A new middle Holocene varve diagram from the river Ångermanälven, northern Sweden: indications for a possible error in the Holocene varve chronology

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Boreas


A new varve diagram from the river Ångermanälven could be correlated to the postglacial varve chronology to between 4903 and 4415 varve years BP. An AMS 14C measurement on terrestrial macrofossils obtained between 4715 and 4706 varve years BP gave a calibrated age of between 5730 and 5040 calendar years BP. The discrepancy between varve and calendar-year age indicates that an error or part of an error in the Swedish varve chronology may be situated between 2000 and 5000 varve years BP.

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The importance of annually laminated sediments as proxy data for past climate reconstructions has led to a renewed focus on the Swedish Time Scale or Swedish varve chronology with the initiation of several new research projects. Both the youngest Holocene and the Late Weichselian varves are currently investigated regarding their suitability as past climate indicators.

Following the last decade's major revisions (Strömberg 1985; Kristiansson 1986; Cato 1987; Strömberg 1989; Cato 1992; Björck et al. 1992; Brunnberg 1995; Lidén & Cato unpublished), the Swedish varve chronology had been regarded as a continuous annual record, as far back as c. 13 300 BP (Wohlfarth et al. 1995). However, when AMS 14C dates from the Late Weichselian varves and their corresponding varve years BP were compared with other AMS 14C-dated calendar-year records, such as the laminated lake sediment sequence from Gosciaz (Goslar et al. 1995a, b) or the U/Th coral record (Bard et al. 1993, 1996), an offset between the Swedish varve chronology and these data sets was clearly visible (Wohlfarth 1996).

Recently, the calibration of the densely spaced AMS 14C measurements derived on terrestrial plant macrofossils from three Swedish lakes made it possible to assign a calendar-year age to the Younger Dryas–Preboreal climatic change and to the so-called Preboreal Oscillation (Björck et al. 1996). Based on a preliminary revised dendro-calibration curve, the new calendar-year age for the Younger Dryas–Preboreal transition was placed at 11 450–11 390 BP and the Preboreal Oscillation could be dated to 11 200–11 050 calendar years BP (Björck et al. 1996). In addition to this revision, it was recently possible to overlap the 9000–8800 14C-year plateau with radiocarbon dates from both oak and pine tree-rings (B. Kromer, pers. comm.). With this new calibration the German pine chronology becomes 154 years older than in the preliminary revision by Björck et al. (1996). Accordingly, the onset of the Younger Dryas–Preboreal transition is now situated at 11 600 calendar years BP and the beginning of the Preboreal Oscillation at 11 350 calendar years BP.

Following pollen stratigraphic investigations in lakes and peat bogs on the Swedish east coast, the Preboreal Oscillation coincides with the ingress of saline marine water into the Baltic Sea, the so-called Yoldia ingress (Svensson 1989; Björck et al. 1996). This marine ingress is also clearly marked in the varved clays by a change from distinct grey varves to silicic clays and by the occurrence of marine bivalves (Portlandia arctica) and foraminifera (e.g. Elphidium excavatum) (Strömberg 1989; Brunnberg & Possnert 1992; Brunnberg 1995, Wastegård et al. 1995). According to the varve chronology, the marine ingress commenced at c. 10 430 varve years BP (Strömberg 1989; Brunnberg 1995) and lasted for c. 70–120 varve years (Wastegård et al. 1995). The Younger Dryas–Preboreal climatic transition in the varved clays has not yet been assessed by direct pollen stratigraphic evidence, but may indirectly be interpreted from the rapid increase in ice recession (Strömberg 1994). Accelerated ice recession started c. 10 940 varve years BP, but is most pronounced from c. 10 740 varve years BP onwards (Strömberg 1994; Brunnberg 1995).

The comparison between the above cited calendar years and the varve years assigned to the Younger Dryas–Preboreal transition and to the Preboreal Os-
The Holocene varve chronology

Lidén (1913, 1938) has originally established the younger part of the Holocene chronology. Based on clay-varve measurements in numerous bluffs along the river Ångermanälven, he presented a 7522 varve-year long chronology. In contrast to the glaciolacustrine Late Weichselian and early Holocene varves, these varves were deposited as annually laminated delta sediments. The down-river sloping delta was gradually built up during the isostatic uplift from areas now situated c. 230 m a.s.l. and down to the present coast of the Gulf of Bothnia (Cato 1987). Accordingly, each varve in the delta sediments begins at the delta surface, where its proximal part corresponds to the river mouth situation for the corresponding year. From the delta surface the varve plunges distally towards the lower reaches of the valley at the same time as it progressively becomes finer grained, thins out, and is overlain by gradually younger varves. In this way, the upper postglacial sediment series of the alluvial sediments was successively formed along the valley down to the position of the present river mouth.

During recent years, Cato (1987, 1985) revised the youngest part of Lidén’s (1913, 1938) chronology, between AD 37 and 1978, and could thus prolong Lidén’s chronology to 9266 varves (up to AD 1979) or 9237 varves BP (AD 1950). He showed that the varves were deposited annually and that varve formation is still in progress in the estuary of Ångermanälven.

A validation of the older part of Lidén’s chronology has indirectly been made by comparing shore-displacement curves derived from the isolation of lake...
basins with Lidén’s shore-displacement curve established upon former delta surfaces along the river Ångermanälven (Renberg & Segerström 1981; Lundqvist 1987; Cato 1992). For these comparisons, both Lidén’s uncorrected (Renberg & Segerström 1981; Lundqvist 1987) and, according to Cato (1992) revised curves were used (Lundqvist 1987). On the whole these comparisons showed a fairly good agreement with Lidén’s curve and indicated that the Holocene varve chronology can be regarded as acceptable. However, the lake-isolation studies had all been made at lakes located far outside the region of the Ångermanälven valley. Cato (1992), therefore, compared the extended and revised shore-displacement curve of Lidén (Lidén & Cato unpublished) with lake isolation studies from within the Ångermanälven valley (Segerström et al. 1984; Wallin 1993). The two curves overlap between 3000 and 8000 varve years BP and show a good agreement at their end points, but display an offset of c. 300 years between c. 4000 and 7000 varve years BP. Lundqvist (1987), who found a corresponding discrepancy around 6000 varve years BP, interpreted this as a slow-down of the general regression of the sea. This slow-down, which cannot be seen in Lidén’s curve, was interpreted as an effect of the eustatic sea-level movement which, outside the central parts of the former glaciated area, appears as a transgression between 6000 and 8000 varve years BP (Cato 1992).

Field and laboratory methods

Lidén’s (1913, 1938) main sections are located along river Ångermanälven, north and south of the town of Sollefteå (Fig. 1), where several of the 20–30 m high bluffs of blueish-grey and orange-coloured fine sand to silt and clay laminae are now a nature conservation area. During summer 1996, we measured a new varve section in a bluff, located between Lidén’s (1913) sites Sollefteå-Risöviken and Multrä-Nyland.

The measured bluff is situated NE of the Sollefteå at the locality ‘Sollefteå-Bruket’ (N63°10'10'"; E17°18'45'") between an altitude of 5 and 30 m a.s.l. (Fig. 1). The total thickness of the section was estimated at approximately 25 m. However, only the uppermost c. 11 m was accessible, while the lower part was covered by debris. To reach into the underlying varves, a 1-m-deep hole had to be excavated. Before measuring the varves, the outcrop was cleaned carefully. Varve thickness was measured with a ruler and the thickness of each summer and winter lamina was noted. The data set (available in an ASCII format from the authors) is displayed in Fig. 2.

A total of eight sediment samples (c. 3–5 kg each) was taken at irregular intervals throughout the whole section and covered between 1 and 20 varve years. Within one month after fieldwork, the samples were sieved wet through an 0.5 mm mesh and visible macrofossils were continuously picked out. Clearly determinable, terrestrial macrofossils were immediately dried overnight at 50°C and submitted in sterilized glass bottles to the AMS facility in Uppsala.

Description and results

The measured section has a total thickness of 9.14 m and comprises 489 varve years. Varve thickness increases gradually upwards, but is most pronounced from varve no. 446 upward (Fig. 2). The varves are generally composed of blueish-grey clayey winter and orange to reddish silty summer laminae. However, from varve no. 448 and upwards and coinciding with an increase in varve thickness, the winter laminae are made up of silt and summer layers of fine sand. The uppermost 3 m of the bluff, where the varve thickness was not measured, consists of thick coarse sandy and silty flood-plain sediments, which overlie the varved delta sediments. Characteristic features, such as organic content, uncertain varves, erosive varve boundaries and eroded summer and winter laminae were observed in a few cases and are noted in Table 1.

Out of eight samples, only samples 3 (varves 95–105) and 4 (varves 188–197) contained terrestrial macrofossils, i.e. seeds and catkin scales of Betula (Fig. 2). The organic material in sample 3 was not enough for an AMS 14C measurement (dry sample weight 1.0 mg), but sample 4 with a dry weight of 1.7 mg gave an age of 4720 ± 135 14C BP (UA-11230). When calibrated according to Stuiver & Pearson (1993), this 14C date gives a calendar-year age of 5610–5290 BP (one standard deviation) or 5730–5040 BP (double standard deviation).

Correlation to the Holocene varve chronology

Lidén’s (1913, 1938) varve diagrams are all characterized by a drastic increase in varve thickness in the youngest part of each diagram. This change in thickness is also accompanied by a change in lithology from silty summer and clayey winter laminae to sandy summer and silty winter laminae, reflecting the gradual build-up to the delta surface and the change from distal to proximal formed delta varves. The varve diagrams, which were established in the vicinity of Sollefteå (Figs. 1, 3), clearly illustrate this development. The revised Holocene chronology (Lidén & Cato unpublished) places Lidén’s Sollefteå diagrams between 5651 and 3996 varve years BP (Table 2).

The visual correlation of our new diagram from Sollefteå-Bruket to Lidén’s diagrams Nyland-Multrä and Risöviken-Sollefteå shows that they correlate well
with each other in the time period between 4903 and 4415 varve years BP (Fig. 4). The varve age BP for our AMS $^{14}$C date, obtained on sample 4, is situated between 4715 and 4706 varve years BP, while the calibrated date gives an age of 5610–5290 (one standard deviation) and 5730–5040 (double standard deviation) calendar years BP. Although these values show a wide age range, they indicate that the varve age of our sample is at least 300 years or as much as 1000 years younger than the time-span covered by the calibrated date.

### Discussion

When only one radiocarbon date has been obtained on a sediment sequence, it is not possible to cross-check the reliability of such a date. Although the measurement may give the correct age, possible sources of error exist; the date may be unreliable because of contamination by older, redeposited material, or it may become too young because of the small sample size. In our case, the radiocarbon sample could be too old, owing to redeposition as a consequence of

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**Table 1. Characteristics of the varves measured in the bluff at Sollefteå Bruket 1996.**

<table>
<thead>
<tr>
<th>Varve No.</th>
<th>Remarks</th>
</tr>
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<tbody>
<tr>
<td>75, 77</td>
<td>Organic material in summer lamina</td>
</tr>
<tr>
<td>156–159</td>
<td>Perhaps 1 or 4 varve years</td>
</tr>
<tr>
<td>309 311, 321</td>
<td>Upper boundary eroded</td>
</tr>
<tr>
<td>335 339</td>
<td>Varves uncertain and difficult to measure</td>
</tr>
<tr>
<td>357</td>
<td>Upper boundary (summer lamina) eroded</td>
</tr>
<tr>
<td>385 391</td>
<td>Symmict varves</td>
</tr>
<tr>
<td>402</td>
<td>Upper boundary (summer lamina) eroded</td>
</tr>
<tr>
<td>404–411</td>
<td>Varves uncertain and difficult to measure</td>
</tr>
<tr>
<td>406 411</td>
<td>Uncertain, summer lamina may be eroded</td>
</tr>
<tr>
<td>412</td>
<td>Upper boundary (summer lamina) eroded</td>
</tr>
<tr>
<td>446–454</td>
<td>Varves uncertain and difficult to measure</td>
</tr>
<tr>
<td>448</td>
<td>Diffusely laminated sand layer with reworked clay balls (possibly winter lamina)</td>
</tr>
<tr>
<td>454</td>
<td>Only silt lamina present</td>
</tr>
<tr>
<td>472</td>
<td>Upper boundary (summer lamina) eroded</td>
</tr>
</tbody>
</table>
isostatic uplift and erosion of older sediments containing organic matter. When the river mouth was shifted to lower levels and the delta plains upstream were elevated above sea level, the watercourses had to cut a new way through the loose sediments down to the underlying substratum. Consequently, already deposited sediments including organic material were transported and redeposited on the continuously expanding delta downstream.

The comparison between Liden’s shore-displacement curve and the timing of the isolation of lake basins in the Ångermanälven area points to a divergence of c. 300 years between c. 4000 and c. 7000 varve years BP (Cato 1992). This offset, which shows that Liden’s curve is several hundred years younger, could be interpreted in terms of an error in the chronology and not as previously assumed as a result of the eustatic sea-level movement (Lundquist 1987; Cato 1992). If our radiocarbon date reflects the true age of the sediments and not older, reworked material, this discrepancy between calibrated ages and corresponding varve years will be in the order of 300 to 1000 years. Such an error is comparable to the conclusions drawn by Björck et al. (1996), who discuss a 800–900-year difference between the calendar-year and varve-year age for both the Preboreal Oscillation/Yoldia ingression and the beginning of the Holocene.

Although we certainly need a larger series of radiocarbon measurements to confirm the discrepancy of 300 to 1000 years between the calibrated age and the varve age of our radiocarbon date, our results add to the fact that an error is present in the Holocene varve chronology. This error may be entirely or partly found between 5000 and 2000 varve years BP. Since the Swedish varve chronology is among those high-resolution geological records, which allow the recon-
struction of decadal to centennial climate fluctuations, a thorough revision of this time scale would certainly seem appropriate.

Conclusions

1. A new middle Holocene varve section from the river Ångermanälven was sampled and measured. The obtained varve diagram, which could be correlated to Lidén’s revised varve chronology (Lidén & Cato unpublished), spans the varve years 4903–4415 BP. Out of eight sediment samples, one sample with a varve age of 4715–4706 BP could be radiocarbon dated.

2. The AMS $^{14}$C date performed on seeds and catskin scales of Betula gave an age of $4720 \pm 135$ $^{14}$C BP or a calibrated age $5610–5290$ BP (one standard deviation) or $5730–5040$ BP (double standard deviation).

3. The discrepancy of 300 to 1000 years between varve ages and calibrated years is a strong indication that an error may be present in the Holocene varve chronology between 5000 and 2000 varve years BP.

4. Although the Swedish varve chronology has been revised several times in recent decades, efforts for a new revision of this geological record should be undertaken.

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