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Abstract

Three sites, Torreberga in Skåne, Farslycke in Blekinge and Lake Bolmen in Småland, with Late Weichselian lake sediments were studied with respect to pollen analysis and palaeomagnetism. The chronologies are based on pollen stratigraphical correlations, radiocarbon dating and, for two of the sites, on a clay-varve chronology. The stratigraphies were correlated to the GRIP event stratigraphy and their ages are expressed in calendar years BP.

The pollen records compare well to the established Late Weichselian pollen stratigraphy for southern Sweden, and reflect the vegetation development from the deglaciation to the transition to the Holocene. The annual time-resolution of the varved clays has made it possible to calculate pollen accumulation rates based on actual sedimentation rates. The delayed onset of sedimentation in Torreberga implies that dead ice was present for at least 2000 years after the regional deglaciation of the area.

Although the clay varve chronologies could not be absolutely dated through connections to the Swedish Time Scale, they have been assigned approximate calendar-year ages based on the pollen stratigraphies and their correlation to the GRIP event stratigraphy. These correlations made it possible to assign calendar year ages for the deglaciation of Blekinge and south-western Småland, and to discuss the deglaciation chronology for southern Sweden with enhanced accuracy. Farslycke and the northern end of Lake Bolmen were deglaciated at c. 14,350 and at c. 14,400 calendar (GRIP) years BP, respectively.

Palaeomagnetic secular variation records for the three sites are presented. Among the series of directional changes, the main characteristic, which can be found in all stratigraphies, is a broad westerly declination swing between c. 13,000 and 12,000 calendar years BP. This swing can be recognised in other records from southern Sweden and in Estonia.

Key words: Pollen stratigraphy, palaeomagnetic secular variations, Late Weichselian, calendar year chronology, southern Sweden

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Contents

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This thesis is based on three papers and the present synthesis. The papers are presented below as appendices I-III and referred to in the text according to their respective Roman numerical label.

App. I: Ising, J. 1990: Late Weichselian pollen stratigraphy, palaeomagnetic secular variations and radiocarbon chronology at the Torreberga ancient lake, Skåne, Sweden. *Geologiska Föreningens i Stockholm Förhandlingar 112*, 281-292.

App. II: Ising, J. 1998: Late Weichselian pollen stratigraphy, clay-varve chronology, radiocarbon chronology and palaeomagnetic secular variations in Farslycke, central Blekinge, south Sweden. *GFF 120*, 321-332.

App. III: Ising, J. 2001 (in press): Late Weichselian pollen stratigraphy, clay varve chronology and palaeomagnetic secular variations in Lake Bolmen, Småland, south Sweden. *Boreas, 31*, 000-000.

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Fig. 1. Photo from the field work at Lake Bolmen during winter. The orientation of the corer is measured, relative to magnetic north.

Introduction

The end of the Late Weichselian was a dramatic period in many respects and the climatic and environmental changes that occurred during this period have been the subject of numerous studies for more than a century. Despite this, or possibly because of this, controversies, particularly those dealing with the chronology of the Late Weichselian, have been frequent. One reason may be the accuracy of the different chronologies and time series that have been applied. During recent years, AMS radiocarbon dating of selected terrestrial plant material (e.g. Amman & Lotter 1989; Cwynar & Watts 1989; Wohlfarth et al. 1993, 1998; Björck et al. 1996, 1998a) has led to a better control of the Late Weichselian chronology and to suggestions to replace the radiocarbon-year based chronostratigraphy of Mangerud et al. (1974) by calendar-year chronologies, such as the GRIP event stratigraphy (Björck et al. 1998b; Walker et al. 1999) and the extended radiocarbon calibration curve (Stuiver et al. 1998).

The overall aim of this study was to circumvent these chronological problems, by establishing a Late Weichselian magnetostratigraphy for southern Sweden, based on carefully selected and chronologically well-constrained lake sediment sequences. Palaeomagnetic analyses of varved clays to study secular variations of the Earth's magnetic field at a high time resolution were first applied by McNisch & Johnson (1938), Ising (1942) and Granar (1959). These initial studies demonstrated the problems in acquiring a reliable natural remanent magnetisation (NRM) in clastic sediments due to the effects of e.g. bottom water currents and gravitation. Owing to these problems, the interest in the late 1960's and 1970's was focussed on palaeosecular variation studies of more organic rich sediments, where deposition generally occurred under more quite conditions (e.g. Mackereth 1971, Thompson 1973). However, not all sites are affected by such problems as shown by more recent investigations (Sandgren et al. 1997, Saarnisto & Saarinen in press), which demonstrated that the NRM of clastic sediments deposited under favourable conditions may hold a true record of the Earth geomagnetic field. During the 1970's and 1980's, the potential use of palaeomagnetic secular variations as a dating tool emerged and a number of geomagnetic master curves for the Holocene were presented (compiled by Thompson 1984). Global reviews of such master curves for the Holocene were presented by Thompson (1984) and Creer (1985). However, in some cases the results were contradictory. In sediments with magnetite dissolution (Karlin & Levi

Table 1. Summary of preliminary studied sites, which were not investigated further. The ages are in most cases approximately estimated values. For a more detailed sediment description of some sites, see the references.

Site name	Coordinates, altitude	Approximate time span (calendar years BP)	Sediments (lateglacial part)	Results / why the site is not used.
Vallensgaard Mose (Bornholm)	55°06'N, 14°55'E	15,000-11,500	Clay, gyttja clay and clay gyttja (Usinger 1977)	Palaeomagnetic values too dispersed.
Lake Ivösjön	56°06'N, 14°27'E 6 m a.s.l.	–	–	Lateglacial sediments not reached
Lake Gyllebosjön	55°36'N, 14°12'E 67 m a.s.l.	?	Clay gyttja, sand and marl	Not enough lateglacial sediments
Vanstads Mosse	55°37'N, 13°52'E 74 m a.s.l.	15,000-11,000	Silty calcareous clay gyttja (Hammarlund & Keen 1994)	Palaeomagnetic values too dispersed.
Nöbbelövs Mosse	55°44'N, 13°09'E 20 m a.s.l.	13,500-11,000	Clay and gyttja clay, partly with high calcareous content.	Palaeomagnetic values too dispersed.
Körslätta-mossen	56°06'N, 13°04'E 118 m a.s.l.	15,500-11,200	Silty clay to clay gyttja with high calcareous content in some layers (Hammarlund & Lemdahl 1994)	Palaeomagnetic values too dispersed.
Döderhult	57°16'N, 16°25'E 2 m a.s.l.	11,500-10,000	Clay, gyttja clay and clay gyttja (Svensson 1989)	Not enough lateglacial sediments

1983) and with a high content of iron sulphides (Snowball 1991), the origin of the NRM direction has to be carefully evaluated. In Swedish Late Weichselian sediments, palaeomagnetic secular variation measurements have previously been carried out by Noël (1975) and Björck & Sandgren (1986) in Blekinge, Thompson & Berglund (1976) and Sandgren (1984, 1986) in Skåne, Mörner (1975,1977) at the Swedish west coast, and Björck et al. (1987) and Sandgren et al. (1988) in Östergötland and Södermanland.

In the present study, ten sites were altogether sampled and analysed for palaeomagnetic secular variations (Table 1, Fig. 2), but only three of them

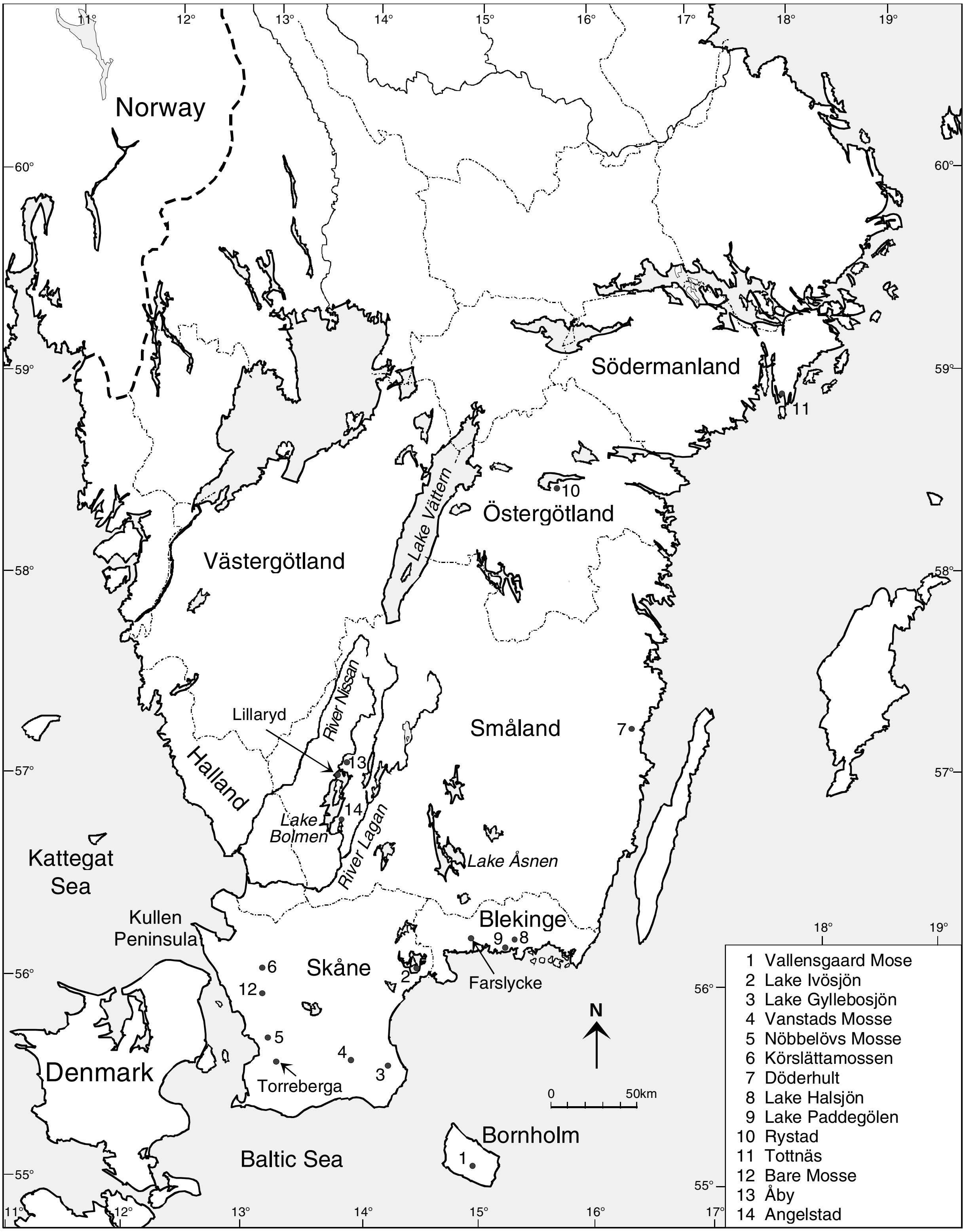

Fig. 2. Map of southern Sweden showing the investigated sites and those mentioned in the text.

were regarded as suitable for further analyses. These are Torreberga in Skåne (Paper I), Farslycke in Blekinge (Paper II) and Lake Bolmen in western Småland (Paper III). Their chronology is based on local pollen zones, which were correlated to regional, radiocarbon dated pollen stratigraphies. In addition, clay-varve diagrams were established for Farslycke and Lake Bolmen and correlated to the local varve chronologies. The occurrence of varved clays made it furthermore possible to perform high-resolution pollen stratigraphic studies. The combination of clay-varve chronology, pollen-, magnetostratigraphy and AMS radiocarbon dates allows a detailed reconstruction of the vegetation development during parts of the Late Weichselian and adds new information concerning the deglaciation chronology in southernmost Sweden.

The chronology adapted here is based on a correlation of local/regional pollen stratigraphic zones to the GRIP event stratigraphy (Björck et al. 1998b) and rests on the assumption that the climatic changes registered in the GRIP ice core and in north European pollen stratigraphies, are approximately time synchronous. All ages are in the following expressed as 'calendar years BP (Before Present; present = AD 1950)', since 'GRIP ice years BP' are assumed to be comparable to calendar years BP (Björck et al. 1998b). In the summaries of the published papers (I, II, III) presented here, the original radiocarbon ages have been converted to calendar years. This was done, because the ^{14}C chronologies, which had been used in the articles, can in some cases be misleading or be misinterpreted, due to the non-linear relationship between ^{14}C and calendar years (Stuiver et al. 1998). The pollen zonation used here relates to Björck & Möller's (1987) regional pollen zones for southern Sweden (i.e. BÖ, OD, AL I, II, III; YD I, II). However, the YD III pollen zone is in accordance with Björck et al.'s (1997) study named 'YD-PB transition zone', based on the term defined by Berglund (1966).

Site descriptions

Torreberga

The fen at Torreberga (55°37'N, 13°14'E, Fig. 2) is a former lake, situated in south-western Skåne, about 10 km south of Lund, at an altitude of c. 7 m a.s.l. in the transition zone between the hummocky moraine landscape to the south and the Lund plain to the north. The hummocky moraine area is dominated by sandy till and clay till (Ringberg 1980). The Lund plain consists of a clay rich diamicton which has been interpreted as till according to Ringberg (1988) and as glaciolacustrine sediment according to Lagerlund (1980, 1983, 1987a, 1987b) and Malmberg Persson (1988).

Farslycke bog

Farslycke (56°14'N, 14°55'E, Fig. 2) is a small bog (elevation 35-40 m a.s.l.) situated c. 10 km north-east of the town Karlshamn in Blekinge. The area is described as a fissure valley landscape with valleys generally trending NNW/SSE and NNE/SSW (Björnsson 1946). The bedrock around Farslycke consists mainly of Precambrian Karlshamn granite, granodiorite and gneiss (Kornfält & Bergström 1991).

The Quaternary deposits in the coastal area of Blekinge, in which Farslycke is situated, are characterised by a relatively thin till cover with frequent bedrock exposures. Varved clay and silt cover the till in the valleys and can be found in basins below the highest shoreline (HK). Above the HK, the till is generally thicker and areas of both hummocky moraines and transverse moraine ridges can be found (Björck & Möller 1987). Glaciofluvial deposits are mainly concentrated to the valleys and are dominated by silt to sand below c. 55 m a.s.l. and coarser fractions above that level (Lagerlund & Björck 1979).

Lake Bolmen

Lake Bolmen, is one of the largest lakes in southernmost Sweden, with a surface area of c. 183 km^2. It is situated in south-western Småland, at the margin of the South Swedish Upland (Fig. 2) at an elevation of c. 140 m a.s.l. The elongated lake trends north-south. It is about 30 km long and 10 km wide with a maximum depth of c. 20 m in the northern part and c. 36 m in the southern part (County administration, Jönköpings län and Kronobergs län, unpublished map 1976). The corings were performed in the outer part of a bay, outside Lillaryd, in the northern part of the lake (57°3'N, 13°43'E). The bottom in the bay seems to be smooth with gradually deeper water away from the shore.

The bedrock around Lake Bolmen consists predominantly of Precambrian gneiss (Samuelsson et al. 1988) and the Quaternary deposits are mainly till and in lower areas sand and peat (Blomberg 1879; Daniel 1986; Fredén 1988a).

Methods

Field work

Lakes were cored during winter from the ice while bogs and fens were cored during summer. At all sites the coring points were selected carefully to obtain long and undisturbed sediment sequences. Corings were performed both with a Russian peat sampler (Jowsey 1966) (6 cm Ø and 1 m length) and with a piston corer (Wright 1967) (63 mm Ø and a tube-length of 1.3 m). The azimuthal orientation of individual core segments for palaeomagnetic analyses was measured relative to the magnetic north pole (Fig. 1) to allow construction of declination curves in absolute degrees.

Laboratory work

The sediments have been classified according to Troels-Smith (1955) and Birks & Birks (1980). Clay varve measurements were carried out following De Geer's classical method (De Geer 1940). Carbon analysis was made using a LECO RC-412, multiphase carbon determinator. Terrestrial macrofossils have been used for AMS radiocarbon measurements.

To the volume-determined samples for pollen analysis, *Lycopodium* tablets, with a known number of spores, were added to allow calculation of pollen concentration and pollen influx. The pollen samples were prepared using the $ZnCl_2$ method (Björck et al. 1978). To concentrate the samples even more and to remove minerogenic particles, which could not be disintegrated by HF treatment, the samples were also sieved through a 7 µm mesh screen (Cwynar et al. 1979). Pollen identifications are based mainly on Moore et al. (1991) but also on reference samples. The taxonomy follows Krok & Almquist (1984). The pollen stratigraphies have been divided visually into local pollen assemblage zones (LPAZ's) according to Birks (1973) and Salvador (1994). The zonations were then cross-checked by correspondence analysis (Greenacre 1984). For Farslycke and Lake Bolmen stratigraphically constrained cluster analysis (CONISS, Grimm 1987) was also applied.

For palaeomagnetic measurements, the sediment cores were sub-sampled into cubic plastic boxes with a volume of 7 cm^3. The cores obtained with the Russian corer were sub-sampled in the field by pressing the box into the cores from the side after cleaning. The piston cores were sub-sampled in the laboratory by pressing the box into the bottom of the core, using a template to be able to press the box in a known direction relative to the determined marking of the core. The boxes were extracted after pushing out the sediment at 2.5-5 cm sampling intervals.

Direction and intensity of the NRM was determined by using a Molspin "Minispin" fluxgate spinner magnetometer. After measuring the NRM, the samples were either stored for some months in a non-magnetic field to allow any viscous components to decay, or demagnetised in an alternating field demagnetiser after a stability test (Thompson & Oldfield 1986). The standard measurements were made after a demagnetisation in a field of 10 mT (milliTesla).

At Farslycke and Lake Bolmen (Papers II and III), mineral magnetic analyses were performed on a number of dried samples to study the carriers of remanence. Magnetic susceptibility (χ) was measured on a Geofyzika Brno "Kappabridge" (KLY-2) susceptibility meter. Anhysteretic remanent magnetisations (ARM's) were induced by a bias DC field of 0.1 mT imposed on a peak AF field of 100 mT. Saturation isothermal remanent magnetisations (SIRM's) were measured on the spinner magnetometer after induction with a Redcliff pulse magnetic charger in a field of $B = \mu_0 H = 1$ Tesla (T). The samples were then magnetised in a series of reversed magnetic fields to allow determination of the backcoercivity of remanence $(B_0)_{cr}$ and to allow calculation of the S-ratio (IRM_{-100mT}/SIRM, Stober & Thompson 1979). ARM reflects the presence of finer magnetite particles. χ and SIRM both are measures of the concentration of ferrimagnetic minerals (Thompson & Oldfield 1986), but SIRM is more strongly affected by magnetic grain size and by the presence of "harder" magnetic minerals. In contrast to χ, SIRM is not affected by the presence of paramagnetic and diamagnetic minerals. The S-ratio has been used as a guide to ferrimagnetic mineralogy (Snowball 1993).

Summaries of the papers

Paper I

Ising, J. 1990: Late Weichselian pollen stratigraphy, palaeomagnetic secular variations and radiocarbon chronology at the Torreberga ancient lake, Skåne, Sweden. *Geologiska Föreningens i Stockholm Förhandlingar 112*, 281-292.

In this paper, a lake sediment study from a former lake at Torreberga, Skåne, southern Sweden, is presented. These sediments, which cover the Allerød and Younger Dryas Chronozones sensu Mangerud et al. (1974), have earlier been pollen analysed by Berglund & Digerfeldt (1970) and investigated with respect to palaeomagnetic secular variations by Sandgren (1986). In this paper the new pollen and radiocarbon stratigraphies show that the sedimentation in the lake did not start until c. 13,500 calendar years BP, i.e. more than 1000 years after the deglaciation.

The pollen stratigraphy is correlated to several Late Weichselian pollen diagrams from southern Sweden and to the chronozones according to Mangerud et al. (1974). It is mainly characterised by rather high tree pollen percentages during the LPAZ's T1 and T2 (corresponding to the late AL I to early AL II pollen zones, GRIP events GI-1c–GI-1b), an increase in shrubs, especially *Juniperus*, and decrease of tree pollen during the LPAZ T3 (the late AL II pollen zone, GI-1a) and a distinct increase in herbs at the transition between the LPAZ's T3 and T4 (AL II/YD I pollen zone, corresponds to GI-1/GS-1).

The vegetation history is described on the basis of the presented pollen diagram, an earlier published macrofossil diagram (Berglund & Digerfeldt 1970) and comparisons to adjacent biostratigraphical analysed sites. Birch and pine were sparsely present during the AL I-AL II pollen zones. They almost disappeared at the AL II/YD I pollen zone transition, but reappeared shortly afterwards to form an open forest. During the YD-PB transition zone (Berglund 1966) or YD III pollen zone, pollen influx values increased significantly as a result of the climatic warming.

The palaeomagnetic secular variation curve is characterised by a distinct westerly declination swing from about 13,200 to 12,000 calendar years BP. The inclination shows four major cycles on an overall trend of increasing values upward. The secular variation record has been compared to the stratigraphies from Lake Halsjön and Lake Paddegölen in Blekinge (Björck & Sandgren 1986) and Tottnäs and Rystad in Östergötland and Södermanland (Björck et al. 1987; Sandgren et al. 1988). The broad westerly declination swing or parts of it is clearly documented in all these curves.

Paper II

Ising, J. 1998: Late Weichselian pollen stratigraphy, clay-varve chronology, radiocarbon chronology and palaeomagnetic secular variations in Farslycke, central Blekinge, south Sweden. *GFF 120*, 321-332.

This paper presents and discusses the results of a Late Weichselian lacustrine sediment sequence study from Blekinge in south-eastern Sweden. Pollen analysis, AMS ^{14}C datings and varve counting indicate that the site was deglaciated during the BÖ pollen zone, at c. 14,350 calendar years BP.

Varved clay makes up 5 m of the sediment succession and comprises c. 360 varves, which were deposited during the Bølling and Older Dryas Chronozones sensu Mangerud et al. (1974). The varve chronology could be correlated to the regional varve chronology for Blekinge (Ringberg 1979, 1991), but varve connections to the Swedish Time Scale (De Geer 1940; Cato 1985, 1987; Strömberg 1985) are not yet possible (Wohlfarth et al. 1998). The ice recession rate between Karlshamn and Farslycke is calculated to c. 100 m/year. Similar to earlier investigations (e.g. Björck 1979, Björck & Möller 1987 and Wohlfarth et al. 1994), this study shows that varved-clay sedimentation in the area ceased during the Older Dryas stadial. This is most likely due to the disappearance of stagnant ice from the drainage area in Blekinge and south-central Småland. The chronology is supported by AMS radiocarbon dates, which were obtained on macrofossils extracted from the varved clays from this site as well as from nearby sites, correlated to Farslycke by varve diagram connections.

The pollen diagram has been correlated to the Late Weichselian pollen stratigraphy for Blekinge (Björck 1979; Björck & Möller 1987). The LPAZ's from Farslycke are correlated to the proposed Late Weichselian pollen zones for southern Sweden (Björck & Möller 1987) and to the Chronozones according to Mangerud et al. (1974) and Mangerud & Berglund (1978).

The detailed pollen analysis displays a vegetation development from the deglaciation at the BÖ pollen zone to the transition to the Holocene. The succession, during the BÖ pollen zone, from arctic pioneer vegetation to a more stable tundra environment with increasing tree pollen values is interrupted by a distinct OD pollen zone, characterised by pioneer and drought tolerant elements, like *Artemisia*, *Rumex*, *Betula nana* and *Hippophaë*. During the AL I pollen zone the vegetation development is re-established with higher tree pollen values but still quite high values of tundra elements. At the AL II pollen zone, the tundra elements decrease in favour of the tree pollen values. At the onset of the YD I pollen zone, another set-back of the development is registered with low tree-pollen values and a reestablishment of the pioneer and tundra vegetation. Finally, at the transition to the Holocene, the tree pollen values abruptly increase. These results are broadly in agreement with Björck (1979, 1984) and Björck & Möller (1987).

The site was isolated from the Baltic Ice Lake at c. 12,900 calendar years BP. This age is based on pollen stratigraphy and on one radiocarbon date immediately above the isolation and fits to the general shoreline displacement curve (Björck 1979, Berglund & Björck 1994). After the isolation, the sediment became less minerogenic, the sedimentation rate decreased drastically and the pollen influx values, except for secondary pollen, increased.

The palaeomagnetic secular variation record shows mainly two westerly declination swings at c. 13,800-13,200 and 12,800-11,800 calendar years BP, respectively, the upper one in accordance with declination records from other sites in southern Sweden. High inclination values are found at c. 12,800 and 11,500 calendar years BP, especially in profile 1, but both curves show similar trends. The overall tendency of higher inclination upwards probably could be ascribed to "inclination error", i.e. too low inclination values, depending on either compaction of the sediment or elongated grains with the magnetic moment parallel to the maximum axis, which have settled with the maximum axis parallel to the sediment surface (King 1955; Griffiths et al. 1960).

Paper III

Ising, J. 2001 (in press): Late Weichselian pollen stratigraphy, clay varve chronology and palaeomagnetic secular variations in Lake Bolmen, Småland, south Sweden. *Boreas, 31*, 000-000.

This paper presents a study of a Late Weichselian lake sediment sequence from western Småland, South Sweden. The investigations include pollen analysis, clay varve chronology, palaeomagnetic secular variation analysis, mineral magnetic analyses and carbon analysis. The chronology is based on correlations to the GRIP event stratigraphy (Björck et al. 1998b), assuming that the climatic changes registered in the GRIP ice core and in north European pollen stratigraphies are approximately synchronous, and expressed as calendar years BP corresponding to 'GRIP ice years BP' (Björck et al. 1998b). The sediment sequence covers the period from the deglaciation at c. 14,400, to c. 11,300 calendar years BP.

The glacial varve series encompasses about 930 varves in a c. 8 m long sequence, which have been connected to the local varve chronology established by Nilsson (1968). The varve thickness increases markedly at the OD/AL I pollen zone boundary, which indicates an accelerated deglaciation and melting of dead ice. The combined varve chronology and pollen stratigraphy indicates that the area was deglaciated c. 500 years before the onset of the AL I pollen zone.

The pollen diagram displays the vegetation development, from the deglaciation at c. 14,400 calendar years BP up to the transition to the Holocene. The vegetation succession starts after the deglaciation during the BÖ pollen zone with an arctic pioneer vegetation, which is succeeded by a more stable tundra environment. This succession was shortly interrupted during the OD pollen zone, when pioneer and drought tolerant plants displayed a minor comeback. During the AL I-AL II pollen zones the vegetation development continued with increasing *Betula* values. At the beginning of YD I pollen zone, the vegetation development was again interrupted and the high *Betula* values were replaced by increasing herb values. This lasted until the beginning of the Holocene, when the tundra elements decreased. These results are in accordance with the traditional Late-Glacial pollen stratigraphy for southern Sweden (Berglund 1966, Björck 1979; Liedberg Jönsson 1988; B. E. Berglund et al. 1994; M. Berglund et al. 1994; Björck & Möller 1987).

A palaeomagnetic secular variation curve is presented, which displays two westerly declination swings, at 14,200-13,800 and 12,800-11,600 calendar years BP, respectively. The upper one can be recognised from other palaeomagnetic stratigraphies from southern Sweden and Estonia. Between these there is a narrow easterly declination swing and a period of almost normal declination. The inclination shows a series of minor oscillations on a generally increasing trend, towards the top of the core, which is most probably due to a decrease in “inclination error” (see above) upwards.

Discussion

The radiocarbon-year based chronologies for Torreberga ancient lake (Paper I) and for Farslycke (Paper II) have been converted to calendar years BP by correlating the pollen zones, and their inferred climate succession, to the GRIP event stratigraphy (Björck et al. 1998b; Walker et al. 1999). The calendar-year ages for the pollen zones follow Björck et al. (1996, 1998b). The pollen assemblage zone boundaries that determine the correlation to the GRIP time scale are summarised in Table 2. Between these levels the ages are interpolated. Below the lowest zone boundary, at the site Torreberga they are extrapolated and at the site Farslycke they are based on varve counting.

Pollen stratigraphy and regional vegetation development

The pollen stratigraphies for the investigated sites are summarised in Fig. 3. Comparisons have been made for each site to adjacent pollen stratigraphies as well as to the regional pollen assemblage zones for the Åsnen area and Blekinge and to the pollen zones for southern Sweden (Björck & Möller 1987), which are modified following Björck et al. (1997). They are also compared to the LPAZ's for Björkeröds Mosse at Kullen (Liedberg Jönsson 1988). The radiocarbon-year-based pollen-/climato-stratigraphies have been correlated to the GRIP event stratigraphy (Björck et al. 1998b), assuming that the climatic changes registered in the GRIP ice core and in north European pollen stratigraphies are approximately synchronous. The calendar-year ages for the regional pollen zones follow Björck et al. (1996, 1998b).

During the GI-1e (BÖ pollen zone), all pollen diagrams are characterised by high values of *Betula*, Poaceae and secondary pollen. Especially, the basal parts of the sequences are rich in pioneer vegetation elements such as *Artemisia*, Brassicaceae and *Saxifraga*, together with secondary pollen. Substantial parts of the *Betula* and *Pinus* frequencies may also represent redeposited pollen grains, which are not possible to separate from primary grains (cf. Björck & Möller 1987). Additionally, many *Pinus* pollen are probably long-transported, especially where the total pollen influx value is low. However, macrofossil finds confirm that tree-birch was present at least in south-westernmost Sweden (Liedberg Jönsson 1988). *Betula nana*-type pollen and Poaceae are also relatively frequent in most diagrams. The total pollen accumulation rate is low but increasing upwards. The vegetation during this period seems to have been half-open park tundra, dominated by *Betula nana*, grasses and scattered stands of tree birch (cf. Björck & Möller 1987; Liedberg Jönsson 1988; Berglund et al. 1994).

The GI-1d (OD pollen zone) is characterised by high pollen values of *Artemisia*, *Rumex*, *Chenopodiaceae* and sometimes *Salix*, while tree-pollen values are low. The pollen accumulation rate decreases and displays normally a minimum during this period. Stands of tree birch probably almost completely disappeared and the landscape turned into an arid arctic tundra. This is in accordance with Björck & Möller (1987). Whether the climate during this period was mainly cold or dry has been widely discussed (e. g. van Geel & Kolstrup 1978; Kolstrup 1982; Björck & Möller 1987; Lemdahl 1988; Liedberg-Jönsson 1988; B. E. Berglund et al. 1994; Hammarlund & Keen 1994; Hammarlund & Lemdahl 1994; Hammarlund 1999).

The GRIP events GI-1c, GI-1b and GI-1a correspond to the Allerød interstadial (AL I and AL II pollen zones), which in many biostratigraphical studies has been divided into three parts (e.g. Berglund 1966). The early part of the period is mainly characterised by high pollen values of *Betula*, *Artemisia*,

Table 2. Summary of the LPAZ boundaries that determine the correlations between the three main sites, the pollen zones for southern Sweden (Björck & Möller 1987) and the GRIP event stratigraphy (Björck et al. 1996, 1998b).

GRIP events	Age (calendar years BP)	Pollen zones	Torreberga LPAZ	Farslycke LPAZ	Bolmen LPAZ
GS-1 upper boundary	11,500	YD II / YD-PB	T5 / T6	F5 / F6	B6 / B7
GI-1 / GS-1	12,650	AL II / YD I	T3 / T4	F4 / F5	B4 / B5
GI-1b / GI-1a	12,900	–	T2 / T3	–	–
GI-1c / GI-1b	13,150	AL I / AL II	~ T1 / T2	F3 / F4	–
GI-1d / GI-1c	13,900	OD / AL I	–	~ F2 / F3	B2 / B3
GI-1e / GI-1d	14,050	BØ / OD	–	F1 / F2	B1 / B2

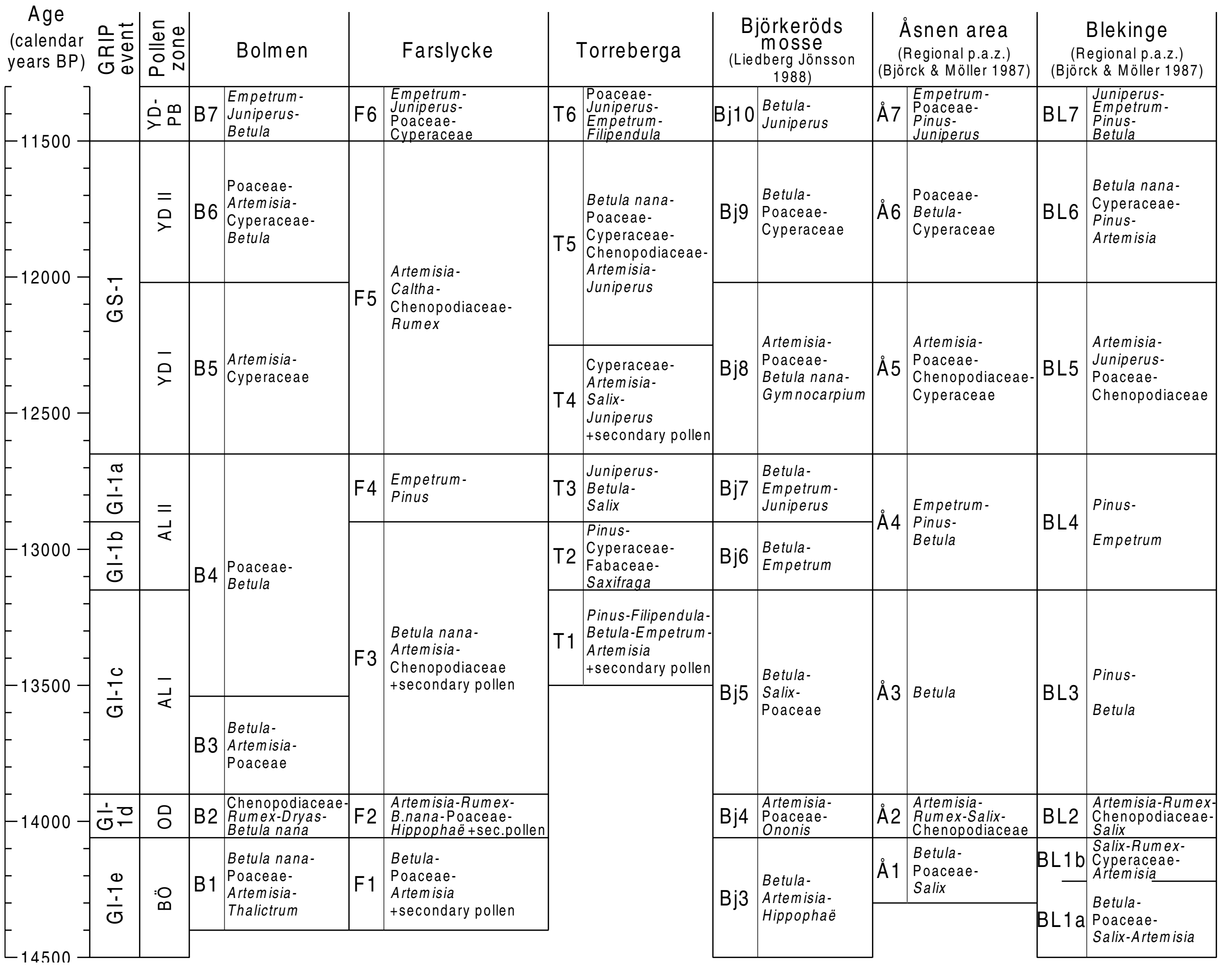

Fig. 3. Correlation of LPAZ's from the investigated sites to Björkeröds mosse (Liedberg Jönsson 1988) and to the regional pollen assemblage zones from the Åsnen area and Blekinge (Björck & Möller 1987). They are also compared to the pollen zones for southern Sweden (Björck & Möller 1987), and to the GRIP event stratigraphy (Björck et al. 1998b).

Poaceae, *Betula nana* and *Salix* and in some areas also *Pinus* and Chenopodiaceae. In the second part (GI-1b), correlated to the Gerzensee oscillation (Andresen et al. 2000), *Betula* decreases while *Empetrum* is abundant in most diagrams. This part may be missing in the Bolmen stratigraphy. During the last part (GI-1a), tree pollen values are decreasing, while shrubs, especially *Juniperus*, and *Empetrum* are increasing. The pollen accumulation rates increase markedly at the lower transition to this period. At the GI-1c/GI-1b transition, the pollen accumulation rate normally increases (c.f. Björck & Möller 1987), but this is not observed at Farslycke, until the GI-1b/GI-1a transition, which could be explained as the result of the isolation from the Baltic Ice Lake. The low pollen accumulation rate for Lake Bolmen is probably due to irregular sedimentation rate and possibly also erosion. The vegetation changed, during the Allerød interstadial, from an open tundra to a more closed shrubland and subsequent a woodland tundra with tree-birch. Pine was likely present in favourable areas (Berglund 1966; Björck & Möller 1987; B. E. Berglund et al. 1994). At the AL II pollen zone (correlated to the GI-1b and GI-1a), the woodlands opened up into heaths or shrubs with abundant *Empetrum*.

At the transition to the GS-1 GRIP event, correlated to the YD I and YD II pollen zones, the pollen diagrams are characterised by a drastic decrease in tree pollen and *Juniperus* values, while herbs such as *Artemisia*, Cyperaceae, Poaceae, and Chenopodiaceae, but also *Betula nana* increase. The pollen accumulation rates decrease at the transition to the GS-1, but in the second half of the period a marked increase is normally displayed (c.f. Björck & Möller 1987). The vegetation almost totally opened up with tree birch surviving only in favourable positions (Björck & Möller 1987). However, in the middle of GS-1, increased tree birch pollen values indicate a recovery of tree birch as a response to ameliorated conditions and the open tundra gradually turned into a park tundra or shrubland (Björck & Möller 1987; B. E. Berglund et al. 1994).

The transition to the Holocene is marked by an initial increase in *Empetrum* and *Juniperus*, during the Younger Dryas/Preboreal transition zone (Berglund 1966; Björck et al. 1996, 1997).

Varve chronologies and deglaciation ages

The clay varve diagrams established here cannot be directly correlated to each other since the deposition of the varved clays did not take place in the same sedimentary basin and because the source material is derived from different catchment areas. Neither of the sites is correlated to the revised Swedish Time Scale (Cato 1985, 1987; Strömberg 1985). However, using pollenstratigraphic correlations, the varve diagrams can approximately be correlated and used to date the deglaciation of the sites. In this way the deglaciation of Farslycke is dated to c. 14,350 calendar years BP by adding 300 varve years to the LPAZ F1/F2 boundary (correlated to the GI-1e/GI-1d transition in the GRIP ice core) at 14,050 calendar years BP (Björck et al. 1998b). The deglaciation of the northern part of Lake Bolmen is dated to c. 14,400 calendar years BP by adding 340 varve years to LPAZ B1/B2 boundary (correlated to the same GRIP transition). These deglaciation dates can be compared to age estimates, which have earlier been suggested for the deglaciation in southern Sweden (Table 3 and Fig. 4).

Table 3. Deglaciation ages for different ice marginal lines and areas in southern Sweden according to various studies. The calendar-year ages are either [1] 'GRIP years' (Björck et al. 1998b) or [2] converted from radiocarbon years according to INTCAL98 (Stuiver et al. 1998).

Area / ice marginal line	References	^{14}C years BP	Calendar years BP
The Halland Coastal Moraines	Lagerlund & Houmark-Nielsen 1993	14,000	17,000-16,000 [2]
The Göteborg Moraine	Hillefors 1975, 1979; Björck et al. 1988	12,650	15,500-14,400 [2]
	M. Berglund 1995	>12,500	>15,400-14,300 [2]
	this study - paper III		>14,640 [1]
The Berghem Moraine	Berglund 1979, Hilldén 1979	12,400	15,400-14,200 [2]
	Björck et al. 1988	12,350	15,400-14,200 [2]
	Fredén 1988b	12,350-12,250	15,400-14,100 [2]
	M. Berglund 1995	12,000	14,100-13,800 [2]
	Lundqvist & Wohlfarth 2000	~14,350-14,250	~14,400-14,200 [2]
The Trollhättan Moraine	Björck & Digerfeldt 1982	>11,900-11,800	>14,100-13,900 [2]
	Björck et al. 1988	12,175	15,200-14,100 [2]
	Fredén 1988b	11,900-11,800	14,100-13,900 [2]
	Lundqvist & Wohlfarth 2000	~11,900-11,800	~14,100-13,900 [2]
The Levene Moraine	Björck et al. 1988	12,050	14,300-13,800 [2]
	Fredén 1988b	11,400-11,300	13,500-13,200 [2]
	Björck & Digerfeldt 1991	>11,600-11,500	>13,600-13,400 [2]
	Lundqvist & Wohlfarth 2000		13,600-13,200 [2]
Western Skåne	Lagerlund & Houmark-Nielsen 1993	>14,000	>17,000-16,000 [2]
Southern Blekinge (Regional varve year –100)	Björck & Möller 1987	12,625	15,500-14,400 [2]
	this study - paper II		14,450 [1]
Lake Bolmen (N end)	this study - paper III		14,400 [1]
Lake Bolmen (S end)	this study - paper III		14,700 [1]
Upper part of the Lagan and Nissan river valleys	this study - paper III		13,700 [1]
The Åsnen area	Björck & Möller 1987	12,350	15,300-14,200 [2]
Högsby area	Combination of Kristiansson 1986, Svensson 1989 & Wohlfarth et al. 1998		14,150 [1]
Eastern Småland-Östergötland boundary	Wohlfarth et al. 1998, Lundqvist & Wohlfarth 2000		13,050 [1]

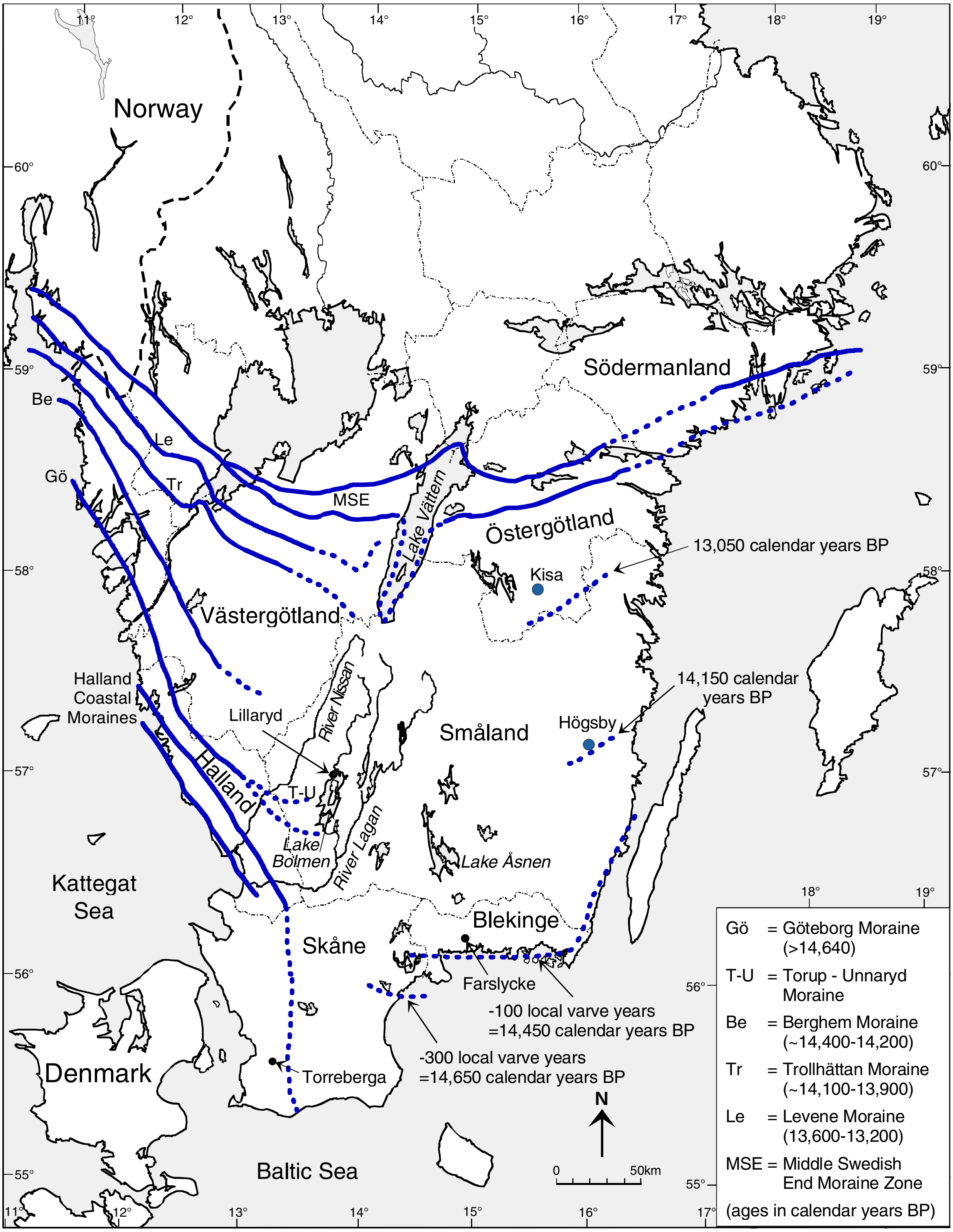

Fig. 4. Map of the deglaciation of southern Sweden. The ages are according to Lundquist & Wohlfarth (2001) or discussions in the text.

Along the Swedish west-coast, the Halland Coastal Moraines, have been assigned an age of c. 14,000 ^{14}C years BP (Lagerlund & Houmark-Nielsen 1993), which corresponds to 17,000-16,000 cal years BP (INTCAL98, Stuiver et al. 1998), and this zone is also extended southwards through central western Skåne. The deglaciation of the province of Halland has recently been studied by M. Berglund (1995). His deglaciation chronology is based on a compilation of previous investigations (e.g. Mörner 1969; Berglund 1979; Björck et al. 1988; Fredén 1988b), combined with new pollen stratigraphies, radiocarbon measurements and shore displacement studies. Age estimates for the Göteborg Moraine have been presented by Hillefors (1975, 1979), who also suggested a southward continuation of the Göteborg Moraine towards the southern end of Lake Bolmen. A new attempt to find the southward continuation of the Göteborg Moraine was made by Andersson (1998), who proposed a continuation towards Torup and Unnaryd, i.e. towards the central western part of Lake Bolmen. The age of the Göteborg Moraine was estimated to c. 12,650 ^{14}C years BP by Björck et al. (1988) and to >12,500 ^{14}C years BP by M. Berglund (1995), which approximately corresponds to 15,500-14,300 cal years BP (Stuiver et al. 1998). Paper III suggests a minimum age of 14,640 calendar years BP for the Göteborg Moraine, if the southward continuation of either Hillefors (1979) or Andersson (1997, 1998) is accepted. However, the absence of disturbances in the varve series from Angelstad (Nilsson 1968) does not support the continuation towards the central western part of Lake Bolmen, proposed by Andersson (1997, 1998). The Berghem Moraine has been investigated by e.g. Hilldén (1979) and dated to between 12,400 and 11,000 ^{14}C years BP. However, its age should most probably be situated at 12,400-12,200 ^{14}C years BP (e.g. Berglund 1979; Hilldén 1979; Björck et al. 1988; Fredén 1988b), which corresponds to c. 15,400-14,100 cal years BP (Stuiver et al. 1998), i.e. slightly older than the Older Dryas stadial. Lundqvist & Wohlfarth (2001) determined the age to c. 14,400-14,200 cal years BP. The Trollhättan Moraine has been investigated by among others Johansson (1982) and Fredén (1984) and dated to 11,900-11,800 ^{14}C years BP (Fredén 1988b) and 12,175 ^{14}C years BP (Björck et al. 1988). Lake sediment studies at Hunneberg, south of Lake Vänern, indicate a minimum age of 11,900-11,800 ^{14}C years BP (Björck & Digerfeldt 1982). These radiocarbon ages give a deglaciation age of c. 14,100-13,900 cal years BP (Stuiver et al. 1998; Lundqvist & Wohlfarth 2001). The Levene Moraine has been studied by e.g. Johansson (1982) and the age, based on radiocarbon dates from lake sediments, has been estimated at 11,400-11,300 ^{14}C years BP by Fredén (1988b), 12,050 ^{14}C years BP by Björck et al. (1988) and to before 11,600-11,500 ^{14}C years BP by Björck & Digerfeldt (1991). These radiocarbon ages correspond to ~13,500-13,200 cal years BP, to ~14,300-13,800 cal years BP and to >13,400 cal years BP, respectively (Stuiver et al. 1998). Recently, Lundqvist & Wohlfarth (2001) suggested an age of 13,600-13,200 cal years BP for the formation of the Levene Moraine, based on an evaluation of older radiocarbon dates.

The deglaciation of western Skåne has been intensely discussed during the last decades (e. g. Lagerlund 1980, 1983, 1987a; Adrielsson 1984; Sandgren 1984; Malmberg Persson 1988; Ringberg 1988, 1989; Malmberg Persson & Lagerlund 1990, 1994). The traditional view, established by Holmström (1904), is a deglaciation towards the east - north-east, followed by a "Low Baltic ice stream" coming from the south-west (Ringberg 1988, 1989). Recent investigations (Malmberg Persson & Lagerlund 1990, 1994; Lagerlund & Houmark-Nielsen 1993) indicate a deglaciation towards the east and a subsequent transgression, which deposited clay and diamict sediments. Additionally, in south-western Skåne, large areas may have been covered by stagnant ice, and the many controversies on the glaciation/deglaciation pattern of Skåne are still not resolved. Only a few radiocarbon dates, mainly on bones and shells, which are associated with the deglaciation, have been obtained from the area (see e.g. Lagerlund & Houmark-Nielsen 1993), since most lake basins were occupied by stagnant ice. Exceptions are e.g. the Kullen Peninsula (Berglund 1971; Hammarlund 1999; Sandgren et al. 1999), Bare Mosse (Ringberg 1984) and Körslättamossen (Hammarlund & Lemdahl 1994), where the sedimentation started before or during the Oldest Dryas stadial. The southward extension of the Halland Coastal Moraines through central Skåne gives a minimum age for the deglaciation of western Skåne of 14,000 ^{14}C years BP (Lagerlund & Houmark-Nielsen 1993), which corresponds to 17,000-16,000 cal years BP (INTCAL98, Stuiver et al. 1998). However, stagnant ice remained in many areas. The beginning of lacustrine sedimentation at Torreberga at 11,700 ^{14}C years BP (Paper I), which corresponds to c. 13,500 calendar years BP, indicates that in some areas stagnant ice bodies have been blocking the sedimentation for at least 2 millennia.

The deglaciation of eastern Skåne has been studied by Åmark (1984), but no radiocarbon dates were obtained. Clay varve correlations between north-eastern Skåne (Antevs 1915) and Blekinge were made by Ringberg (1979). The deglaciation of southern Blekinge (regional varve year -100) has in turn been estimated to c. 12,625 ^{14}C years BP (Björck & Möller 1987), which corresponds to 15,500-14,400 cal years BP (Stuiver et al. 1998), and is calculated to 14,450 calendar years BP in this study (Paper II). The clay varve correlations by

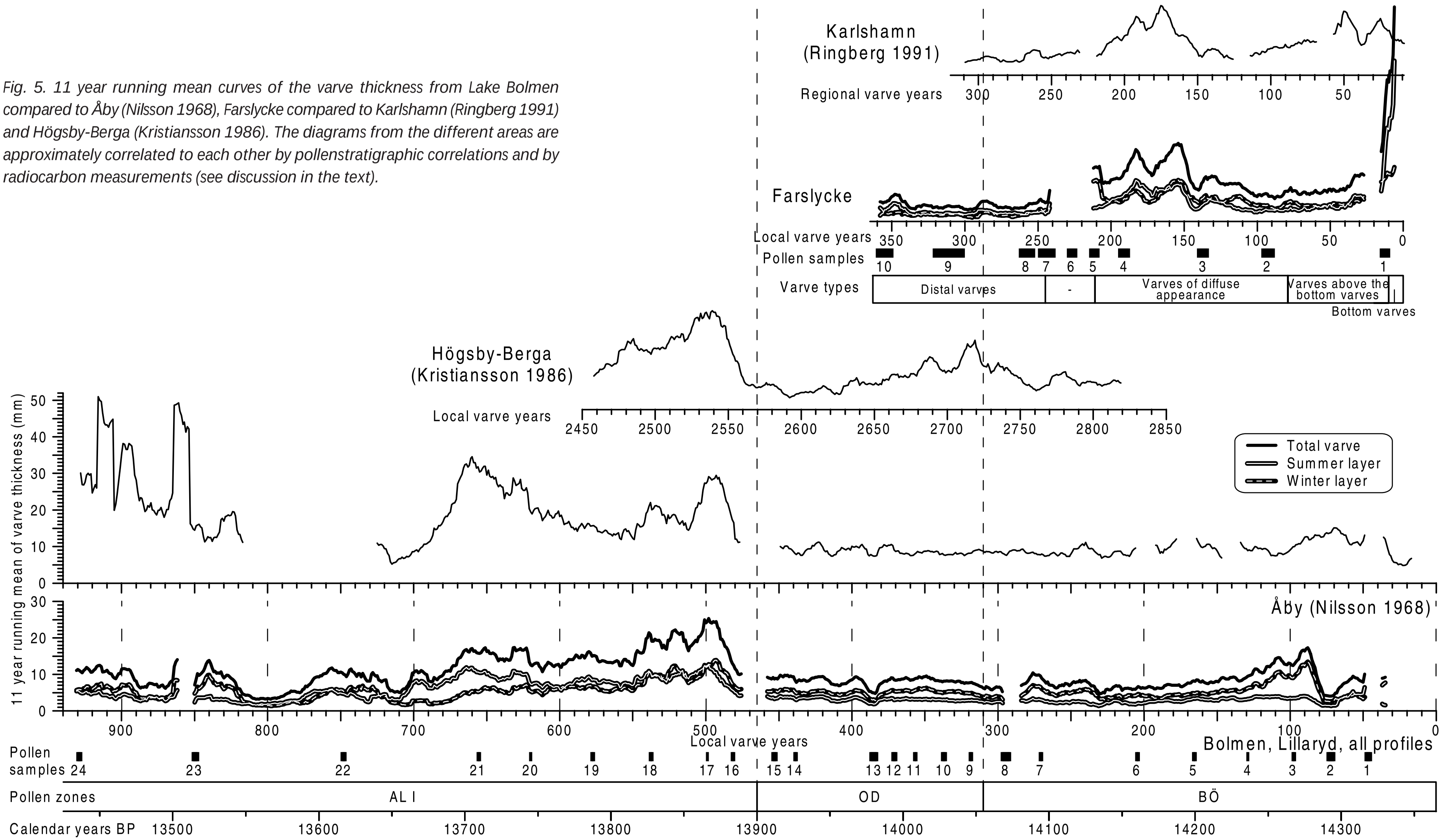

Fig. 5. 11 year running mean curves of the varve thickness from Lake Bolmen compared to Åby (Nilsson 1968), Farslycke compared to Karlshamn (Ringberg 1991) and Högsby-Berga (Kristiansson 1986). The diagrams from the different areas are approximately correlated to each other by pollenstratigraphic correlations and by radiocarbon measurements (see discussion in the text).

Ringberg (1979) show that east central Skåne became ice free 200 years earlier than southern Blekinge, i.e. at c. 14,650 calendar years BP (Lundqvist & Wohlfarth 2001).

During the deglaciation of the inland of Småland, probably large amounts of stagnant ice remained (Björck & Möller 1987) and it is thus not possible to construct ice recession lines for the region, except in areas which were covered by glacial lakes, like the Bolmen area. The deglaciation of the site Lillaryd at the northern part of Lake Bolmen (Paper III) is dated to c. 14,400 calendar years BP by combining clay varve chronology and pollen analysis (see above). The clay-varve chronology by Nilsson (1968) allows correlation to the site Angelstad at the southern part of Lake Bolmen, and indicates a deglaciation of the southern Bolmen area at around 14,700 calendar years BP. The sedimentation of varved clays continued until the drainage area northwards (Nissan and Lagan river valleys) was free from melting of glacial ice. Possibly, the change to irregular varves with unclear correlations, after c. varve number 700, reflects the disappearance of active ice from the drainage area. This would give a deglaciation age of c. 13,700 calendar years BP for the northern part of the Nissan river valley. At the Åsnen area, the start of the sedimentation in Lake Skulingen started at c. 12,350 ^{14}C years BP (Björck & Möller 1987), which corresponds to c. 15,300-14,200 cal years BP (Stuiver et al. 1998). In Farslycke, the deposition of varved clays persisted until c. varve number 360, i.e. at the middle of GI-1d (OD pollen zone), when south central Småland was almost free from stagnant ice (Björck & Möller 1987).

The deglaciation chronology from eastern Småland to Östergötland is based mainly on clay-varve studies (Rudmark 1975; Kristiansson 1986) and an attempt to correlate southwards to the Blekinge varve chronology has been made by Ringberg & Rudmark (1985). However, the varve chronologies from these areas are not satisfactory connected neither between the areas nor to the Swedish Time Scale (Holmquist & Wohlfarth 1998). Therefore, these varve chronologies have to be regarded as floating chronologies and must be combined with radiocarbon dates or pollen stratigraphic correlations to obtain absolute ages for the ice recession. Svensson (1989) presented a pollen diagram from the site Nedre Leksjön, west of Högsby, where the pollen zone correlated to the Older Dryas starts immediately above the upper boundary of the varved clay. The varve diagram for the site, which is connected to Kristiansson's (1986) Högsby-Berga diagram, corresponds to the local varve years 2764-2712 in Kristiansson's (1986) chronology and implies that the Older Dryas pollen zone starts shortly after the local varve year 2712. Högsby-Berga became ice free at the local varve year 2825, i.e. slightly more than 113 years before the beginning of the Older Dryas pollen zone. The GRIP age for the GI-1e/GI-1d transition is c. 14050 calendar years BP (Björck et al. 1998b), which gives an age for the deglaciation at Högsby of c. 14,150 calendar years BP (Fig. 5). AMS radiocarbon dates from varved clays at the site Toregöl, NE of Högsby, give an age of 11,700 ^{14}C years BP (Wohlfarth et al. 1998) for the varved sequence above the transition to thicker varves, which is calibrated according to INTCAL98 (Stuiver et al. 1998) to c. 13,900 cal years BP. This transition is tentatively correlated to a similar transition seen in the Högsby varve diagrams (Kristiansson 1986), at 265 varves above the bottom (Fig. 5). Assuming that the transition to the thicker varves represents the OD/AL I pollen zone boundary (GRIP event GI-1d/GI-1c transition) at 13,900 calendar years BP, the deglaciation age for Högsby would correspond to c. 14,150 calendar years BP. Furthermore, the transition to the thicker varves has recently been pollen analysed at a nearby site (Ringberg pers. comm.; Ringberg et al. in prep.) and confirms a correlation to the OD/AL I pollen zone boundary (GI-1d/GI-1c). Through AMS radiocarbon dates on terrestrial macrofossils from varved clay, Wohlfarth et al. (1998) and Lundqvist & Wohlfarth (2001) dated the deglaciation of the Småland-Östergötland boundary south of Kisa to 13,050 calendar years BP.

Palaeomagnetic correlations

The palaeomagnetic secular variation curves for the investigated sites are summarised in Fig. 6 and 7. In Table 4 these curves have also been correlated to Late Weichselian palaeomagnetic stratigraphies from Lake Halsjön and Lake Paddegölen in Blekinge (Björck & Sandgren 1986), Lake Tamula in Estonia (Sandgren et al. 1997) and Lake Onega in western Russia (Saarnisto & Saarinen, submitted).

The declination curves are mainly characterised by a broad westerly declination swing between c. 13,000 and 12,000 calendar years BP. This swing is also found in the records from Lake Halsjön, Lake Paddegölen, Lake Tamula and Lake Onega. At Torreberga and Lake Bolmen the mean declination curve reaches values of c. 45° W, but at Farslycke and Lake Tamula it is 20-30° W. At Lake Onega,

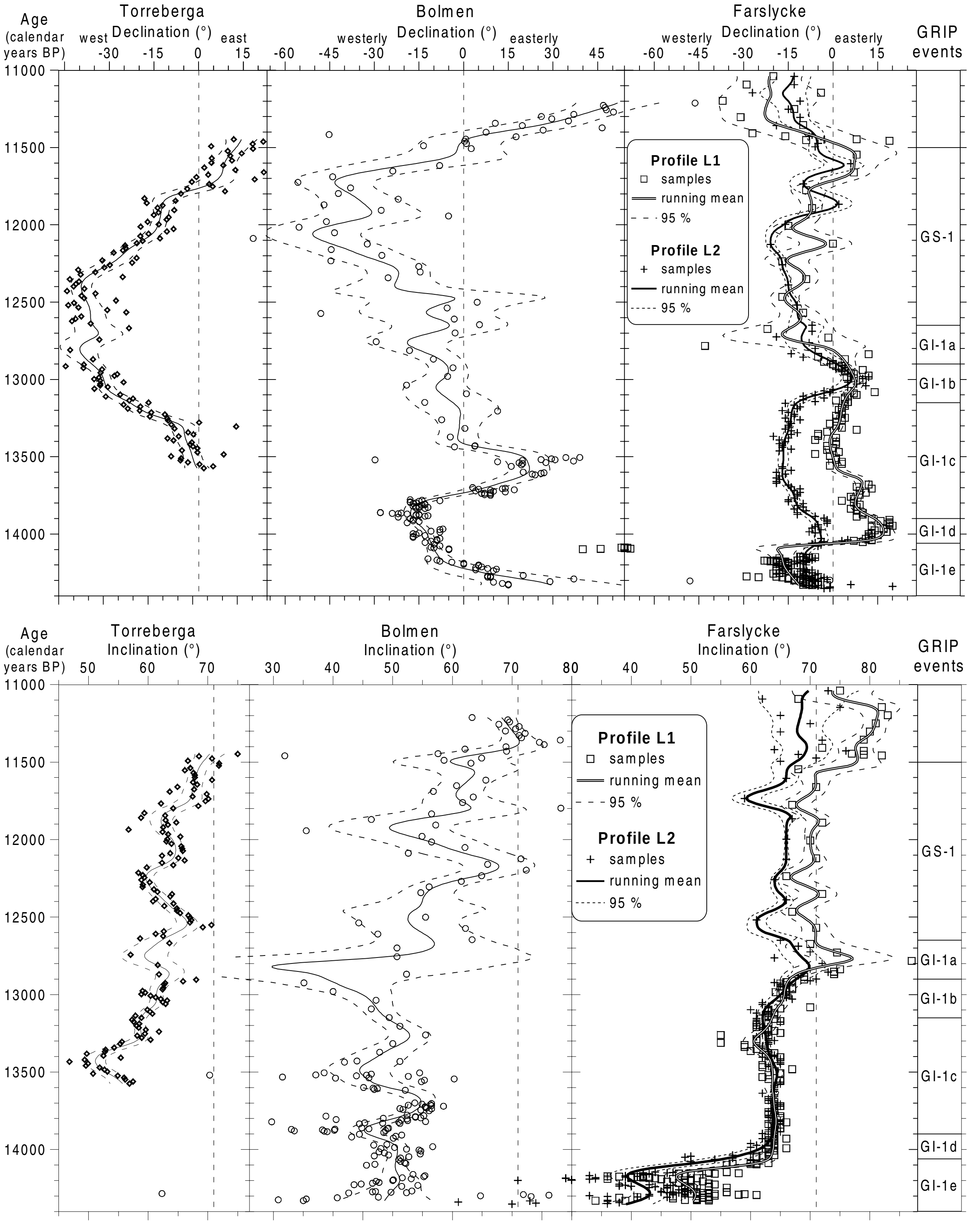

Fig. 6. Palaeomagnetic secular variation curves for Torreberga (Paper I), Lake Bolmen (Paper III) and Farslycke (Paper II). The curves are plotted against a calendar-year time scale ('GRIP years', Björck et al. 1998b). The directional values are smoothed using a running circular mean (Holmquist 1985) of 150 calendar years. 95% circular confidence limits are shown by dashed curves. The sample values for the individual sites are marked with different markers, which in some cases exceed the diagram limits.

the declination values are relative since the orientation of the core could not be measured in field. Minor variations in the age of the swing between the sites (Table 4), may be results of dating errors, since the time-depth curves often assume a constant sedimentation rate between dated levels. Below this swing, the declination curves are not possible to correlate to each other.

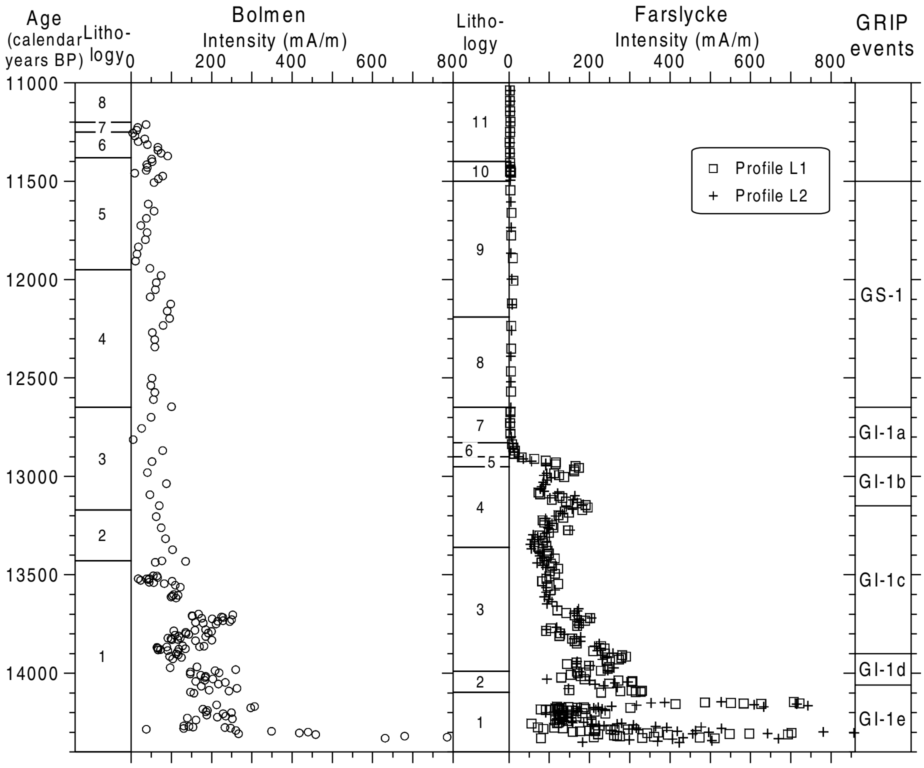

Fig 7. Palaeomagnetic intensity values for Lake Bolmen (Paper III) and Farslycke (Paper II). For descriptions of the lithology columns, see the separate papers.

All inclination curves show generally higher inclination upwards, which is explained by higher inclination error downcore, which in turn depends on both grain-size and compaction (see discussion in Paper II). The minor oscillations are in some cases possible to correlate to each other, but the significance of these are yet not possible to evaluate. However, there seems to be a general low-inclination event at c. 13,500 calendar years BP and another one at c. 11,900 calendar years BP (Table 4). The synchroneity of these events seems, however, somewhat uncertain due to inaccuracies in the time scales.

No evidence in support of the “Gothenburg Magnetic Excursion”, a short geomagnetic anomaly, at c. 12,400 ^{14}C years BP (c. 15,300-14,200 cal years BP, Stuiver et al. 1998), found by Mörner (1975, 1977) were found in any of the magnetic

Table 4. Comparison of secular variation events observed at the separate sites. All ages are expressed as calendar years either [1)] according to the GRIP event stratigraphy ((‘GRIP years’, Björck et al. 1998b) using pollen correlations as described in the text, or [2)] according to INTCAL98 (Stuiver et al. 1998). [3)] The chronology of Lake Tamula has been obtained through a palaeomagnetic correlation to Torreberga, which means that the chronology is not independent. [4)] Relative declination values.

Character	Site	References	Magnitude	Age (calendar years BP)	Dating method
Westerly declination swing	Torreberga	Paper I	c. 40°W	13,200-12,000[1)]	Pollen, ^{14}C
	Lake Bolmen	Paper III	c. 45°W	12,800-11,600[1)]	Pollen, varves
	Farslycke	Paper II	c. 20°W	12,800-11,800[1)]	Pollen, varves, ^{14}C
	Lake Halsjön	Björck & Sandgren 1986	c. 45°W	>13,000-12,400[1)]	Pollen, ^{14}C
	Lake Paddegölen	Björck & Sandgren 1986	c. 55°W	>13,000-12,100[1)]	Pollen, ^{14}C
	Lake Tamula	Sandgren et al. 1997	c. 30°W	(13,200-12,100)[3)]	relative varves [3)]
	Lake Onega	Saarnisto & Saarinen (submitted)	c. 50°W [4)]	13,400-12,750[2)]	^{14}C
Low inclination	Torreberga	Paper I	60-65°	11,900[1)]	Pollen, ^{14}C
	Lake Bolmen	Paper III	c. 50°	11,900[1)]	Pollen, varves
	Farslycke	Paper II	c. 60°	11,700[1)]	Pollen, varves, ^{14}C
	Lake Halsjön	Björck & Sandgren 1986	c. 60°	12,000[1)]	Pollen, ^{14}C
Low inclination	Torreberga	Paper I	c. 50°	13,400[1)]	Pollen, ^{14}C
	Lake Bolmen	Paper III	c. 45°	13,500[1)]	Pollen, varves
	Farslycke	Paper II	c. 60°	13,300[1)]	Pollen, varves, ^{14}C

records. The existence of this excursion was already questioned by Thompson & Berglund (1976).

Palaeoclimatic implications

The varve diagrams have been smoothed, using a (11 yr) running mean, to obtain a (climatic) signal that can be better compared to the more low-resolution pollen data (Fig. 5). The total varve thickness variations at Farslycke (Paper II) follow Ringberg's (1991) division into "bottom varves or proximal varves", "varves above the bottom varves", "varves of diffuse appearance" and "distal varves". The distribution of the varve types in the Farslycke section is displayed in Fig. 5. At Lake Bolmen, the bottom varves range up to c. local varve number 60, but the lowermost ones were not reached. Between varve number 60 and 480, the winter layers are generally thicker than the summer layers. At varve number 480 the varve thickness increases from about 1 cm to 1.5-2.5 cm and the summer layers become thicker than the winter layers. The varve thickness remains high until the local varve year 670, from where it decreases to c. 0.5-1 cm, and after c. varve number 710 the winter layers become thicker than the summer layers. However, after c. varve number 700, the varves are irregular and the correlations slightly uncertain. The change to thicker varves at c. varve number 480 coincides with the OD/AL I pollen zone transition (GI-1d/GI-1c), and is possibly a response to increased melting of glacial ice. As mentioned above, a similar increase in varve thickness, of possibly the same age, is recorded from sites in the Högsby area in eastern Småland (Fig. 5).

Comparison have recently been made between palaeomagnetic NRM intensity and climate (e.g. Kok 1999) but at the investigated sites the predominant component for variations in NRM intensity must be ascribed to the lithology since all major changes in intensity can be correlated to lithological changes.

Conclusions

The pollen stratigraphies in the three study areas display a vegetation development, which compares well to earlier investigations (e.g. Berglund 1966; Björck 1979; Björck & Möller 1987; B. E. Berglund et al. 1994). Major signals are the development from a pioneer vegetation to a tundra or park tundra with scattered stands of tree birch during the BÖ pollen zone, the change into an arid arctic tundra dominated by herbs in the OD pollen zone, the re-establishment of a more closed shrubland and woodland tundra with tree-birch, but also pine during the AL I-II pollen zone, the rapid change to an open tundra at the beginning of the YD I pollen zone, which is followed by a park tundra or shrubland, and the change to a more dense forest at the beginning of the Holocene.

An abrupt increase in varve thickness is recorded from Lake Bolmen at the OD/AL I pollen zone transition (GI-1d/GI-1c). A similar and approximately synchronous increase is seen in sites in the Högsby area in eastern Småland.

The pollen stratigraphies and the varve chronologies have, together with correlations to the GRIP event stratigraphy (Björck et al. 1998b), made it possible to assign approximate ages in calendar years BP for the deglaciation of southern Blekinge and the Bolmen area. Farslycke and the northern end of Lake Bolmen became ice-free at c. 14,350 and 14,400 calendar (GRIP) years BP, respectively. These deglaciation ages can be extended to areas in western Småland and Blekinge-NE Skåne, which are covered by floating varve chronologies (Nilsson 1968; Ringberg 1991). The ages obtained here fit well into, and give valuable contributions to a new calendar-year based deglaciation chronology for southern Sweden (Lundqvist & Wohlfarth 2001). A probable deglaciation age of 13,700 calendar (GRIP) years BP for the northern end of the Nissan and Lagan river valleys can be calculated by extrapolating the ice recession rate obtained from the varve diagrams from Bolmen (Nilsson 1968). This age coincides with the change to irregular varves with unclear correlations after c. local varve number 700, which could be an indication of the disappearance of active ice from the drainage area. Based on the combined pollen stratigraphy and varve chronology for the Bolmen area, a minimum age of c. 14,640 calendar years BP can be assigned to the Göteborg Moraine. .

Relatively well-dated palaeomagnetic records from three sites in southern Sweden display a characteristic westerly declination swing at c. 13,000-12,000 calendar years BP, preceded and followed by northern/slightly eastern directions, which can be recognised from other palaeomagnetic stratigraphies from northern Europe (Björck & Sandgren 1986; Sandgren et al. 1997; Saarnisto & Saarinen, submitted).

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