^{-1} followed by a dramatic drop to 1.25 mAm^{2}kg^{-1} at 5.42 m. Susceptibility values fluctuate between 1.5 S.I. units at 5.54 m, 0.8 S.I. units at 5.49 m and 0.2 S.I. units at 5.42 m. Core 5.75-4.75 m contains a longer sequence of clayey silt (5.70-5.48 m) (Fig. 14). The SIRM values are fairly constant around 7 mAm^{2}kg^{-1} between 5.70-5.54 m. They decrease to 5 mAm^{2}kg^{-1} in the next two samples (5.52 and 5.50 m), but increase again to 7.5 mAm^{2}kg^{-1} at 5.48 m. Bulk susceptibility values fluctuate between 0.8 and 1.8 S.I. units.

Layer B3 (5.41-5.39 m), contains three c. 0.5 cm thick silty fine sand horizons, with different colours. The lower boundary is sharp and the colour of the sediments changes from: bluish -, to reddish-and bluish-grey. No magnetic measurements were carried out on the reference core. In core 5.75-4.75 m , the SIRM values drop from 9 mAm^{2}kg^{-1} at 5.48 m to 6 mAm^{2}kg^{-1} at 5.46 m (Fig. 14). The decrease in susceptibility from 2.2 S.I. units at 5.48 m to 2.0 S.I. units at 5.46 m is not so marked.

Total carbon content remains close to zero from the base of the core up to the middle of the next layer, (B4 5.39-5.31 m), which follows with a sharp to gradual lower boundary. B6 is characterised by a reddish-grey silty fine sand, containing some gravel with spots and stains of FeS. This sediment was almost destroyed during sampling because of its high water content. The first sample taken at the bottom (5.39 m), shows a sudden increase in SIRM of about 7.5 mAm^{2}kg^{-1} (Fig. 14). A similar development can be observed in the susceptibility, which increases to 1.9 S.I units at the same level, and continues to rise up to 2.8 S.I. units at 5.35 m. The values of SIRM fall to 6.25 mAm^{2}kg^{-1} at 5.35, but rise once more to 7.5 mAm^{2}kg^{-1} at 5.33 m. At this level, susceptibility is reduced to 1.5 S.I. units. Core 5.75-4.75 m displays a similar pattern in susceptibility, which increases to 2.5 mAm^{2}kg^{-1} at 5.43 m, after which it continuously decreases to 0.9 mAm^{2}kg^{-1} at 5.38 m (Fig. 14). The bulk SIRM
values fluctuate but stabilise around 6.25 mAm^{2}kg^{-1} at 5.38 m.

The transition from layer B4 to layer B5 (5.31-523 m) is characterised by a gradual to sharp lower boundary. This fairly compact reddish-grey clayey silt with some FeS stains is distinguished by a continuous decrease of SIRM and susceptibility values in both cores (Fig. 14). However, the drop is steeper in susceptibility (from 0.8 mAm^{2}kg^{-1} at 5.30 m to 0.25 mAm^{2}kg^{-1} at 5.23 m) than in SIRM (from 6.3 S.I. units at 5.30 m to 5 S.I. units at 5.23 m) (Fig. 14). There is a slight increase in total carbon between 5.35-5.23 m, but the values remain below 1%.

Between 5.23-5.15 m (unit B6), the sediments are composed of light grey silty clay with some moss remains and FeS spots. The lower boundary is diffuse and the concentration of ferrimagnetic minerals (as indicated by SIRM) is reduced to halve towards to the top of the unit, in both the reference core and the 5.75-4.75 m core. The bulk susceptibility remains constant at 0.25 S.I. units throughout the whole layer in the reference core. Core 5.75-4.75 m shows stable values of susceptibility at 0.5 S.I. units with an insignificant oscillation of 0.1 S.I. units at 5.26 m in the next layer (Fig. 14). The total carbon content increases constantly from 0.1% to 2.5% (Fig. 14).

Layer B7 (5.15-5.125), which has a gradual lower boundary, has also a depositional structure made up of round pellets of gyttja, which point upward into the clay. Isolated nodules of clay similar to load casts float in the gyttja (Fig. 14).

The lower boundary of layer B8 (5.125-5.04 m) appears sharp and marks the transition to a green-yellowish brown clayey gyttja. The bulk SIRM values continue to decrease to 1.25 mAm^{2}kg^{-1} at 5.09 m (Fig. 11). However, a superficial increase of 0.4

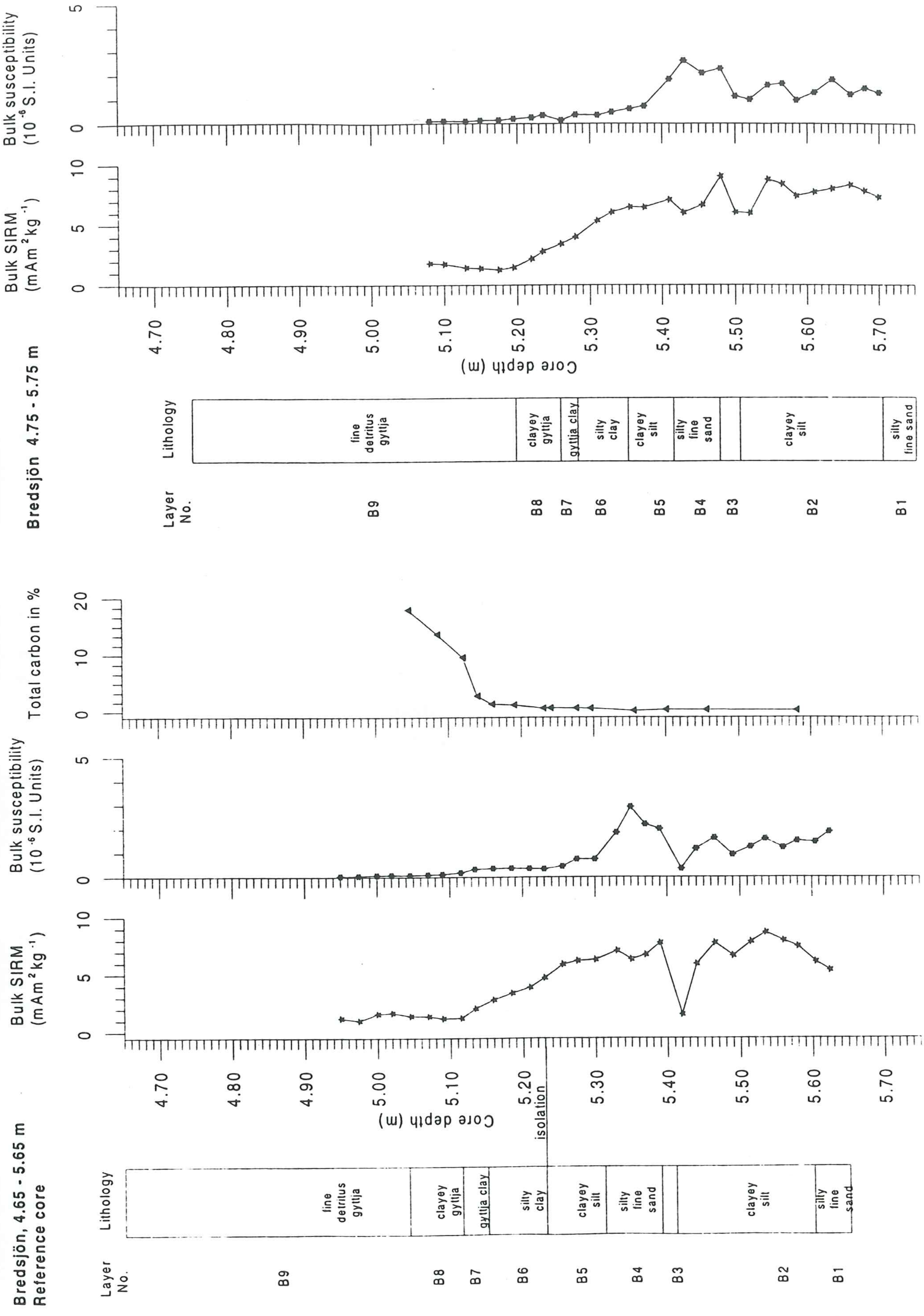

Fig. 14. SIRM, susceptibility and total carbon content of the reference core (depth in m) from Bredsjön and SIRM and susceptibility of core 4.75-5.75 m.

mAm^2kg^{-1} is visible between 5.09 m and 4.97 m. In core 5.75-4.75 m, the SIRM values reach 2.5 mAm^2kg^{-1} between 5.20-5.14 m, while values drop to very close to zero (Fig. 14).

The transition to the uppermost layer B9 (5.04-5.65 m) is gradual. Susceptibility decreases to zero in both cores while SIRM increases slightly. The total carbon content displays a marked rise to 17.5% between 5.15 and 5.05 m, again due to the increase in organic matter (Fig. 14).

Most of the carbon peaks in Togölen and Bredsjön appear below 400 °C. Some samples, however, do show a very weak peak of 0.01-0.03% C below 500 °C. As this is below the detection error, it was not considered to be significant. In order to eliminate all sources of error, a randomly chosen sample was boiled in 10% HCl for 60 minutes. The material was then rinsed three times in distilled water and burnt at 950 °C. The results gave 0.0661% total carbon, where 0.0385% burnt at 346 °C and 0.0276% burnt at 723 °C. After this treatment, the total carbon content should reflect the amount of older carbon contained in the sediment, and no carbon should have burned below 500 °C. The results from this additional preparation show, however, that the air is not clean and that particles of modern carbon exist in the air.

Björck's (1979) lithostratigraphic description of the sediments from Bredsjön compare well with the new study. They are from bottom to top: a reddish grey silty clay (layer 1), a grey silty clay (layer 2), a grey slightly muddy clay (layer 3), a light brown clay gyttja (layer 4) and a brown fine detritus gyttja (layer 5). In the lithostratigraphic subdivisions (B1-B9) described from the present work: B9 corresponds to layer 5, B8 to layer 4, B6 and B5 to layer 3, B4 and B3 to layer 2 and B1 and B2 to layer 1, respectively. However, the transition between minerogenic and organic layers, represented in B7, has not been made in the earlier study.

5.2. Pollen stratigraphy

5.2.1 Togölen

32 pollen levels were counted between 5.45 m and 5.72 m below surface. The results are presented as percentages in Fig. 15, and the profile was subdivided into four local pollen assemblage zones. A square root transformation (Edward & Cavalli Sforza's chord distance counts) was applied to verify the division of the local pollen assemblage zones. The total pollen sum counted ranges between 235 and 441 pollen/sample in the lower part increasing to between 253 and 527 pollen/sample further up the sequence (Appendix 2). The local pollen assemblage zones at Togölen are as follows:

LPAZ T1 6.45-5.01 m. ***Pinus-Betula nana* - *Juniperus*** zone. This LPAZ is the oldest pollen assemblage. *Pinus* values reaches between 20 and 50%, *Betula nana* and *Juniperus* values are high (up to 20%) and Cyperaceae (15%) and *Salix* (4%) remain constant throughout. Non-identified and/or broken pollen consist of 10% in the initial stages, decreasing to 2-3% at the top.

LPAZ T2 5.01-4.87 m. ***Salix*** -Cyperaceae zone. *Salix* pollen peaks at the beginning of this LPAZ with values of up to 15%. Cyperaceae vary between 5 and 10%, while *Juniperus* and *Betula nana* at c. 10%, are also significant. *Artemisia* pollen fluctuates between 1 and 7%. The total terrestrial pollen concentration increases slightly while *Pediastrum* maintains approximately constant values of 2-3%. *Pinus* also peaks at 60% at the beginning of the zone, subsequently decreasing to between 30 and 40%.

LPAZ T3 4.87-4.79 m. ***Juniperus*** -Cyperaceae - ***Empetrum*** zone. *Juniperus* values increase in the middle of this zone with values of almost 20%. Increased quantities of *Empetrum* and *Calluna* reach values of 6% and 5% respectively. At the top there is a decrease in Cyperaceae and *Betula nana* disappears. The total terrestrial pollen concentration increases significantly while *Pediastrum* is equivalent to 45% of the total terrestrial pollen sum.

LPAZ T4 4.79-4.72 m. ***Betula* -*Empetrum* - *Hippophaë*** zone. This LPAZ is the uppermost zone analysed in Togölen and is dominated by high percentages (> 85%) of *Betula* pollen while there is a decrease in *Pinus*, *Juniperus* and Cyperaceae. *Hippophaë* reaches almost 1% and *Empetrum* and *Salix* are comparatively high.

LPAZ T4 corresponds closely to zone T8 in Björck (1979) (see Table 4), where high values of tree pollen dominated by *Betula*, abundant *Empetrum* and significant *Hippophaë* (1%) are described. LPAZ T3 (***Salix*** -Cyperaceae) matches zone T7, which is described as being characterised by abundant shrub pollen, mainly *Juniperus*, and the highest values of *Empetrum*. However, a major difference between this diagram and the one presented by Björck (1979) is in LPAZ T2 (***Salix* -*Artemisia***-Cyperaceae), where the increase in *Artemisia* is stepwise rather than continuous. The fall in Cyperaceae described by Björck (1979), is represented here by fluctuating values of between 5 and 20%. This may be due to the close sampling interval in the present study. A match is made between LPAZ T2 and zone T6 (Björck, 1979), and between LPAZ T1 and T5 (Björck, 1979). These zones are considered to be part of the regional zone PAZ 6 (Björck, 1979).

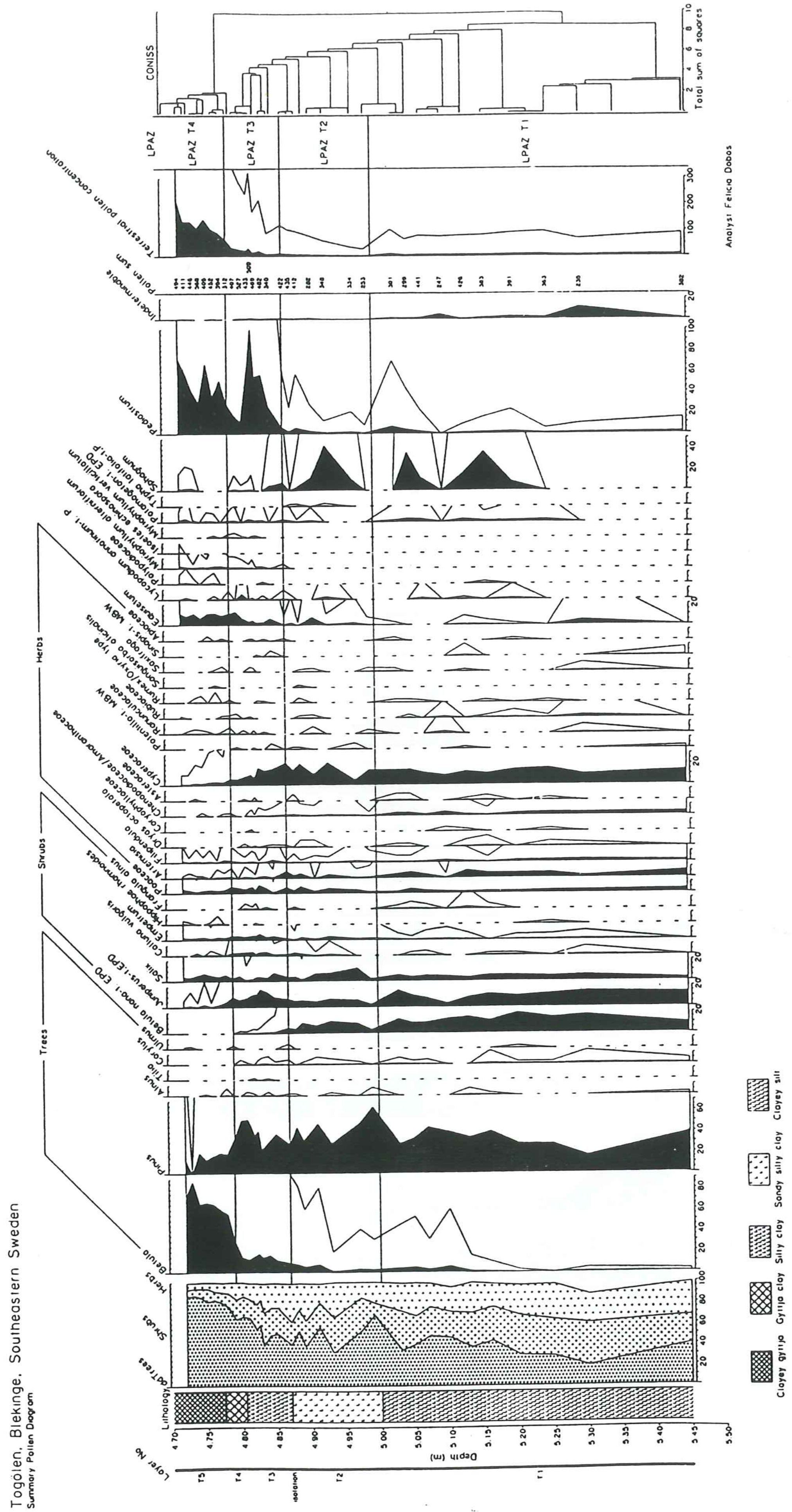

Fig. 15. Pollen, spore and algae percentage diagram for the reference core from Togölen.

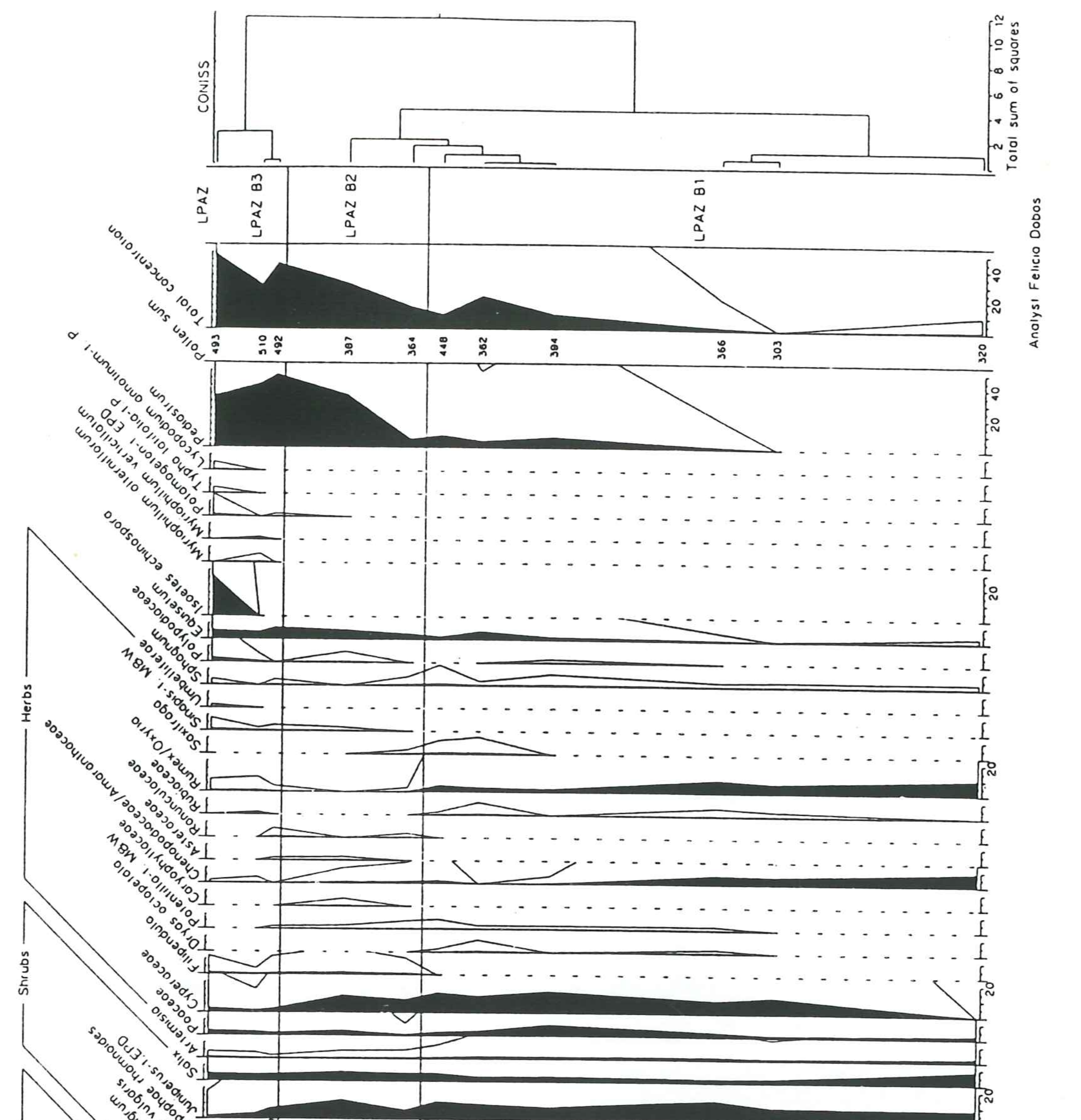

Fig. 16. Pollen, spore and algae percentage diagram for the reference core from Bredsjön.

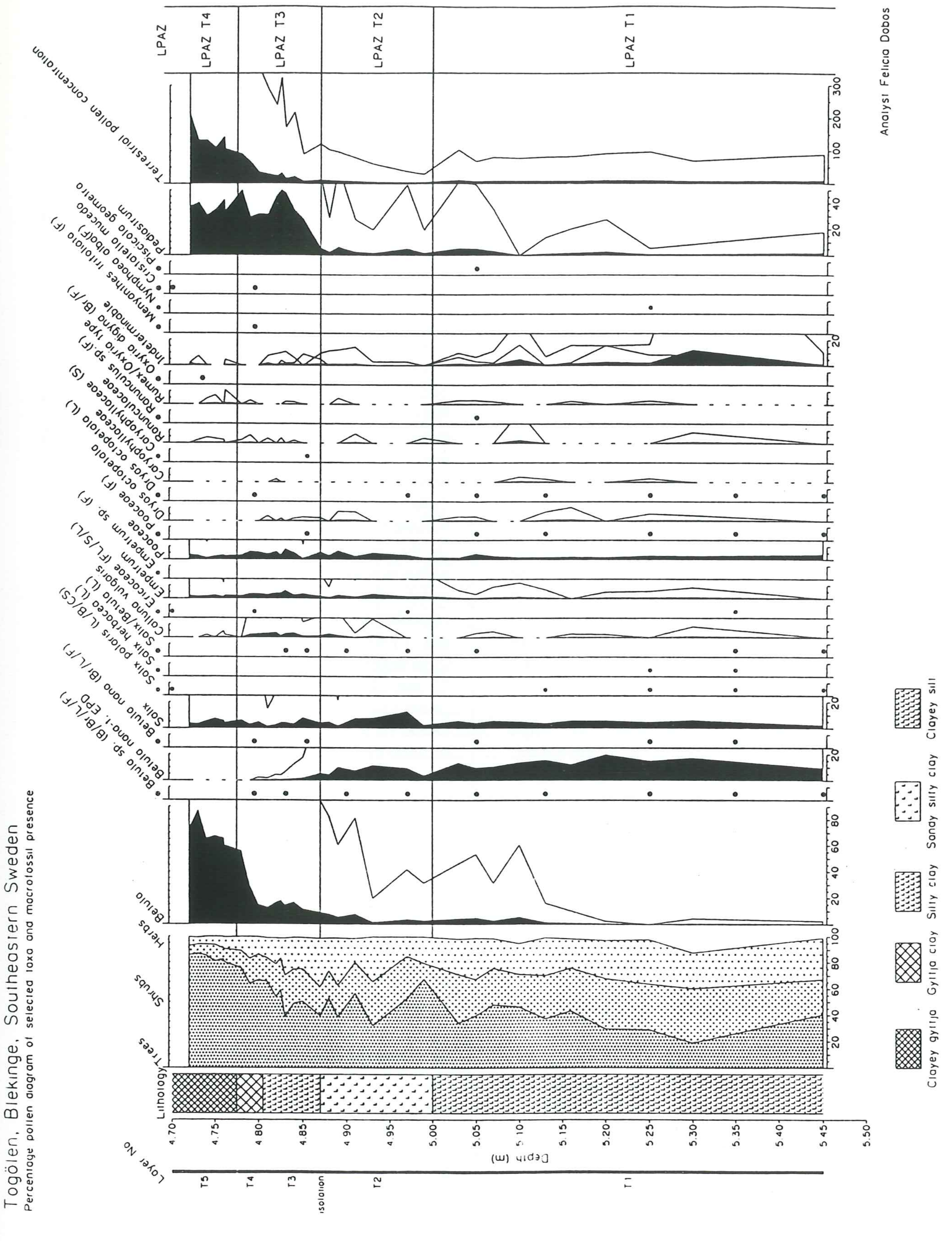

Fig. 17. Percentage pollen diagram of selected taxa and macrofossil presence at Togölen. B=budscales; Br=bud bract; CS=catkin scale; F=fruit; FL=flower; L=leaf; S=seed.

5.2.2. Bredsjön

On Fig. 16, the pollen diagram from the reference core is made up of 12 levels between 560 and 510 cm. Three local pollen assemblage zones have been identified. The total pollen sum ranges between 303 and 448 pollen/sample in the lower part of the sequence and 364 and 510 pollen/sample in the upper part. A square root transformation (Edward & Cavalli Sforza's chord distance counts) was applied to statistically verify the division of the local pollen assemblage zones and it is presented with the pollen diagrams (Fig. 16). The local pollen assemblage zones (B1-B3) distinguished in Bredsjön are as follows:

LPAZ B1 5.58-5.22 m. ***Pinus-Betula nana-Juniperus*** zone is the lowermost LPAZ recorded. This zone represents a long sedimentary sequence, but as few samples were counted, no further sub-division was made. High values of *Pinus* pollen (up to 45%), *Betula nana* (between 10 and 20%) and relatively high values of *Juniperus* (between 5 and 12%) are characteristic. Gramineae reach values of between 2 and 7% and Cyperaceae between 2-15%.
LPAZ B2 5.22-5.14 m. ***Juniperus*-Cyperaceae-*Empetrum*** zone. High values of *Juniperus* and Cyperaceae (up to 15%) and decreasing values of *Betula nana* (from 10% to only 2-3%) characterise this zone. *Empetrum* reaches its highest values compared to the other two zones. An abrupt increase in *Pediastrum* combined with an increase in total pollen concentration is also observed.
LPAZ B3 5.14-5.10 m. ***Betula-Pinus*** zone. High values of mainly *Betula* tree pollen, are characteristic. *Juniperus* and Cyperaceae decrease to levels below 5%, while *Salix* remains at values of 5-7%.

The pollen analysis carried out by Björck (1979), was concentrated on the gyttja and the highest part of the clay. High values of *Pinus* in the lowermost LPAZ in Bredsjön (B1) were recorded. Herb pollen was dominated by Cyperaceae and Gramineae and shrub pollen by *Juniperus* and *Betula nana*. Zone B1 in this diagram can be compared to B1 as described by Björck (1979), but it probably contains at the lowermost level a part of sediment which was not analysed by Björck (see Table 5). The second local pollen assemblage zone B2 is similar to the B2 zone described by Björck (1979), where *Juniperus* reaches a maximum of 15% and *Betula* increases from 10 to 35%. The equivalent section from the present study LPAZ B3 can be compared to zones B3 and B4 (Björck, 1979), despite the fact that *Populus* which was recorded by Björck with values of up to and more than 1%, was not identified here. Abundant *Betula* and *Pinus* pollen characterise these zones (Björck, 1979). The total pollen sum counted by Björck (1979) was higher and the analyses are denser than in the present study. However, some variation in pollen percentages is to be expected from samples in different cores related to the same stratigraphic horizon, especially when the pollen content is low. On the basis of the comparison presented above, the pollen stratigraphy established here was considered to match the regional pollen assemblage zones presented by Björck (1979): LPAZ T1, LPAZ T2 and LPAZ B1 correspond to the *Betula nana*-Cyperaceae-*Pinus-Artemisia* (regional PAZ 6), LPAZ T3 and LPAZ B2 are similar to the regional PAZ 7 (*Juniperus-Empetrum-Pinus-Betula*) and finally, LPAZ T4 in Togölen and LPAZ B3 in Bredsjön can be included in the regional pollen zone (PAZ 8) *Betula-Pinus*.

	Local pollen assemblage zones in this work		Local pollen assemblage zones according to Björck (1979)		
	B3	Betula-Pinus	B4	Betula-Pinus-Populus	
Isolation			B3	Betula-Salix-Hippophaë	
	B2	Juniperus-Cyperaceae-Empetrum	B2	Juniperus-Betula-Empetrum-Filipendula	
	B1	Pinus-Betula nana-Juniperus	B1	Pinus-Cyperaceae-Gramineae-Betula nana	* Isolation according to Björck (1979)
			?		

Table 5. Correlation between the local pollen assemblages at Bredsjön presented by Björck (1979) and the diagram presented here.

Layer	Depth below surface (m)	Betula sp	B. nana	Dryas octopetala	Salix	Salix polaris
T 5	4.69-4.717	1 fruit			2 catkin bud scales	
T 5	4.717-4.746	1 bud scale	2 fruits			
T 5	4.746-4.775	21 fruits and 6 bud bracts	6 fruits			
T 4	4.775-4.81	1fruit and 2 bud scales	3 fruits	1 leaf		
T 3	4.81-4.84	1 bud scale				
T 3	4.84-4.87		2 fruits			
T 2	4.87-4.94	2 bud scales				
T 2	4.94-5.01	3 fruits and 4 bud scales		2 leafs		
T 1	5.01-5.11	1 fruit and 4 bud scales	1 leaf	2 leafs		
T 1	5.11-5.21	7 leafs, 1 fruit and 2 bud scales		3 leafs		2 leafs
T 1	5.21-5.31		10 leafs, 2 fruits and 1 catkin scale	5 leafs		2 leafs
T 1	5.31-5.41		5 bud scales, 5 leafs and 1 bud scale	4 leafs	2 leafs	3 leafs
T 1	5.41-5.51		5 leafs and 2 fruits	1 leaf		1 leaf

Layer	Depth below surface (m)	Salix/Betula	Empetrum	Ericaceae sp	Oxyria digyna	Poaceae	Carex sp
T 5	4.69-4.717	1 leaf piece		1 flower			
T 5	4.717-4.746	1 bud bract and 1 leaf			1 bud bract		
T 5	4.746-4.775		2 fruits				
T 4	4.775-4.81			1 flower and 1 leaf			
T 3	4.81-4.84	2 leaf pieces					
T 3	4.84-4.87	3 leaf pieces				1 seed	
T 2	4.87-4.94	7 leaf pieces					
T 2	4.94-5.01	8 leaf pieces		1 leaf			
T 1	5.01-5.11	9 leaf pieces				2 seeds	
T 1	5.11-5.21					2 seeds	
T 1	5.21-5.31	2 catkin scales				3 seeds	1 leaf
T 1	5.31-5.41	5 leafs		1 leaf		5 seeds	
T 1	5.41-5.51	3 leafs				3 seeds	

Layer	Depth below surface (m)	Nymphea alba	Caryophylaceae cf Spergula	Cristatella mucedo	Piscicola geometra	Menyanthes trifoliata	Ranunculus
T 5	4.69-4.717	1 seed		10			
T 5	4.717-4.746						
T 5	4.746-4.775			10			
T 4	4.775-4.81			10		1 seed	
T 3	4.81-4.84						
T 3	4.84-4.87		1 seed				
T 2	4.87-4.94						
T 2	4.94-5.01						
T 1	5.01-5.11				2		1 fruit
T 1	5.11-5.21						
T 1	5.21-5.31	1 fruit					
T 1	5.31-5.41						
T 1	5.41-5.51						

Table 6. List over the macrofossils identified in the sediments from Togölen.

5. 3. Macrofossil analysis

The macrofossils found in the samples from Togölen are presented in Table 6. Leafs, fruits, budscales and catkinscale of *Betula nana* are continually recorded up to the fine detritus gyttja, layer T5 (4.717 m below the water surface), and *Cristatella mucedo* from the clayey gyttja upwards (layer T4-T6) (Fig 17 and Table 6). *Dryas octopetala* leafs are continually present up to layer T2 (5.01 m), and again in layer T4 between 4.775-4.81 m. *Ericaceae* leafs and flowers as well as Salix/Betula leaf fragments are recorded through the whole sequence. *Empetrum* seeds were found between 4.746 and 4.775 m (layer T5). *Salix polaris* leaves were present up to 5.01 m and *Salix* sp. bud scales and catkin scales from 4.775 to 4.69 m (layers T1 and T2). The cores were not analysed for macro remains above 4.69 m.

Not all pollen taxa were found in the macrofossil analysis. This may be partly due to the large mesh (0.5 mm) used (many plant seeds such as *Artemisia* have possibly been washed out) but also due to chance factors such as preservation and transport conditions. The macrofossil determinations confirmed the local presence of certain species and give a greater degree of taxonomic precision than pollen alone could.

5.4. AMS ^{14}C measurements

The samples from Togölen selected for AMS ^{14}C measurements consisted only of terrestrial plant macrofossils such as leaves, budscales, seeds and fruits of *Betula* sp., *Salix* sp. and *Dryas octopetala*. The following four samples were chosen for dating: 5.31-5.41 m, 5.11-4.94 m, 4.87-4.81 m and 4.775-4.746 m below the water surface. The ages were expected to be situated around the second ^{14}C plateau at c.10,000 ^{14}C yr. BP (Table 7).

However, the dates subsequently obtained in this work, were somewhat difficult to assess due to the dissimilarity with the dates obtained by Björck (1979) from Bredsjön. The uppermost unit (layer T5 dated to 8950±105 yr. BP) is according to the results here, only 600 years older than the lowermost one (level 5.31-5.41 m in layer T1 dated at 8350±210 yr. BP). For the two samples in-between the difference is of nearly 2000 years (7440±155 yr. BP for layer T2 and 9540±120 yr. BP for level 4.94-5.11 m in layer T1). Obviously, as these ages are mixed, they cannot be used for correlation purposes (Table 7). Björck (1979) considered his dates from Bredsjön to be too old.

5.5. Isolation indicators

The transition from Baltic Ice Lake sediments to sediments of isolated lakes is named isolation level and it should ideally correspond to the mean water-level of the Baltic at the threshold elevation (Svensson, 1989). Two types of isolation indicators can be distinguished: (1) based on the composition of the sediment and its physical parameters and (2) based on microfossils.

5.5.1. Physical parameters

(1) As no material can leave the basin after the isolation the organic content in the sediment is expected to increase at, or just above the isolation level, due to the expansion of algal production and reduced minerogenic sedimentation (Berglund, 1966).

Laboratory number	Layer No	Sample cm below water surface	δ^{13}C % PBD	^{14}C age BP	total (mg)	INS (mg)	SOL (mg)	Carbon content (%)	Carbon content (mg)
Ua-11242	T5	4.746- 4.775	-28.43	8950+105	2.70	1.56	0	71	1.1
Ua-11241	T2	487 - 481	-29.51	7440+155	1.05	0.70	0	86	0.6
Ua-11240	T1	511 - 494	-28.83	9540+120	2.60	1.19	0	84	1.0
Ua-11239	T1	531 - 541	-28.64	8350+210	1.62	0.51	0	78	0.4

Table 7. Results of AMS ^{14}C dating of terrestrial macrofossils from Togölen. INS is the insoluble part, mainly organic matter, and SOL is the soluble part, mainly humus.

(2) Björck (1979, 1981) has demonstrated that magnetic susceptibility is another useful indicator. The reduction in minerogenic matter at the isolation may also be due to decreased wave action at the shore of the basin.

(3) Staining by FeS, seen as dark stripes or thin layers in a lighter sediment, are important indicators of the depositional environment. Svensson (1989) attributed the sulphide staining to anaerobic conditions, which were caused by an increasing organic production. This could be due to a bloom in diatoms during the isolation or caused by stratification of the water-body, leading to an oxygen deficit in deeper water.

(4) Svensson (1989), examines the correlation between the isolation and the increase of calcium

carbonate content in sediments. Calcium carbonate precipitates when the dissolved carbon dioxide is utilised by algal production. In this work no such analyses were made.

5.5.2. Microfossils

The green algae *Pediastrum* is regarded as the most useful isolation indicator in Late Weichselian sediments (Berglund, 1966; Björck, 1979; Svensson, 1989). It is preserved during the pollen preparation process and can thus be counted during routine pollen analysis. Several factors are attributed to the expansion of *Pediastrum* during and after the isolation: (1) low competition by other plant groups; (2) enough nutrient supply; (3) isolated lakes may hold higher temperatures and (4) an increased transparency of the lake water due to the lower clay content.

The increase in *Botryococcus, Isoetes, Sphagnum, Hystrix* together with a decrease in secondary pollen and *Pinus*, can be regarded as a further isolation indicator (Björck, 1979). The accumulation of *Pinus* along shorelines is due to the buoyancy of this long distance pollen type which can then become over-represented in bays (Florin, 1945). Björck (1979) and Svensson (1989) considered that the decrease of *Pinus* associated with a lake isolation is the result of ceased transportation of *Pinus* pollen grains into the basin. The corrosion of pollen grains can also be regarded as a possible isolation indicator (Svensson, 1989).

5.6. Determination of the isolation level

The overall abundance of *Pinus*, which is present with highest values in the lower part of the diagram, is a clear indicator of long distance transport. The step-wise decrease of *Pinus* between c. 5.01 m and 4.87 m in Togölen (layer T2) from 60 to 30% (Fig. 15) is similar to the reduction of *Pinus* between c. 5.22 m and 5.15 m in Bredsjön (layer B6) between 50 and 30% (Fig. 16).

In contrast to Björck (1979), corrosion of pollen grains has not been significant to determine the isolation. However, the proportion of unidentified, broken pollen grains is high (up to 10%) in the lower part of the pollen diagram from Togölen, but decreases and disappears in the upper part (Fig. 15). In the pollen diagram from Bredsjön, the frequencies of unidentified and broken pollen is around 10% in layers B3, B4 and B5, but decreases to under 5% in layer B6.

The presence of FeS stains in the lowermost parts of the sediment core (layers 1, 2 and 3 in Togölen and layers 1 to 6 in Bredsjön) is, however, a possible indicator for an isolation. The sites became gradually shallower and the coastline closer, which favoured in-wash and deposition of organic material as a result of land uplift. However, the FeS staining just prior to the isolation (Svensson, 1989) may be related to the stratification of the water-body, which lead to an oxygen deficit in deeper water.

Layers T2 and B5 are presumed to have been deposited in the Baltic Ice Lake, because the magnetic susceptibility is fairly high (Fig. 11 and 13) and the values of *Pediastrum* are low (Fig. 15, 16). Nevertheless, the carbon content increases gradually (Fig. 12).

The silty clay of layer T3 (Togölen) is similar to the silty clay found in Bredsjön (layer B6) as regards lithology, magnetic susceptibility, total carbon content and bulk SIRM (Fig. 11 and 13). It is assumed, therefore, that these layers have been accumulated in a similar depositional environment in lakes completely isolated from the Baltic Ice Lake.

It is also possible that the drainage of the Baltic Ice Lake may have started earlier than in layers T3 and B6, and that the basin may have become gradually shallower between 5.01 and 5.05 m (layer T1) in Togölen (Fig. 11) and between 5.41 and 5.38 m (layer B3) in Bredsjön (Fig. 12). Other indications which might support this hypothesis are the water-saturated sediments of layers T2, B4 and B5 and, the decreasing magnetic values in these layers. The pollen analysis partly agrees with this hypothesis: despite the fact that the pollen concentration varies in layers T2 and B5, the percentage of most taxa remains constant from the beginning to the end. However, in the diagram from Togölen, the increase in *Betula* and the decrease in *Pinus*, *Potentilla*, Ranunculaceae, Rubiaceae, *Saxifraga* etc. which occur sporadically, do not support this hypothesis (Fig. 13).

Pediastrum colonies increase abruptly in layers T3 and B6, from values of under 5%, up to 30%, within only 2 cm of sediment. This, together with the arguments presented above, suggests that Togölen's layer T3 and Bredsjön's layer B6 were deposited in lakes completely isolated from the Baltic Ice Lake. Thus, the isolation level in Togölen is situated at 4.87 m below the water surface, and in Bredsjön at 5.23 m below the water surface. *Cristatella mucedo* which is a first indicator of a limnic environment supports the possibility of the isolation at this level (Table 6).

6. Discussions

The results presented in the previous chapter show that the silty clay layers at Togölen (layer T3) and Bredsjön (layer B6), which present a gradually decreasing bulk SIRM and fairly low susceptibility values, were deposited in isolated lakes (Fig. 11 and 14). The isolation is marked by the lithological change at 4.87 m and at 5.23 m below the surface in Togölen and Bredsjön, respectively. There are no indications in the results presented in this work that the last Baltic Ice Lake drainage was a two-step event. The magnetic susceptibility and bulk SIRM from both localities display more or less constant values below the determined isolation level, except for the sudden drop at 5.045 m in Togölen and 5.42 m in Bredsjön (Figs. 11 and 14). These drops can be explained by coarser sediments caused probably by erosion on the lake bottom.

Unstable Baltic sediments have covered the new exposed land areas after the drainage. Before these areas were covered by vegetation, sediments could easily have been eroded into the basin during a rapid water-level lowering. If the drainage had started already at 5.01 m in Togölen and at 5.41 m in Bredsjön, then layer T2 and B5 may contain redeposited sediments from the surroundings of these basins. However, as the magnetic values continuously decrease and the pollen analysis only partly lends support this hypothesis, the possibility that the isolation occurred earlier is regarded as unlikely. The sharp boundary in layer 7 from Bredsjön could suggest the presence of a hiatus. However, measurements performed at Togölen, where no sharp boundary is present, and the similarity of the lithostratigraphy in both sites, argues against such a hiatus.

Layers T3 and B3 described in this study as containing deformation structures (see chapter 5.1.1 and 5.1.2), have not been observed by Björck (1979). The formation of these layers may be explained by erosion during the isolation of the lake basins. It may, however, also be possible that the weight of the overlying sediments compressed the water-saturated deposits in layer T5 and B5. This led to a partial escape of the water and possibly caused these post-depositional deformation structures.

Table 8 shows a tentative correlation between the local pollen assemblage zones determined in this work for both localities and the regional pollen assemblage zone as defined by Björck (1979). The low values of AP (arboreal pollen) together with high values of NAP (non arboreal pollen), dominated by *Betula nana*, *Juniperus* and *Salix*, indicate a treeless vegetation before the isolation. Only low values of *Filipendula* are recorded, and *Artemisia* is increasing through the end of layers T2 and B5. Cyperaceae and Poaceae dominate the grass community. The aquatic flora was poorer, only some finds of *Myriophyllum* and *Equisetum* were made. Following the isolation, the pollen and macrofossil record suggests an expansion of the tree flora. *Hippophaë* is rare, increasing first above the next zone boundary, but the diagrams show a succession to *Betula* forest where *Pinus* is richly represented (Figs. 15 and 17, Table 6). *Juniperus* and *Empetrum* reach their maximum and *Betula nana* gradually disappears (see layers T3 and B6 in Fig. 15 respectively Fig. 17). The open grass-vegetation declined distinctively during this period, while aquatic plants such as *Equisetum* and *Myriophyllum* increased. *Myriophyllum alterniflorum* reflects the change in the lake from eutrophic to more oligotrophic conditions. The green algae have a distinct optimum in this period probably caused by slight competition together with rised temperatures.

Periods according to Björck et al., 1996	Togölen's local pollen assemblage zones (this work)	Bredsjön's local pollen assemblage zones (this work)	Regional pollen assemblage zones acc. to Björck (1979)	Chronozones according to Björck (1979)
Preboreal	Betula-Empetrum-Hippophaë	Betula-Pinus	Betula-Pinus	Preboreal
	Juniperus-Cyperaceae-Empetrum	Juniperus-Cyperaceae-Empetrum	Juniperus-Empetrum-Pinus-Betula	Younger Dryas
Younger Dryas	Salix-Cyperaceae	Pinus-Betula nana-Juniperus	Betula nana-Cyperaceae-Pinus-Artemisia	
	Pinus-Betula nana-Juniperus		Artemisia-Juniperus-Gramineae-Chenopodiaceae	

Table 8. Correlation between the local pollen assemblage zones at Togölen and Bredsjön with the regional pollen assemblage zones in Blekinge.

The YD-PB transition in southern Sweden is characterised by an increase in relative pollen frequencies of *Filipendula*, *Juniperus* and *Empetrum*, plants which were favoured by warmer temperatures. The increase in the frequencies in these pollen types and the increase in tree birch together with the decrease of *Betula nana* (Fig. 15, 16 and 17), and the arguments presented above suggests that the YD-PB transition is situated at 4.87 m in Togölen and at 5.23 m in Bredsjön. Thus, the isolation coincides with the beginning of the YD-PB transition zone in both localities. This leads to the interpretation that the second and last drainage of the Baltic Ice Lake occurred immediately before the YD-PB transition zone.

Unfortunately, the dating results obtained in this work are confusing and too young and can, therefore not be used to date the isolation. However, would have been difficult to date even with accurate dates since it lies on the second ^{14}C plateau at 10,000 ^{14}C years BP. Several sources of error connected to erroneous ^{14}C dating can be anticipated: (1) contamination through insufficient care when processing the samples. A randomly chosen sample boiled in HCl illustrates the potential for error even when a sample is handled with care (chapter 5.1.2.). The presence of 0.0385% carbon (see chapter 5.1.2.) in the sample can only be explained after such a treatment by contamination of modern airborne carbon present, either in the oven or in the room where the macrofossils were extracted. The extent to which modern contamination can affect a sample is related to the age of the sample itself. For example, 0.02 mg of modern material on a 10,000 ^{14}C yr. BP old sample (Fig. 18) affects a 2 mg sample by 220 yr. If the size of the sample is 1 mg the sample becomes 450 years younger (Skog, pers. comm.). It is, therefore, possible, that this can be one of the reasons why the ages were so young. (2) The pre-treatment applied before the samples were sent in for AMS measurement could possibly be a source of error. The samples were kept in 5% $Na_4P_2O_7$ or 10% NaOH to disperse the clay and organic particles, prior to sieving. Additional treatment with NaOH (chapter 4.2.6.) could have decreased the amount of measurable carbon content (Skog, pers. comm.). (3) Small sample size, (between 1.05 and 2.70 mg) is not ideal and may have been a further potential error source particularly considering the age of the samples dated. Even if only 0.1-1 mg carbon is required for analysis (Possnert, 1996), the smaller the sample the higher is the risk for contamination. (4) Wohlfarth et al. (submitted) discussed the contamination by fungi and/or bacteria during a long storage of the wet samples and the cores. Since neither the samples nor the cores were stored during a longer period of time, such contamination is not considered to have affected the samples in this work.

Previous works dealing with the second and final Baltic Ice Lake drainage have placed this event at a maximum age of 10,300 ^{14}C yr. BP (Wohlfarth et al., 1993; Svensson, 1989; Bergsten, 1994; Jiang and Klingberg, 1996). Here, it appears that this second drainage occurred immediately before the YD-PB pollen zone transition. Based on three AMS ^{14}C dated lacustrine sequences from Sweden which were synchronised with tree rings and ice core records, it could be shown that the YD-PB pollen zone transition can be placed between 11,450 and 11,390 +- 80 calendar years BP (Björck et al., 1996). Bodén et al., (1997) argue that the two d ^{18}O spikes reflect a two- step drainage of the Baltic Ice Lake, which occurred after the YD-PB transition. The results presented by Jiang and Klingberg (1996), however, show only a single event. The present work indicates, that not only did the second drainage of the Baltic Ice Lake occur immediately before the YD-PB pollen zone transition, but also that there seems no evidence for a two-step drainage.

The Baltic Ice Lake's second drainage may have affected the strength of the North Atlantic heat conveyor, causing the approximately 150 years long cooling named PB Oscillation, which started 300 years after the YD-PB pollen zone transition (Björck et al., 1996). According to Teller (1989, 1990 and 1994) Lake Aggassiz discharged at least twice into the North Atlantic Ocean between 11,000 and 10,000 ^{14}C years BP. Such huge meltwater pulses produced

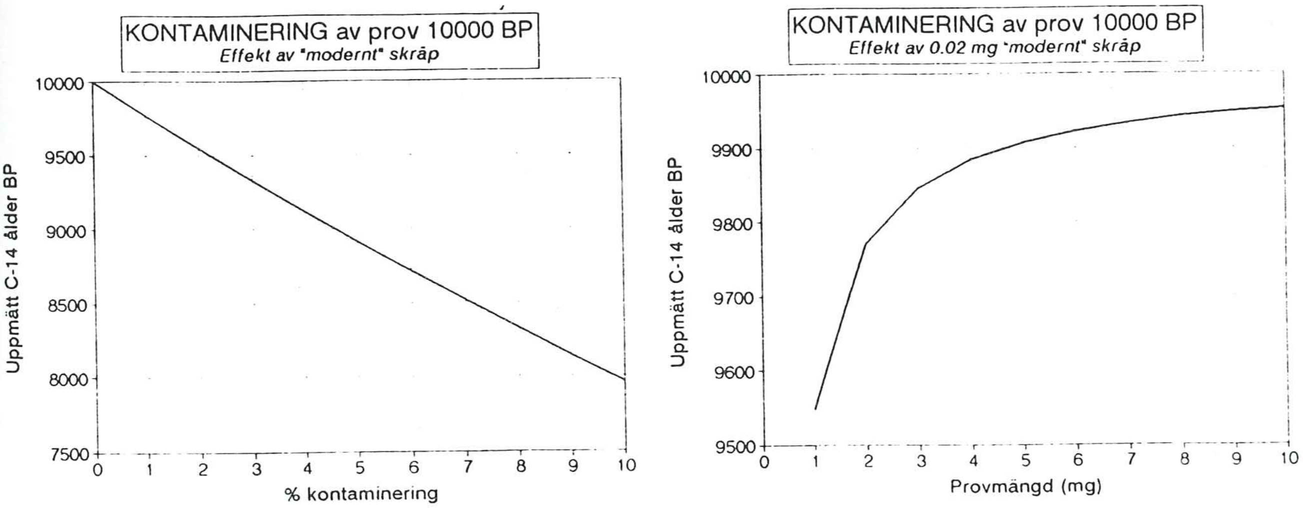

*Fig. 18. **A.**The effect of contamination by contemporary material on a 10,000 ^{14}C year old sample. **B.**The consequence of 0.02 mg "modern" material contamination on a 10,000 ^{14}C year old sample (Skog 1996; pers. com.)*

by massive ice lake drainages make it ,therefore, possible, that the impact of both the first and the second Baltic Ice Lake and Lake Agassiz drainages into the North Atlantic affected ocean ventilation processes (Björck et al., 1996). It is, therefore, important to correlate the timing of these events, and to model (taking into account the topography, deglaciation, water and rebound) their paths over a wider geographical area. This may be achieved by applying the same methodology in order to clarify the impact of meltwater discharge on ocean heat conveyor.

Acknowledgements:

I can never thank my head supervisor Barbara Wohlfarth enough, for offering me such an interesting subject and for her help and support throughout the entire project. A big thank you also, to my supervisor Gunnar Digerfeldt for helping me with the pollen analyses, the encouraging discussions we had and his comments on the manuscript. I am deeply indebted to Mats Rundgren for introducing me to the complexities of pollen identification. Thanks also to Gina Hannon for her guidance in the macrofossil and pollen analyses and for taking the time to read the manuscript which improved the English. Olafur Eggertsson helped with the layout, Siv Olsson with the carbon analyses, Per Sandgren with magnetic analyses, Thomas Persson with pollen processing and Svante Björck was very helpful when interpreting the pollen stratigraphy. A big thank to Dan Dobos for helping me in the field and for his kindly care and support. Finally, I would like to thank Björn Berglund and all people at the Department of Quaternary Geology at Lund University for their constructive comments and suggestions.

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