THE SWEDISH TIME SCALE: A POTENTIAL CALIBRATION TOOL FOR THE RADIOCARBON TIME SCALE DURING THE LATE WEICHSELIAN

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ABSTRACT. The Swedish Time Scale (STS) is a *ca.* 13,300-yr-long varve chronology that has been established for the Swedish east coast from >1000 overlapping clay-varve diagrams. We describe the present state of the STS and illustrate the application of this worldwide unique varve chronology for AMS radiocarbon measurements. The results are compared to other ^{14}C-dated calendar-year chronologies: dendrochronology, laminated lake sediments and U/Th. Our data set agrees with the oldest part of the dendrochronological calibration curve, and with AMS ^{14}C-dated lake lamination data and U/Th on corals down to *ca.* 12 ka calendar years BP. Further back in time, the AMS-dated part of the STS partly compares well with lake lamination chronologies and shows that the difference between ^{14}C and calendar years decreases rapidly between 12,600 and 12,800 calendar years BP. Such a development seems to contrast with U/Th measurements on corals. We suggest that the cause for the divergence among three supposed calendar-year chronologies lies in the fact that the data points on the marine ^{14}C-U/Th curve are more widely spaced in time than the tightly grouped set of terrestrial AMS ^{14}C dates, and thus are not able to reflect short-term changes in atmospheric ^{14}C. Therefore, we argue that the use of the pre-Holocene part of the calibration program is premature and inadvisable.

INTRODUCTION

A qualitative and quantitative interpretation of climatic and environmental data and a correlation of isotope, bio-and lithostratigraphic records require a calibration of the radiocarbon time scale against a calendar-year chronology. The dendrochronological calibration curve has solved this problem for the last 10 ka BP or 11,350 cal BP (Kromer and Becker 1993). Beyond 10 ka BP, ^{230}Th-^{243}U and ^{14}C measurements on corals provided promising results to extend the calibration curve back to *ca.* 18 ka BP (Bard *et al.* 1993). However, terrestrial records such as accelerator mass spectrometry (AMS) ^{14}C dates from the glacial varves of the Swedish Time Scale (STS) (Björck *et al.* 1995; Wohlfarth *et al.* 1993, 1995) and from laminated lake sediments in Germany and Switzerland (Hajdas 1993; Hajdas *et al.* 1993) showed that, although a good correspondence exists among corals, tree rings and varved sediments as far back as *ca.* 10 ka BP, varve data and U/Th records disagree between *ca.* 10,500 and 12,500 BP. Here we present new AMS ^{14}C dates from the Late Weichselian part of the STS, a varve chronology spanning the last *ca.* 13,300 calendar years (Björck *et al.* 1992; Wohlfarth *et al.* 1993) and discuss our results in respect to other high-resolution ^{14}C-dated calendar-year chronologies: annually laminated lake sediments, dendrochronology and U/Th-dated corals.

Difference Between Glaciolacustrine Varved Clays And Organic Varves

The term "varve" (from the Swedish word *varv* = turn, round, layer) was introduced by De Geer (1912) to name a glaciolacustrine sediment with distinct alternating summer (silt) and winter (clay) layers. Although later defined as "a sedimentary bed or lamina or sequence of laminae deposited in a body of still water within one year's time, specifically a thin pair of graded glaciolacustrine layers seasonally deposited (usually by meltwater streams) in a glacial lake or other body of still water in front of a glacier" (Gary *et al.* 1972), the term "varve" is now generally applied to describe the structure of a sediment regardless of its depositional environment and lithologic composition (Sturm 1979). This means that different types of annually deposited sediments, *e.g.* glaciolacustrine varved clays and annually laminated lake sediments, are grouped together under the term "varve", although their lithology and depositional environment are completely different. Varved clays are glaciolacustrine sedi-

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ments that were deposited in a proglacial lake either in front of the retreating ice margin or by glacial meltwater streams. These sediments are composed of clearly separated, several centimeter-thick, light-colored silty-sandy (summer) and dark-colored clayey (winter) layers. The coarsest particles were deposited first (by bottom transport) as a result of rapid spring and summer ice melt, whereas the finer clay particles remained in suspension and settled during winter, when the lake was frozen. Annually laminated lake sediments or organic varves form in deep lakes with oxygen-deficient basal water and result from seasonal variations in the accumulation of organic detritus (Saarnisto 1986). The laminations may be due to the seasonal abundance of diatoms (Simola 1977), precipitation of $CaCO_3$ (Kelts and Hsü 1978), formation of iron oxides (Anthony 1977, Renberg 1981) or variations in mineral matter (Renberg 1976). The thickness of these laminae may vary between 0.5 and 1 mm.

The Swedish Time Scale

More than 100 yr ago, the Swedish geologist Gerard De Geer (1884), discovered alternating layers of light-colored silt and dark-colored clay, which reminded him of tree rings. He understood that these layers had been deposited by glacial meltwater in the Baltic basin during the retreat of the Fennoscandian ice sheet and reasoned that by establishing and correlating varve diagrams from south to north it should be possible to reconstruct the timing of the deglaciation of the Fennoscandian inland ice. After extensive varve measurements along the Swedish east coast, De Geer (1912) and Lidén (1913) presented the first deglaciation chronology for Sweden, the STS, which was divided into "gotiglacial", "finiglacial" and "postglacial" sections (De Geer 1912; Lidén 1913). During the following years, varved-clay measurements and correlations were made not only in Sweden (*e.g.*, Lidén 1938; De Geer 1940), but in former glaciolacustrine basins in many other parts of the world (*e.g.*, Sauramo 1923; Antevs 1932; see Zeuner 1950). However, De Geer's (1930) so-called "teleconnections" (between different areas of glaciation and different sedimentary basins) and the uncertainties in many of the old varved-clay connections provoked controversies, which also influenced the international image of the Swedish varve chronology (*e.g.*, Lundqvist 1975, 1985).

In Sweden, however, many geologists understood the potential of De Geer's research and worked during the last 20 yr on a revision, refinement and extension of the Swedish varve chronology, following the principles outlined by Strömberg (1983): 1) all varve diagrams that are part of the STS have to be established on varved clays deposited in the same sedimentary basin, *i.e.*, the Baltic; 2) correlations among varve diagrams are to be made only over short distances; and 3) reliable correlations must follow the retreating ice margin.

The STS (Fig. 1) is now completely revised, which means that all old varve connections have been checked and several hundred new varve diagrams have been added (Strömberg 1985, 1989, 1994; Kristiansson 1986; Ringberg 1991; Brunnberg 1995). The chronology is linked to the present through extensive studies by Cato (1985, 1987) in the River Ångermanälven, where varves were formed throughout the Holocene. Further, the local and revised chronologies in southeastern Sweden (Kristiansson 1986; Ringberg 1991) have been connected to the STS (Strömberg 1994; Wohlfarth *et al.* 1993, 1995; Wohlfarth and Holmquist, ms.). Several independent approaches also enable us to test and confirm the validity of the STS:

1. Cato (1987) confirmed the annual character of the postglacial varves by comparing the mean annual varve thickness to mean annual discharge records. Similar results were obtained by comparing the mean annual thickness of glaciolacustrine varves with mean annual temperatures, precipitation and discharge records (Perkins and Sims 1983; Leonard 1985; Deslodges 1994; Leemann and Niessen 1994). The length of the postglacial part of the STS can also be directly compared with annual lake lamination chronologies (Cato 1992).

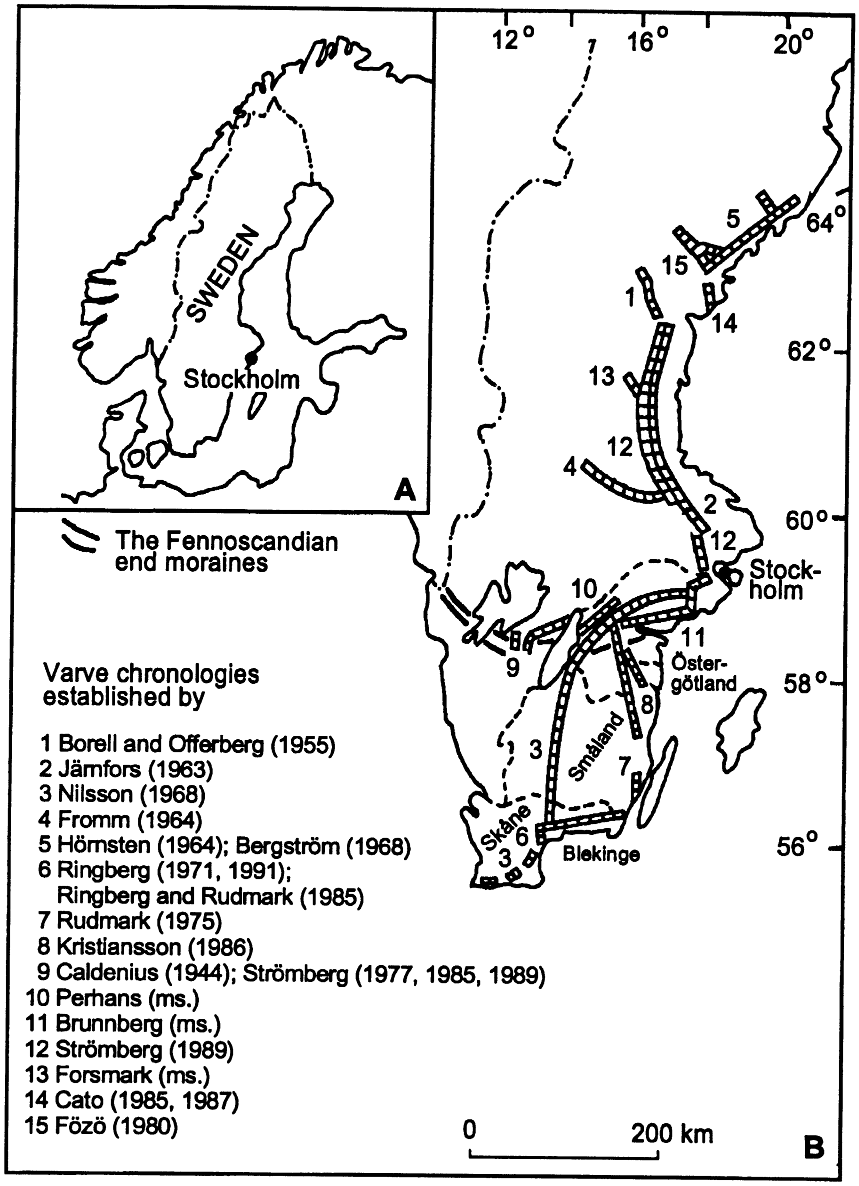

Fig. 1. Sweden (A) and the location of the varved-clay chronologies (B) on which the revised STS is based. Modified after Strömberg (1985); see Strömberg (1985) for references.

2. The first rapid recession of the ice margin in middle Sweden is dated to *ca.* 10,940 (estimated uncertainty: +100/−250) varve years BP and the second rapid ice retreat to *ca.* 10,740 varve years BP, which corresponds, according to Strömberg (1994), to the Younger Dryas (YD)/Holocene transition. In southern Sweden, the end of the YD stadial (not pollen zone) is indicated by insect, plant and marine records showing an increase in temperature already at *ca.* 10,200 ^{14}C BP (bulk dates) (Berglund *et al.* 1994) or 10,000–9900 ^{14}C BP (AMS dates on terrestrial macrofossils) (Björck *et al.* ms.). We believe this climatic signal may be synchronous

with the first rapid retreat of the ice margin at *ca.* 10,940 varve years BP, and that this part of the varve chronology belongs to the later part of the YD chronozone.

3. We know that the second Baltic Ice Lake (BIL) drainage, which marks a drastic event in the history of the Baltic Sea, occurred at *ca.* 10,980 varve years BP (Strömberg 1994). The effect of the drainage can be easily seen in varved-clay sequences (Strömberg 1994), in the sudden isolation of lake basins from the BIL (Björck 1981) and as sandy-silty layers in Late Weichselian lacustrine deposits, where it marks the YD/Preboreal transition zone (Svensson 1989; Björck 1995).
4. The pollen zones established in the Late Weichselian part of the varve chronology confirm, in comparison with pollen-analyzed lake sediments, the length of the chronology (Fig. 2). We know that the varves *ca.* 12,700 varve years BP can be assigned to the Bølling pollen zone and that the varves between *ca.* 12,560 and 12,700 varve years BP were deposited during the Older Dryas pollen zone (Björck 1981; Björck and Möller 1987, Wohlfarth *et al.* 1994).
5. Statistical analyses on the Late Weichselian part of the clay-varve connections show high statistical coefficients and confirm the original varve correlations (Wohlfarth and Holmquist, ms.). As an example, Figure 2 displays the number of diagrams and their overlap on which the Late Weichselian part of the STS is built. These sites are <10 km apart and the overlap per year is based on 5–30 sites per year. This closely grouped set of sites, together with ice recession rate calculations, make it unlikely that many varves are missing from the Late Weichselian part of the STS. If we added *ca.* 2000 varves to the oldest *ca.* 1200–1500 varves, this would mean that perhaps 3500 varves were deposited during the Bølling/Allerød pollen zones in southern Sweden (Figs. 2, 3). As a consequence, the ice recession of 75–150 m/yr (Kristiansson 1986) during these warm periods would not only decrease by 60% and equal the recession rate during the YD cold phase (30–40 m yr^{-1}), but also be incomparable to a retreat of *ca.* 100–200 m yr^{-1} during the early Preboreal (Strömberg 1994) or to a retreat of 200–300 m yr^{-1} during the early Holocene (Strömberg 1985).

The revised STS represents a *ca.* 13.3 ka long varve chronology, established from the dense overlap and connection of >1000 varve diagrams from localities along the Swedish east coast. It constitutes a firm, well-established and consistently checked, independent chronology.

METHODS

To test the feasibility of the STS as a Late Weichselian calibration tool for ^{14}C, we cored present-day lake and peat bog sites, which were part of the BIL, where varved clays deposited during the deglaciation, and we expected accumulation of terrestrial macrofossils (Wohlfarth *et al.* 1993, 1994). For each site, we created a clay-varve diagram and correlated it (visually and statistically) to the established varve diagrams of the STS from neighboring sites. Varved-clay samples comprising *ca.* 20–100 varve-year segments were then sieved through a 0.5-mm mesh. Dispersion of the clay particles was facilitated by storing the samples overnight in distilled water, to which we added a few drops of 5% $Na_4P_2O_7$. Visible macrofossils were picked out during sieving, determined and submitted for AMS measurements. Only leaves of Late Glacial terrestrial macrofossils, such as *Betula nana*, *Dryas octopetala*, *Salix herbacea*, *Salix polaris* and *Salix reticulata* were used for dating (Table 1). However, our first samples included brown mosses and insect fragments. Previously, we stored our macrofossil samples in distilled water, to which we added several drops of 2% HCl to attain a pH of *ca.* 2 and kept them in a cold room for 1 month to 1 yr before the AMS measurements were made. After we realized that bacteria and fungi can easily attack wet-stored samples, we then submitted all samples immediately following sieving and identification to the ^{14}C laboratory. We subjected the

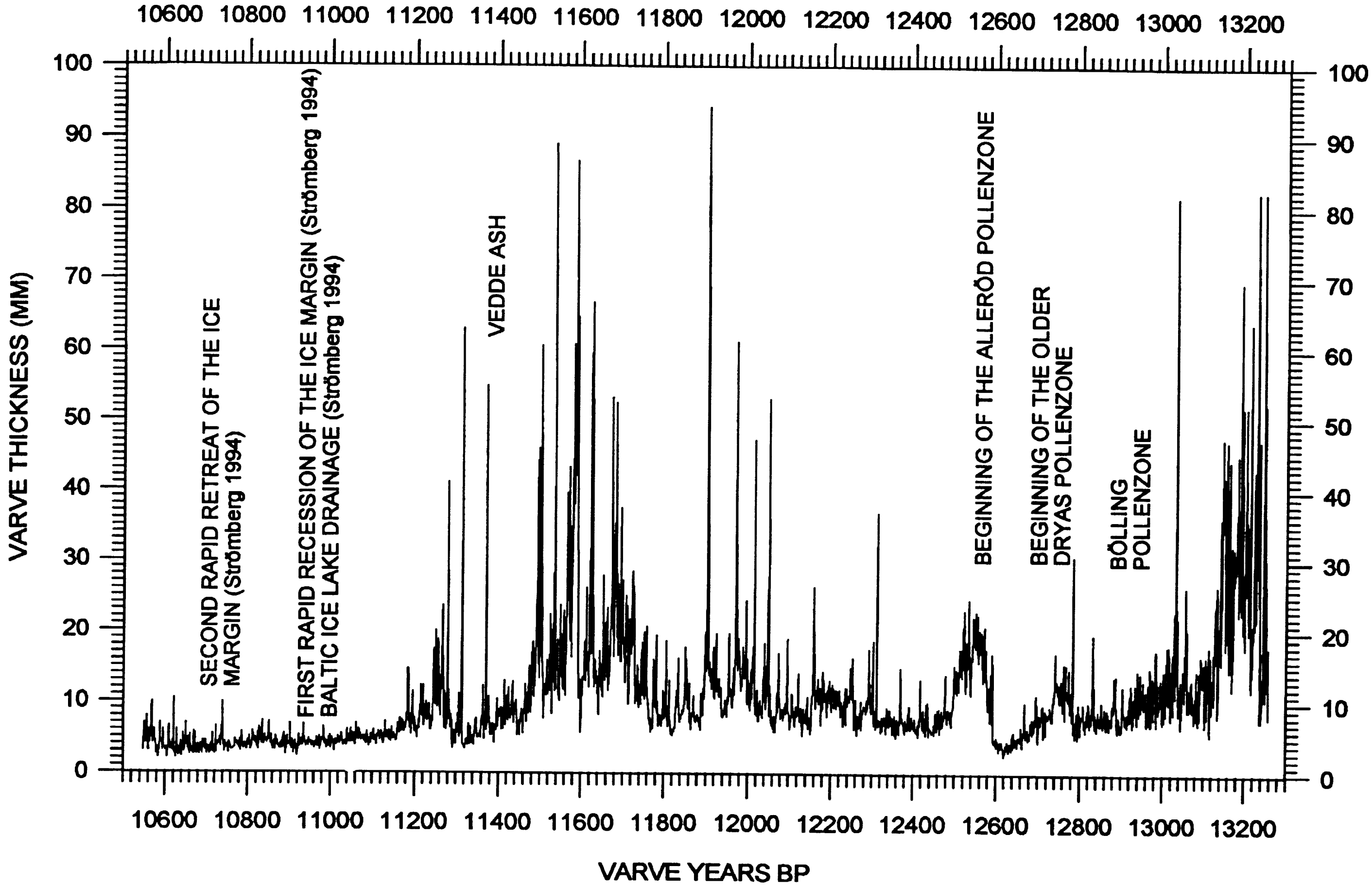

Fig. 2. Mean average thickness of the Late Weichselian part of the STS derived from the digitized diagrams of Kristiansson's (1986), Ringberg's (1971, 1991) and Ringberg and Rudmark's (1985) chronologies. The extremely thick varve years are due to bottom varves (ice-proximal varves) and local drainage varves. The Bølling, Older Dryas and Allerød pollen zones are according to Björck and Möller (1987), Wohlfarth *et al.* (1994) and Ising (ms. in preparation). The location of the Vedde ash is based on Wohlfarth *et al.* (1993), but modified according to Strömberg's (1994) clay-varve age for the second drainage of the Baltic Ice Lake.

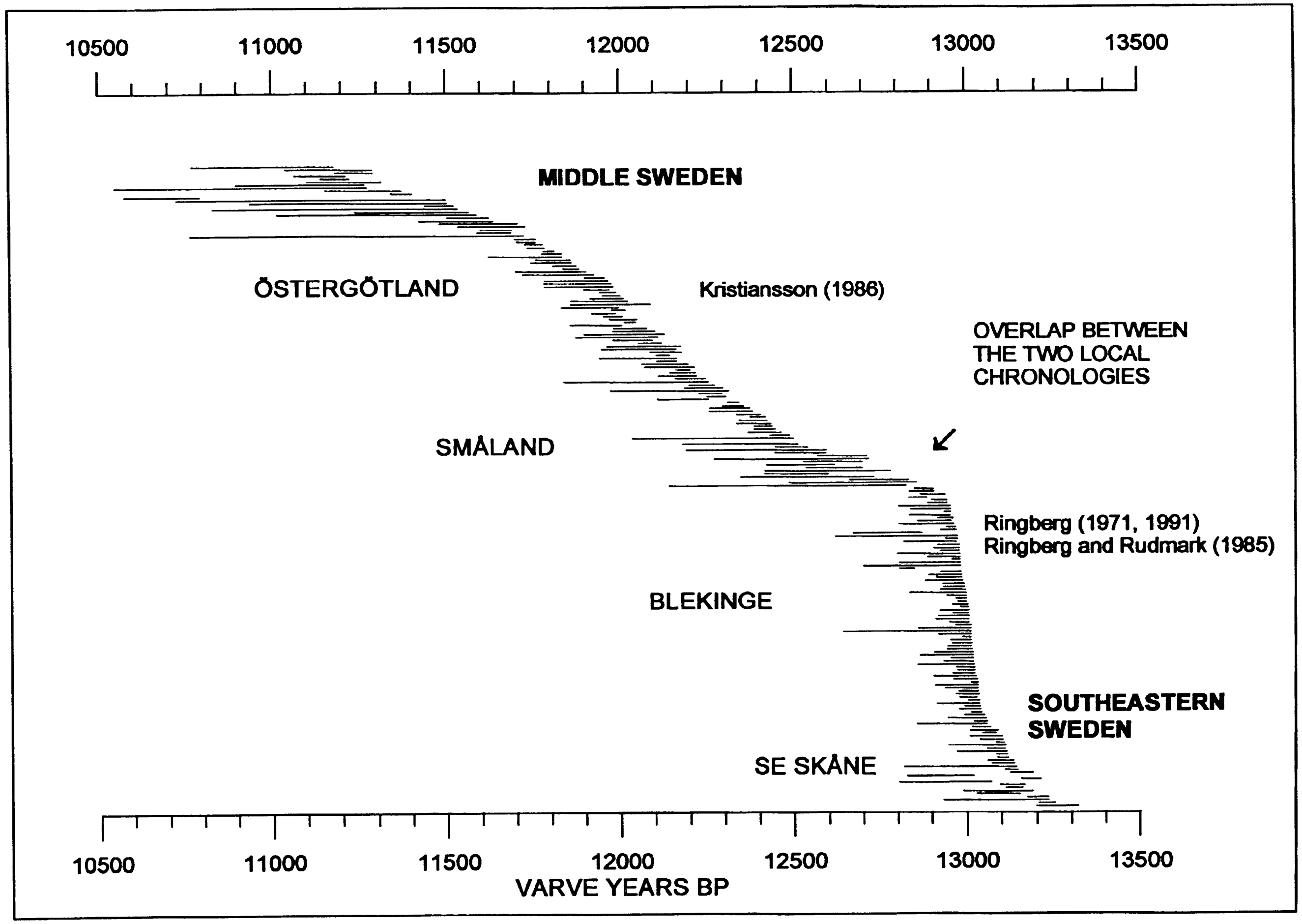

Fig. 3. Length of the Late Weichselian clay-varve diagrams and their overlap in the southern part of Sweden based on the varve chronologies by Kristiansson (1986), Ringberg (1971, 1991) and Ringberg and Rudmark (1985). The overlap between the two local chronologies is indicated with an arrow.

samples to acid-alkali-acid (AAA) chemical pretreatment (1% HCl and 0.5% NaOH at 80°C for 4 h) followed by combustion with CuO, Fe-catalytic graphitization (Vogel *et al.* 1984) and AMS measurements with the Uppsala EN-tandem accelerator (Possnert 1990).

TABLE 1: AMS-Dated Macrofossils and Age of the Samples According to the Swedish Time Scale

Lab no. (Ua-)	Location	Sample*	Swedish Time Scale (varve yr BP)	^{14}C AMS age (yr BP)
2469	Farslycke	*Salix* indet. (L, ff), *Salix* (L), *Salix cf. herbacea* (L), *Betula nana* (L), wood (ff)	12,748 ± 42	12,740 ± 150
2741	Mullsjön	*Dryas octopetala* (L, ff)	11,033 ± 54	9,640 ± 190
2742	Mullsjön	*Betula/Salix* (L, ff), brown mosses (L, F, stems)	11,361 ± 26	9,945 ± 115
2747	Skirgöl	*Dryas octopetala* (L), *Betula/Salix* (L), insects, *?Oligocheta cocc.*	2nd drainage of the BIL†	10,345 ± 150
2748	Skirgöl	*Dryas octopetala* (L, ff), *Salix/Betula* (L, ff), brown moss (L), insects, *?Oligocheta cocc.*	2nd drainage of the BIL†	10,540 ± 140
2749	Skirgöl	*Betula nana* (F), *Salix/Betula* (L, ff), insects, *?Oligocheta cocc.*	2nd drainage of the BIL†	10,965 ± 100
2750	Toregöl	*Dryas octopetala* (L, ff), *Betula/Salix* (L, ff), insects, UP	12,571 ± 20	11,520 ± 225
2752	Toregöl	*Dryas octopetala*(L, ff), *Betula/Salix* (L, ff), insects, UP	12,571 ± 20	11,820 ± 150
2753	Hargsjön	*Betula/Salix* (L, ff), UP	12,045 ± 44	10,480 ± 150
3131	Tynn	*Salix* indet. (L, ff, B), *Dryas octopetala* (L, F)	12,092 ± 32‡	10,890 ± 120
3132	Dönhyltagyl	*Dryas octopetala* (F, L ff), *Salix polaris* (L)	12,649 ± 16	12,090 ± 185
4212	Mullsjön	*Salix herbacea* (Lf), *Salix* undiff. (Lf)	2nd drainage of the BIL†	10,160 ± 115
4214	Mullsjön	*Salix* undiff. (Lf; 1B), *Salix/Betula* (L), *Betula nana* (Lf)	11,121 ± 11	10,170 ± 195
4215	Mullsjön	*Salix* undiff. (Lf), *Salix herbacea* (Lf), *Betula nana*(Lf), *Salix/Betula* (Lf),*Oxyria* (S), *Caryopyllacea* (S)	11,181 ± 48	10,140 ± 155
4216	Mullsjön	*Salix* sp. (Lf), *Betula nana* (Lf), *Oxyria* (S)	11,309 ± 20‡	10,620 ± 155
4217	Mullsjön	*Salix herbacea* (Lf)	11,344 ± 14‡	10,330 ± 175
4245	Skälgylet	*Salix polaris* (L), *Salix/Betula* (Lf)	12,758 ± 7	12,330 ± 370
4246	Skälgylet	*Salix polaris* (Lf), *Salix/Betula* (Lf)	12,733 ± 17	12,590 ± 130
4247	Farslycke	*Salix/Betula* (Lf)	12,793 ± 31	12,595 ± 360
4248	Farslycke	*Salix polaris* (Lf), *Salix/Betula* (Lf)	12,739 ± 22	12,310 ± 145

*L = leaves; ff = fragments; B = budscales; F = fruits; S = seeds; UP = unspecified Late Glacial macrofossils
†BIL = Baltic Ice Lake. The drainage of the BIL is dated at 10,980 varve years BP (Strömberg 1994). See text for further explanations.
‡The connection of Ua-4216, Ua-4217 and Ua-3131 is preliminary.

RESULTS

As shown in Table 1, we obtained 16 dates on macrofossils from varved clays, 3 dates (Ua-2747, -2748, -2749) on macrofossils from BIL drainage sediments and 1 date (Ua-4212) on macrofossils extracted from the BIL drainage sand, which directly overlies the varved-clay sequence at the Mullsjön site. Our dates for the drainage event range between 10,160 ± 115 and 10,965 ± 100 BP, compared to bulk sediment dates of *ca.* 10,300 BP obtained on limnic sediments (Svensson 1989; Wohlfarth *et al.* 1993). Although the great variation between the four dates reflects erosion and redeposition of macrofossils with different age backgrounds, we can conclude that the BIL drainage can be dated at a maximum age of 10,160 ± 115 BP, which corresponds to 10,980 varve years BP (Strömberg 1994). The other measurements (Table 1) on macrofossils from varved clays are: 10,980–11,387 BP (Mullsjön); 11,929–12,592 BP (Hargsjön, Tynn, Toregöl); and 12,633–12,824 BP (Dönhyltagyl, Farslycke, Skälgylet). Based on pollen-analytical investigations of the varved clays (Björck 1981; Björck and Möller 1987; Wohlfarth *et al.* 1994) (see Fig. 2), we know that the oldest ages (12,740 ± 150 to 12,310 ± 145 BP) date approximately the end of the Bølling pollen zone, and that the next younger dates, 11,520 ± 225 to 11,820 ± 150 BP, relate to the beginning of the Allerød pollen zone.

Comparison with Other ^{14}C-Dated Late Weichselian Calendar-Year Chronologies

The group of available ^{14}C-dated, Late Weichselian calendar-year chronologies comprises the varved clays of the STS, lake lamination/organic varve data, dendrochronology and U/Th-dated corals. Among these different methods, dendrochronology is the best established calendar-year chronology and the resulting dendrochronological calibration curve now extends back to 11,600 cal BP (Kromer and Becker 1993; Kromer *et al.* 1994). A floating Late Weichselian dendrochronology from Switzerland has recently been published (Kaiser 1993). This data set is composed of four separate chronologies, a 286-yr Bølling, a 669-yr Allerød-1, a 375-yr Allerød-2 and a 318-yr Allerød-3 chronology, linked together by ^{14}C measurements (Kaiser 1993, Fig. 92). This tentative link corresponds to an approximate duration of 1490 calendar years for the Bølling/Allerød interstadial. Although the data set contains invaluable information, the published match between the four floating chronologies is misleading, because it is based on the assumption of a constant production rate of ^{14}C, which does not correspond to reality (Kaiser 1993).

Both dendrochronology (Kromer and Becker 1993) and the STS build on hundreds of overlapping data sets, whereas lake lamination chronologies are established on cores from a single lake basin; unlaminated sequences are frequent and varve thickness cannot be compared to other organic varve chronologies. AMS ^{14}C-dated lake lamination chronologies are now available from several lakes in Norway (Kråkenäs: Gulliksen *et al.* 1994), Germany (Holzmaar: Zolitschka *et al.* 1992, Hajdas 1993), Switzerland (Soppensee: Lotter *et al.* 1992; Hajdas 1993; Hajdas *et al.* 1993) Poland (Gosciaz: Goslar *et al.* 1992; Rozanski *et al.* 1992; Ralska-Jasiewiczowa *et al.* 1992; Goslar *et al.* 1993) and Japan (Suigetsu: Kitagawa *et al.* 1995). All lake laminations are similar in that they are floating chronologies and several segments in the cores are unlaminated (*e.g.*, Zolitschka *et al.* 1992; Goslar *et al.* 1992; Hajdas 1993). This means that they have to be matched to the dendrochronological calibration curve by wiggle matching (*e.g.*, Hajdas 1993; Hajdas *et al.* 1993) and that the number of varves in the unlaminated sequences has to be estimated (*e.g.*, Hajdas 1993; Goslar *et al.* 1992). Although paleoecological studies have been made at some of these sites (e.g., Gościąż: Ralska-Jasiewiczowa *et al.* 1992), a substantial number of AMS ^{14}C dates has been published only from Holzmaar and Soppensee (Hajdas 1993; Hajdas *et al.* 1993; Hajdas *et al.* 1995).

Correlations among our data set and these lake lamination chronologies can be based on a correlation of pollen-zone boundaries or on a comparison of ^{14}C and calendar years. We know, however, that pollen zones are time transgressive because plant communities or individual species may react to a climatic signal with different time lags (Birks and Gordan 1985) and that the bulk ^{14}C dates of the traditional Late Weichselian pollen zone boundaries suffer from a reservoir effect (Olsson 1986; Wohlfarth *et al.* 1993). Consequently, AMS ^{14}C dates for the same boundary give ages several hundred years younger than a bulk date (Wohlfarth *et al.* 1993). Because of these uncertainties, we compare in Figure 4 our data set only to lake-lamination chronologies from which a large number of AMS ^{14}C dates are available.

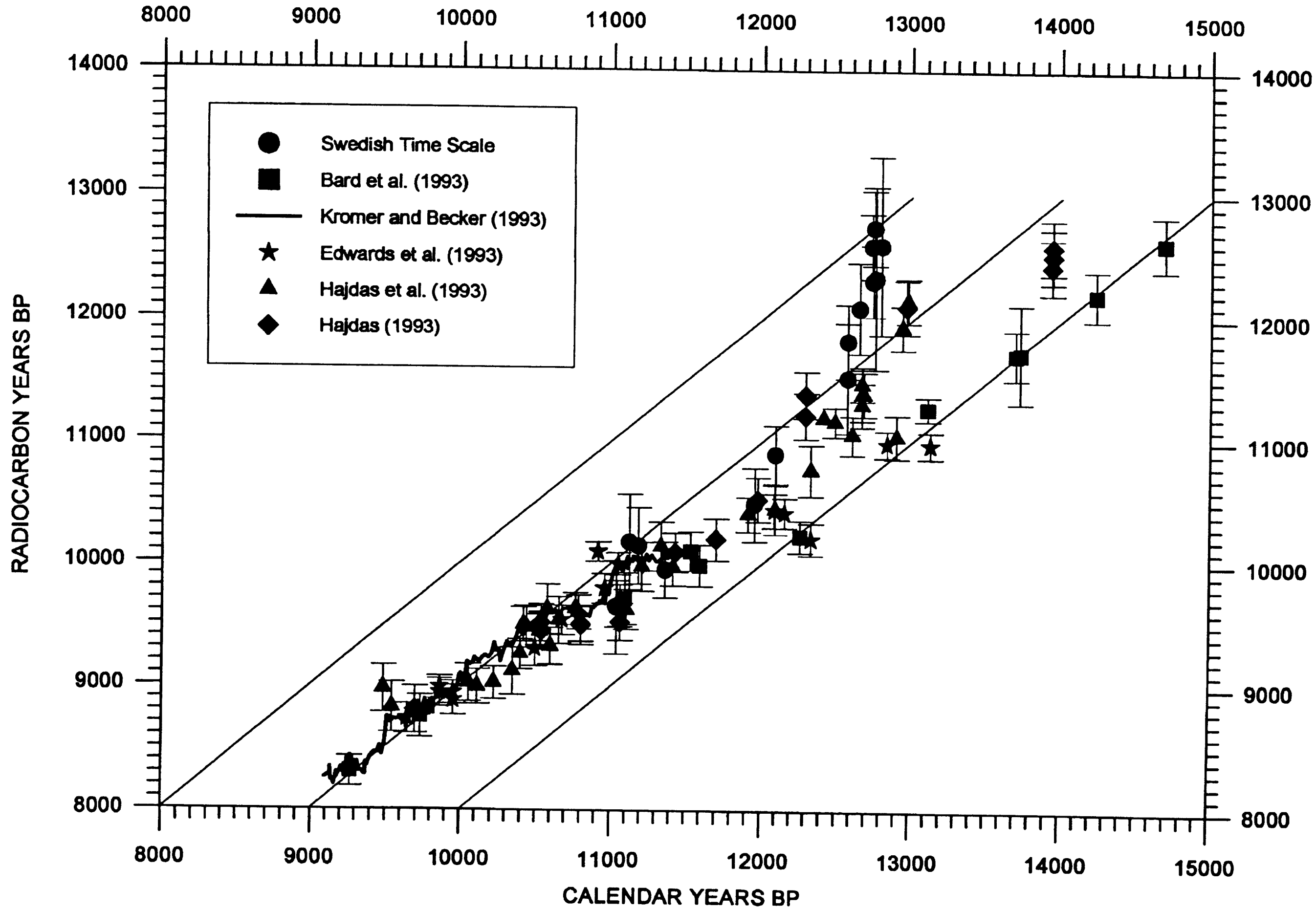

Fig. 4. A comparison among different ^{14}C-dated calendar-year chronologies: dendrochronological calibration curve (—) (Kromer and Becker 1993); laminated lake sediments from Soppensee (▲) and Holzmaar (◆), displayed with 2 σ (Hajdas 1993; Hajdas *et al.* 1993; Hajdas *et al.* 1995); weighted mean averages of the Barbados U/Th data (■), displayed with 2 σ (Bard *et al.* 1993; E. Bard written communication 1993); Papua, New Guinea and Huon Peninsula U/Th coral data (★), displayed with 2 σ (Edwards *et al.* 1993); clay-varve chronology of the STS (●), displayed with 2 σ (see Table 1).

Taking into account a 1-σ-uncertainty margin, our five youngest dates relate well with the oldest part of the dendrochronological calibration curve (Kromer and Becker 1993), with ^{14}C-U/Th measurements on corals (Edwards *et al.* 1993; Bard *et al.* 1993) and with the ^{14}C-dated lake lamination records from Soppensee and Holzmaar (Hajdas *et al.* 1993; Hajdas 1993; Hajdas *et al.* 1995).

Farther back in time, our ^{14}C/varve dates can be compared only to U/Th (Edwards *et al.* 1993; Bard *et al.* 1993) and lake laminations (Hajdas *et al.* 1993; Hajdas 1993; Hajdas *et al.* 1995). As shown in Figure 4, all data sets agree within a 1-σ-uncertainty margin, down to *ca.* 12,000 calendar years, but start to diverge at *ca.* 12,300 calendar years BP. Although ^{14}C-U/Th ages show a constant difference of 2 ka to the ^{14}C scale, the ^{14}C/varve and lake lamination records indicate that the two time scales converge rapidly *ca.* 12,600–12,800 calendar years BP. Exceptions are the ^{14}C/lake lamination dates from Holzmaar (Hajdas 1993; Hajdas *et al.* 1995), which show larger differences between ^{14}C and calendar years with increased age. Such discrepancies between supposed calendar-year chronologies, STS, lake laminations and U/Th data evoke several questions:

1. Are any of these time scales a calendar-year chronology? We rely on the STS as a well-established calendar-year chronology, and we can exclude any large number of missing varves both in the Holocene and in the Late Weichselian part of the time scale (see above). Soppensee and Holzmaar records represent annual chronologies (Lotter *et al.* 1992; Zolitschka *et al.* 1992), which can be matched to the dendrochronology-based calibration curve and are independently confirmed by tephra layers (Hajdas 1993; Hajdas *et al.* 1993; Hajdas *et al.* 1995). Growth-band measurements on corals have also demonstrated that U/Th can be regarded as a calendar-year chronology (Bard *et al.* 1993).
2. Why do the terrestrial data sets (lake-sediment laminations, STS) show partly similar trends between 12,600 and 12,800 calendar years, but disagree with the ^{14}C-U/Th record? The net of ^{14}C dates between 11,700 and 13,100 calendar years BP obtained from both terrestrial chronologies (STS and lake laminations) is much more closely spaced than the dates on the U/Th curve. Between *e.g.*, 12,300 and 13,100 calendar years BP, no values are available on the U/Th curve, whereas >10 data points exist for the terrestrial records. This means that changes in atmospheric ^{14}C content can be detected more easily by the AMS ^{14}C dates from terrestrial chronologies than by the widely spaced ^{14}C-U/Th measurements. This would mean that the trend observed in the terrestrial data set is real and would rather represent changes in atmospheric ^{14}C than erroneous varve measurements. The Holzmaar dates (Fig. 4), AMS ^{14}C dates and ^{14}C values (Zbinden *et al.* 1989) support such an argument.

Conclusion

The Swedish varve chronology or STS, a *ca.* 13,300-yr-long varve chronology, is based on the extensive matching of >1000 clay-varve diagrams. By extracting and AMS ^{14}C dating terrestrial macrofossils from the Late Weichselian varved clays of the STS, we were able to attribute a calendar-year age to each AMS ^{14}C date. Our results agree well with other ^{14}C dated calendar-year chronologies between 11,000 and 12,000 calendar years BP. Farther back in time, our data show a similar trend as ^{14}C-dated lake lamination chronologies, but diverge from the AMS ^{14}C-U/Th dated corals. However, all these chronologies must be regarded as annual, calendar-year chronologies, so that the cause of this divergence is to be found in the methodological approach. We propose that one reason for the obvious difference between varve and U/Th data lies in the fact that the AMS ^{14}C dates are much closer spaced in time in the terrestrial chronologies than in the U/Th-coral record. Therefore, we argue that a pre-Holocene calibration curve (Stuiver and Reimer 1993) is not yet established.

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