



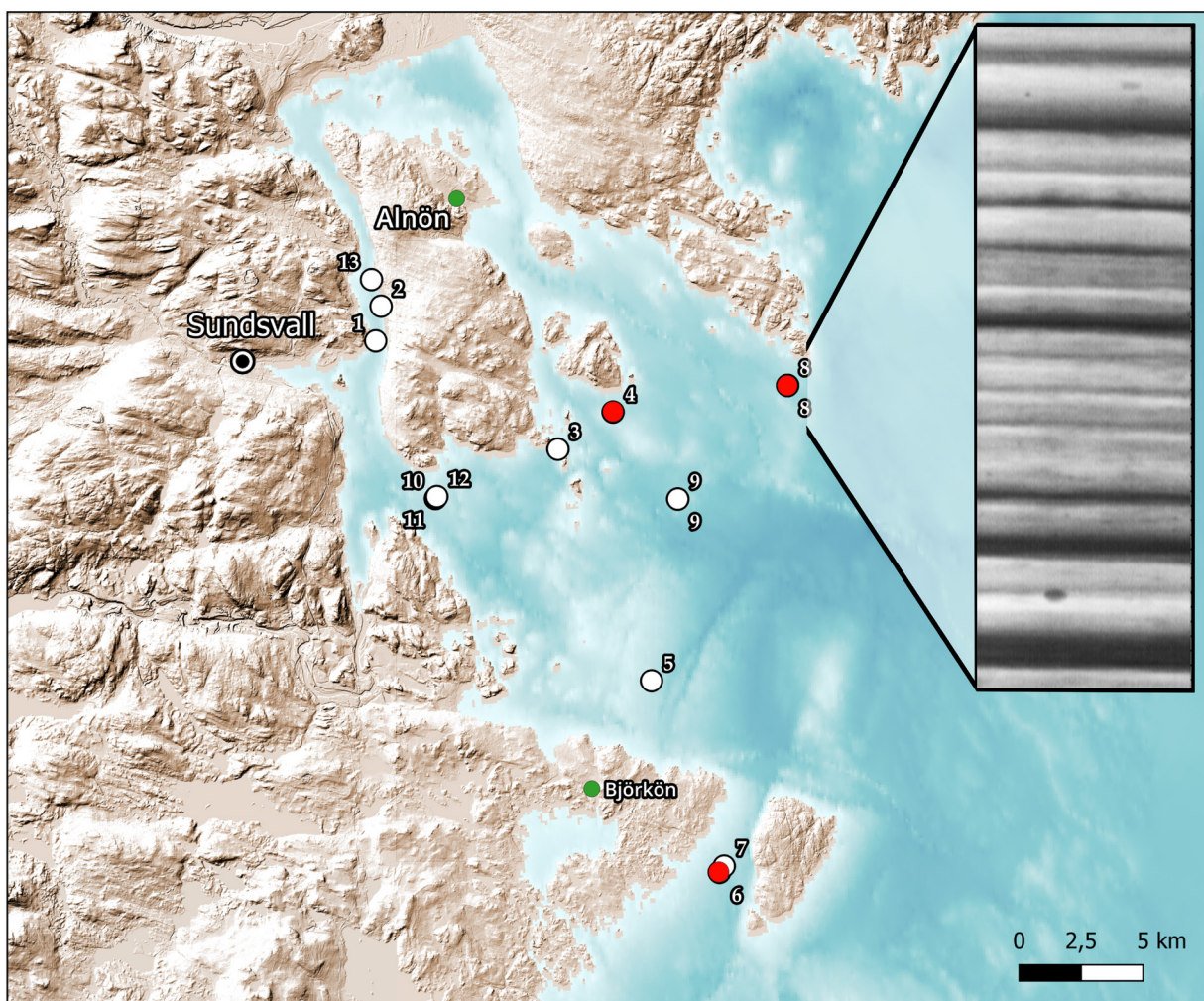
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Towards the development of a varve chronology for Sundsvall Bay

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Abstract

With our rapidly warming climate and growing concerns over the melting of the Greenland and Antarctic Ice Sheets, reconstructing past deglaciation dynamics is crucial for anticipating future changes and mitigating climatic threats facing us today. High-resolution paleoclimate records, such as glacial varves, provide valuable insight into deglaciation patterns of the past with annual resolution. This thesis aims to investigate the potential for cross-correlation between marine varved sediment cores from Sundsvall Bay, central Sweden, and the Swedish Time Scale (STS), an established varve-based chronology. The study involved careful varve counting, thickness measurements, and thickness pattern analysis to potentially extend the Swedish Time Scale offshore. The identification of drainage varves, linked to catastrophic drainages of ice-dammed lakes, provided key chronological anchor points. Similarities in thickness trends between the marine cores and the STS enabled a tentative, yet robust correlation. The findings suggest that marine varve records in Sundsvall Bay are broadly synchronous with onshore glacial varve sequences, promoting their value in refining regional deglaciation patterns. This thesis supports ongoing efforts to refine varve-based chronologies, contributes to our understanding of ice-sheet retreat, and highlights the value of integrating both marine and terrestrial records for reconstructing the Fennoscandian Ice Sheet.

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1. Introduction

1.1. Background

1.1.1. Glacial Varves

Glacial varves (Swedish: *varv*, cycle) are annual glaciolacustrine laminations formed due to seasonal glacial meltwater fluctuations (Avery et al., 2021; Saarnisto & Ojala, 2009; Wohlfarth et al., 1997). Each varve represents a couplet of laminae; a coarser summer layer, and a finer winter layer (Saarnisto & Ojala, 2009). During spring and summer, there is a higher influx of glacial meltwater to proglacial lakes due to increased surface temperatures and subsequent melting. The coarse-grained silt and sand particles are transported away from the continental ice sheets or glaciers and are deposited as a silt-rich, lighter-colored layer. As temperatures fall again, melting decreases and the sediment supply to the water body is reduced. The water column becomes less turbulent, allowing the finer clay particles to gradually settle and form a clay-rich, darker-colored layer (Saarnisto & Ojala, 2009; Stroeve et al., 2016). The following summer layer often arrives as a sharp boundary ('diatactic varves': Saarnisto & Ojala, 2009).

Varves vary in thickness based on the proximity and topography of the deposition site to the glacier, as well as interannual variations in melting intensity, sediment supply, and water flow velocity (Saarnisto & Ojala, 2009). Distal varves may be less than a millimeter thick, while proximal varves can easily reach tens of centimeters in thickness. These thickness variations, alongside color, composition and grain size differences, are used for cross-correlation between different sites (Avery et al., 2021; Saarnisto & Ojala, 2009). The preservation of varves (with annual accuracy) is heavily dependent on the amount of post-depositional disturbances, such as bioturbation, wave action, and similar (Saarnisto & Ojala, 2009).

Historically, varves have been used as critical tools for reconstructing glacial retreat following a glacial maximum (Avery et al., 2021), prior to any other dating techniques. These laminated sediments provide the ability of pinpointing the timing of ice sheet retreat (Avery et al., 2021; Stroeve et al., 2016), because the first varve overlying the glacial substrate (typically bedrock or till), the so-called 'bottom varve' (Avery et al., 2021), is indicative of the onset of deglaciation and thereby the previous location of the ice sheet margin (Stroeve et al., 2016). Varve thickness patterns can furthermore be correlated between sites to construct annual chronologies of ice margin retreat on regional scales, with seasonal to annual resolution (as done in Avery et al., 2021; Brunnberg, 1995; Strömberg, 1989; Wohlfarth et al., 1997).

Today, there is a growing concern over global warming and the subsequent melting of the Greenland and Antarctic ice sheets. This would result in a global mean sea level rise and present many challenges for coastal land (Stroeve et al., 2016). Threats include global-scale large population displacement (e.g. IPCC, 2022: TS.C.4.5), serious dangers of regional flooding in certain low elevation areas (e.g. for Europe, IPCC, 2022: chapter 13.2), disturbance of important ecosystems (IPCC, 2022: chapter 3) and increased risk of climate-sensitive health hazards (IPCC, 2022: chapter 7), to name a few. Researching past deglaciation dynamics is essential to understanding and ultimately combating these potential threats. Over the last few decades, we have been able to observe modern ice sheet change. However, varve sequences present opportunities for furthering our knowledge of millennia-scale responses to climate forcing (Avery et al., 2021) and serve as proxies for paleoclimate reconstructions (Wohlfarth et al., 1997), including patterns of ice sheet decay, ablation, meltwater regimes and the overall climate (Avery et al., 2021). Ice margin retreat can thus be traced by varve chronology with more

accuracy than with any other method, even if the varves are not narrowed down to the calendar year (Stroeven et al., 2016).

1.1.2. Fennoscandian Ice Sheet

A vast amount of the landmass above 60°N was covered by ice during the Last Glacial Maximum (LGM, 26.5-20 thousand years before present, kyr BP: Stroeven et al., 2016). This massive ice cover comprised three separate ice sheets: the British-Irish, Fennoscandian, and Barents Sea ice sheets. These were temporarily unified during peak glacial conditions, but they soon separated: the British-Irish Ice Sheet broke off from offshore Norway in the south and the Barents Sea Ice Sheet split in the north (Stroeven et al., 2016). The Fennoscandian Ice Sheet was one of the largest glaciations of the Northern Hemisphere during the LGM, covering an area of approximately 4 million km² (Krauß et al., 2025) across northern Europe. In a ‘minimum’ extent model (Demezhko et al., 2020), during the Late Weichselian (25-12 kyr BP), the Fennoscandian Ice Sheet’s eastern margin extended to the central Kola Peninsula (Karelia-Finland border), to the Baltic Sea Gulfs (Gulf of Finland, Gulf of Gdansk and Gulf of Riga) in the southeast, and across the Scandinavian Peninsula to Kattegat in the west. In a ‘maximal’ extent model, the Fennoscandian and the Barents Sea sheets merged on the eastern margin, spreading all the way westward to the British Isles and southward to northern Poland and Belarus (Demezhko et al., 2020). The maximum extent model is well supported by observations of chronological and geomorphological evidence of ice sheet margin positions (Hughes et al., 2015).

Deglaciation patterns across the many regions of the Fennoscandian Ice Sheet varied significantly due to differences in climatic, geomorphic, and basal thermal conditions (Stroeven et al., 2016). Oceanic conditions also influenced the retreat of the Fennoscandian Ice Sheet, with active inflow of Atlantic waters through the Faroe-Shetland Channel and over the Iceland-Faroe Ridge contributing moisture and warmth (Simon et al., 2023). There was also an early retreat of the Fennoscandian Ice Sheet (from the maximum LGM extent) due to increasing summer insolation in the Northern Hemisphere (Soulet et al., 2013). Retreat distances of the different regions varied substantially, with some areas (e.g. the southern and eastern ‘sectors’) retreating over 1500 km post 16 kyr BP, compared to only 150 km at the same measured interval along Norway’s maritime margins (Stroeven et al., 2016). In the Baltic sector, the ice sheet was freshwater-terminating (Greenwood et al., 2023), and isostatic rebound caused the water level to rise higher than today’s Baltic Sea level. Because of land uplift and eustatic sea level rise, Baltic underwent episodes of being a freshwater lake and brackish water body connected to the global ocean. Initially, the ice in the eastern Baltic sector was water-terminating but eventually became terrestrial. The western margin of the ice sheet was marine-terminating off the coast of Norway in the earlier stages, then shifted to land-terminating as it retreated through the mountains (Stroeven et al., 2016). It finally became lake-terminating when multiple complexes of ice-dammed lakes formed between the late-stage ice sheet and the mountains. Ice-dammed lakes form when ice margins obstruct the natural drainage of ice-free catchments, causing water accumulation (Stroeven et al., 2016). Due to their instability, such lakes may result in catastrophic drainage events once the ice dam fails (Regnéll et al., 2023). This can happen when the water pressure exceeds the ice’s overburden pressure, the retreating ice margin reveals a lower outlet, or when overtopping initiates rapid failure (Stroeven et al., 2016). These ice-dammed lakes along the Swedish-Norwegian border coalesced into the large Central Jämtland Ice Lake (>3500 km² in area and 360 km³ in volume: Regnéll et al., 2023). Initially, the Central Jämtland Ice Lake was draining westward (toward the Atlantic), but due to high retreat

rates in the lake paired with continued retreat of the ice sheet's eastern margin, a narrow ice saddle formed (Regnéll et al., 2023). Once the saddle collapsed, the resulting glacial lake outburst flood reversed the drainage eastward (toward the Baltic).

To conclude, these deglacial processes did not occur in unison; rather, the Fennoscandian Ice Sheet underwent repeated partitioning, often coupled with catastrophic lake drainage events that played a pivotal role in reshaping the landscape (Regnéll et al., 2023; Regnéll et al., 2025). Although the Fennoscandian Ice Sheet has been extensively studied for over a century, its full extent, chronology, and ice dynamics during its glaciation and deglaciation are still not certain and subject to constant refinement (Demezhko et al., 2020; Regnéll et al., 2023; Regnéll et al., 2025; Ploeg & Stroeve, 2025). One possible analogy for the Fennoscandian Ice Sheet could be the modern Greenland Ice Sheet, due to similar ground surface temperature patterns (Demezhko et al., 2020); this further stresses the importance of understanding the rates and processes of Fennoscandian Ice Sheet deglaciation, particularly with the climate concerns facing society today (as elaborated in 1.1.1.).

1.1.3. Swedish Time Scale

The Swedish Time Scale (STS) is a varve-based geochronological framework that provides an annually resolved record of ice sheet retreat in Sweden, developed originally by Gerard De Geer in the late 19th and 20th century (De Geer, 1884, 1896, 1912, 1940, as cited in Avery et al., 2021; Stroeve et al., 2016). Since De Geer began his work on the STS, the record has evolved into one of the most refined sediment-based chronologies in Europe, now covering approximately 13,300 varve years (Regnéll et al., 2025; Saarnisto & Ojala, 2009; Stroeve et al., 2016; Wohlfarth et al., 1997). The goal of STS is to provide a continuous, high-resolution timeline from the onset of the deglacial processes, following the Last Glacial Maximum (Avery et al., 2021; Regnéll et al., 2025), all the way to present through studies on more recent deltaic varve sediments in the Ångermanälven river, northern Sweden (Saarnisto & Ojala, 2009).

The STS is based on cross-correlating varve thickness patterns (via overlapping varve-thickness diagrams: Holmquist & Wohlfarth, 1998) across a wide range of sites throughout Sweden's deglaciated terrain (Regnéll et al., 2025). As a result, the STS functions as a relative chronology which allows for determining when deglaciation happened at one site compared to another – how many varve years apart they are. In order to align this relative timescale with global climate records, it is important to anchor them in absolute ages. This has been achieved in previous studies by correlating distinct events recorded in varve sequences with independently dated ones from Greenland ice cores (GRIP and NGRIP: Stroeve et al., 2016), or by directly dating varves themselves using embedded organic material or associated depositional events (Regnéll et al., 2023; Regnéll et al., 2025).

The temporal calibration, alongside the geographical extent of the STS, is constantly being improved upon. A recent study by Regnéll et al. (2025) radiocarbon dated the so-called 'zero varve', which formed during a catastrophic drainage event from the Central Jämtland Ice Lake (according to De Geer's original interpretation, as mentioned in Regnéll et al., 2025). Previously, the zero varve was assigned the age of 9.2-10.1 cal. kyr BP (Saarnisto & Ojala, 2009). However, now it has been narrowed down to $10,008 \pm 87$ cal. yr BP (Regnéll et al., 2025). The first and largest marker varve which recorded the Central Jämtland Ice Lake drainage event, approximately 48 varve years before the zero varve, has also been found and dated to $10,056 \pm 87$ cal. yr BP (Regnéll et al., 2025). The ~2000 varve-years of the STS preceding the zero varve are considered credible (Regnéll et al., 2025).

Despite its significance and general precision, the biggest drawback of the STS are the ~700-900 missing varves (Stroeven et al., 2016; 875 according to Saarnisto & Ojala, 2009; more recently, 770 ± 87 varves after the zero varve, according to Regnéll et al., 2025) from the Holocene portion. Furthermore, many regional varve sequences – such as those from Skåne-Blekinge, Småland-Östergötland, and southeastern Sweden – are still local ‘floating’ chronologies (Avery et al., 2021), meaning they are not yet anchored to absolute time nor to the rest of the STS. There is also a limited extent of STS in marine environments, likely due to the transition from fresh to brackish conditions during deglaciation because of climate fluctuations that occurred throughout the Holocene (Preboreal Oscillation: Wohlfarth et al., 1997). For example, the Yoldia ingression – inflow of saline water into the Baltic Sea – caused significant disturbance in varve deposition, which is observable through the altered sediment structure and presence of marine fauna (Wohlfarth et al., 1997). Additionally, hydrodynamic instability during early Holocene delta formation (shifting of the river mouth to lower levels, delta plain elevation above sea level, and the subsequent reworking of sediments) complicated efforts to trace continuous varve sequences in coastal and estuarine settings (Wohlfarth et al., 1997).

Despite the unresolved gaps and regional floating sequences, which present hardships in correlating the STS to other climate archives (Regnéll et al., 2025), ongoing refinements continue to enhance the temporal precision and relevance of the STS, marking it a critical component of Sweden’s geoscientific and cultural heritage. Recent modern tools for sediment sampling (epoxy-embedding, thin sectioning, etc.) and digital imaging shifted the usage of these varved records from simple chronological tools to high-resolution paleoenvironmental indicators of climate forcing (Saarnisto & Ojala, 2009). This makes varve chronology and the STS record a necessity for making educated predictions about future climate responses.

1.1.4. Study area

Sundsvall Bay (Swedish: *Sundsvallsbukten*; Fig. 1) is located on the eastern coast of central Sweden, within the Gulf of Bothnia. The retreat of the ice margin toward Sundsvall Bay occurred 10.4 cal. kyr BP (Greenwood et al., 2017; 9818 - 9662 varve years BP: Strömberg, 1989). This interval corresponds to the Ancyclus Lake stage (10,700-10,200 cal. yr BP: Björk, 2008, as cited in Feldens & Schwarzer, 2012) of the Baltic Sea, a freshwater phase that allowed for formation of continuous varve records with less disruptions than the brackish Yoldia phase. This area is thus likely to contain good quality varves. Furthermore, Sundsvall Bay was chosen because it potentially plays a key role in the Swedish Time Scale. Firstly, it is situated in the distal part of the Indalsälven catchment, where glacial-age varves have been correlated to post-glacial and modern estuary varves in the neighboring Ångermanälven (Saarnisto & Ojala, 2009; Wohlfarth et al., 1997). Secondly, the bay served as the outlet for major flood events caused by the sudden release of floodwater from the drainage of the Central Jämtland Ice Lake. These sudden drainage events deposited distinctive drainage varves up to meters in thickness, which serve as important stratigraphic markers and temporal anchors within the STS (Saarnisto & Ojala, 2009), and aid in reconstructing the retreat of the Fennoscandian Ice Sheet (Regnéll et al., 2023; Regnéll et al., 2025).

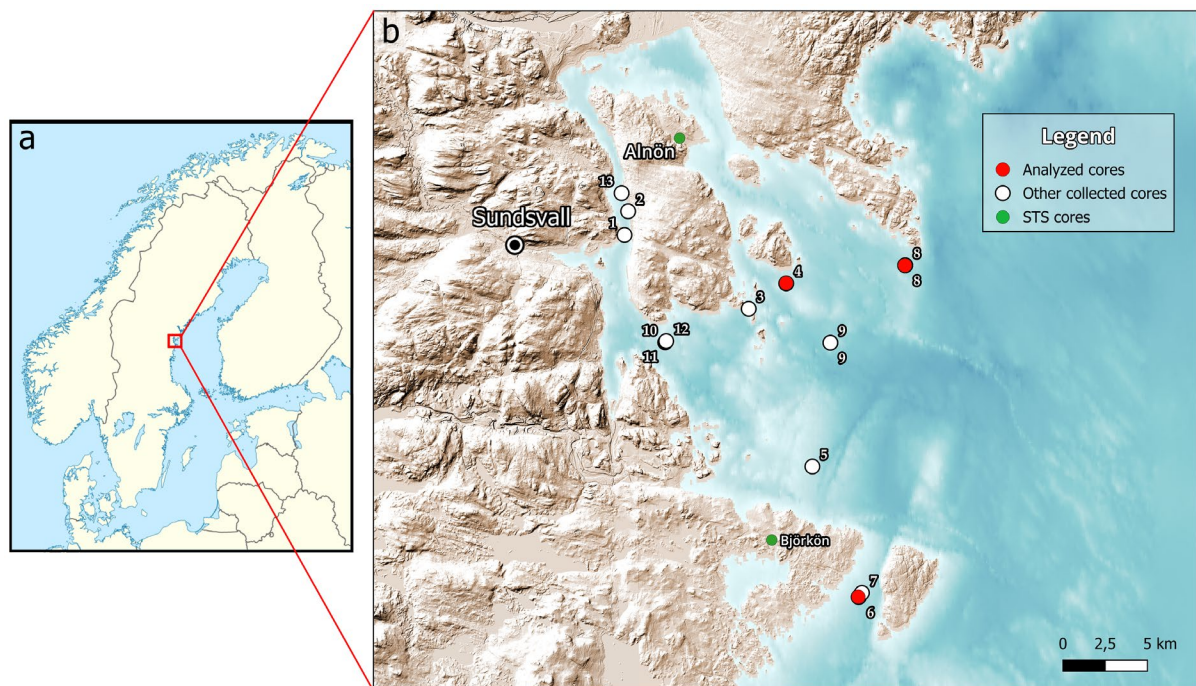


Figure 1. a) Map of Scandinavia showing the location of the study area (red rectangle). Map adapted from NordNordWest (2008), licensed under CC BY-SA 3.0 via Wikimedia Commons. b) Map of the Sundsvall Bay area. Red dots (cores 04, 06, 08) indicate the marine cores used for cross-correlation in this thesis. The white dots indicate cores that were collected aboard RV Electra in the summer of 2024. The green dots correspond to STS core sites published by Strömberg (1989), '313 a Alnön a' and '289 Björkö'. These will be used for cross-correlation of the Sundsvall Bay marine cores with the STS.

1.2. Objectives

This thesis primarily aims to evaluate the possibility of expanding the Swedish Time Scale varve record from the Swedish east coast into Sundsvall Bay. This will be done by cross-correlating the varved offshore cores collected from Sundsvall Bay during the summer of 2024 with the already established onshore varve chronology records, focusing on the presence of diagnostic marker varves and distinct thickness patterns.

In order to assess the likelihood of correlation with onshore sites, the first objective is to reliably identify, measure, and interpret any varved sequences in the marine sediment cores 04-GC01, 06-GC02 and 08-GC01 from Sundsvall Bay. A further objective is to gauge whether the varve thickness patterns observed in each of these cores correlate across multiple sites within the bay. Causes and implications of any mismatches will be explored.

Secondary objectives include analyzing macro-scale sedimentary structures – such as grading, changes in color, erosional contacts, and similar – to infer the possible deglaciation process of Sundsvall Bay. Alongside this, potential varves associated with the catastrophic drainage of the Central Jämtland Ice Lake will be explored.

1.3. Research questions

Can individual varves be reliably identified, measured, and interpreted in the selected cores from Sundsvall Bay?

Do thickness patterns in the Sundsvall Bay cores correlate across sites?

Can varved sequences from Sundsvall Bay be confidently correlated with the STS?

What do macro-scale sedimentary features imply about deglaciation and post-glacial environment of the Sundsvall area?

Are there drainage varves in the Sundsvall Bay cores?

2. Method

2.1. Cores

The sediment cores were collected using a gravity corer aboard RV Electra during the summer of 2024. Site selection was guided by sub-bottom profiling data acquired with Electra's parametric echosounder, Kongsberg TOPAS PS40. Locations (Fig. 1) were chosen based on acoustic signatures showing thick sequences of well-defined laminations, interpreted as varved sediments situated within approximately one meter of the seabed (written communication, Richard Gyllencreutz, 2025-05-23). Multiple sediment cores collected aboard RV Electra were then split, cleaned, and subjected to preliminary visual logging. A subset of cores was shortlisted based on initial visual criteria including clarity of the varves, degree of core disturbance, and the possible presence of identifiable marker varves. These candidate cores were then scanned using Itrax core scanner to obtain high-resolution X-ray images which enhanced lamination visibility. Based on both visual inspection and radiographic analysis, cores 04-GC01 (150 cm depth), 06-GC02 (147.2 cm depth), and 08-GC01 (96.2 cm depth) were selected for further analysis (Fig. 1). These cores were chosen due to their well-preserved, undisturbed stratigraphy, presence of a thick varve potentially serving as a marker, and consistently clear varve sequences with minimal ambiguity.

2.2. Varve identification

Varves were identified based on visual interpretation of the Itrax X-ray images. In these images, higher density (coarser grain size) layers are dark; lower density (fine grain size) layers are light colored. Each varve was defined as a couplet consisting of a summer layer and a winter layer. The summer layer typically appears as a sharp, coarser-grained layer composed of silt to fine sand, interpreted to represent rapid sedimentation during ice melt and high energy conditions. This is followed by a gradational transition into a finer-grained clay winter layer, indicating lower energy deposition under ice-covered conditions. Varves can be seen in Figure 2 below.

For a lamination to be classified as a complete varve, the couplet had to begin with a sharp contact boundary, indicating the start of the summer deposition, and end with gradation into the winter layer. A new varve was only considered to begin when another sharp boundary to a dark, coarse-grained layer was observed. These criteria were applied consistently throughout all the cores to avoid misidentification of sub-annual events (mid-seasonal temperature fluctuations, for example) as varves (Fig. 3).

In cases where the boundary between the summer and winter layers was unclear or poorly preserved, a conservative approach was taken. If a varve couplet could not be confidently identified (missing seasonal layer, or too indistinct transition), the layer was not considered a varve (Fig. 4). This decision was made to minimize the risk of overcounting and to ensure that only confidently recognized annual layers were included in the final varve chronology. Ambiguous sections were noted, but left uncounted unless supported by additional evidence, such as correlation with other cores or presence of nearby marker varves.

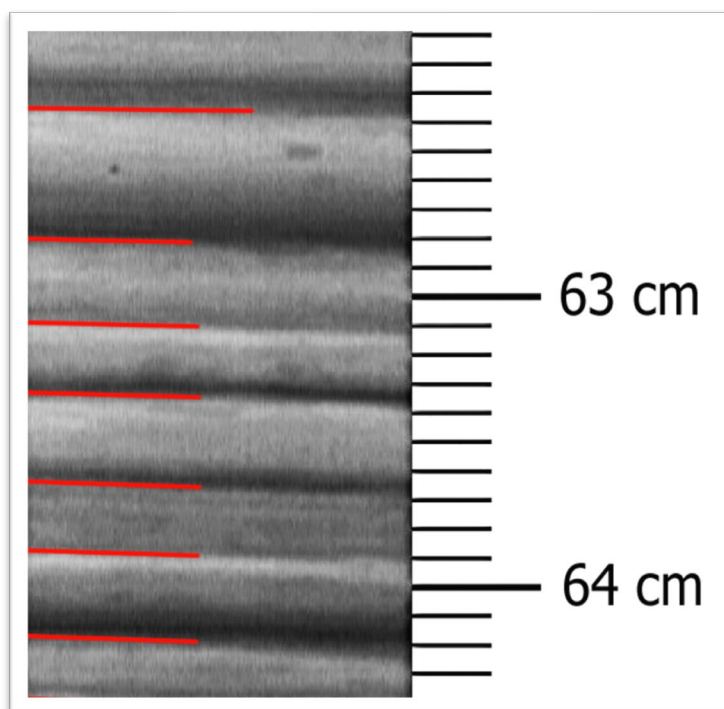


Figure 2. Example of varved sediment in x-ray. The delineations (red) are used to show the boundaries of a single varve. They are purposefully not completed to the right side in order to show their true visibility. Sharp contacts can be clearly seen between the light and dark layers of different varves, and the internal gradation from a dark summer layer to a lighter winter layer can also be observed.

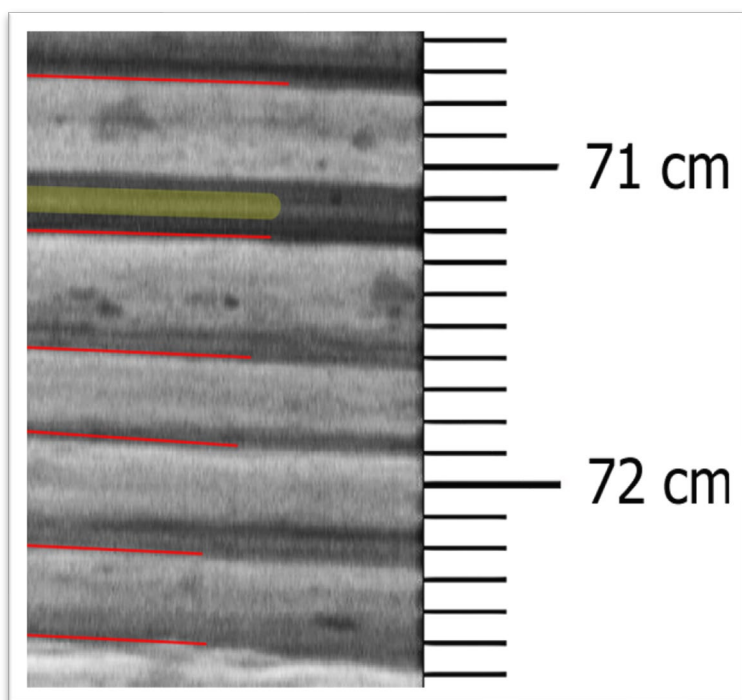


Figure 3. Example of a plausible sub-annual event (highlighted in yellow) and true varves delineated in red. The faint variation in lightness, likely due to a pause in meltwater inflow during the spring-summer, and settling of finer particles, could be mistaken for a small varve. However, this was not identified as an individual varve in this thesis.

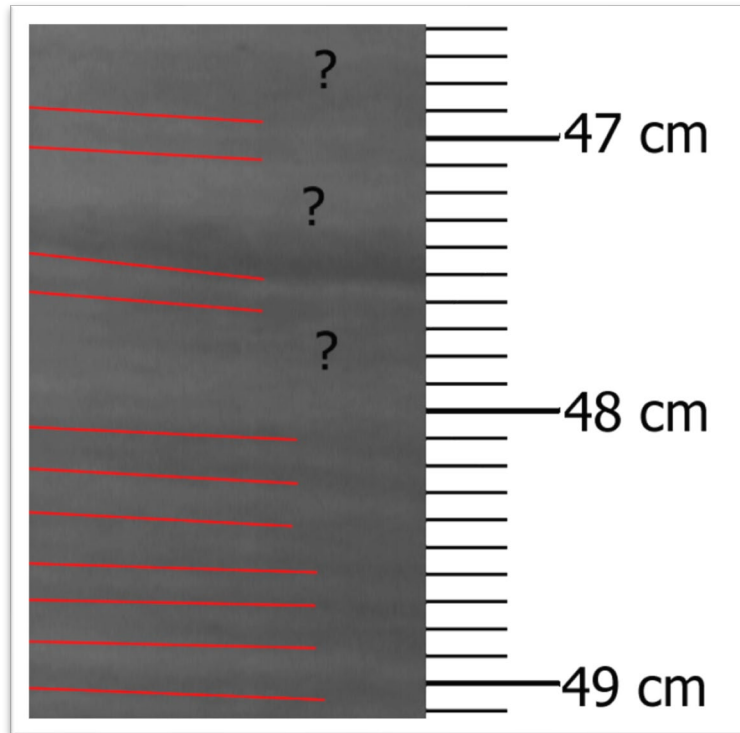


Figure 4. An example of the varve identification process for ambiguous layers in X-ray. This section of the core is very hard to analyse; however, varves can still be identified based on alternating light and dark bands. The delineations (red) are confident and were intentionally not completed on the right side to show the true visibility of the varves. The question marks indicate the ambiguity of the section due to very low varve contrast and thickness. Those were left uncounted.

2.3. Counting and measuring

Varve counting and thickness measurements were conducted using high-resolution X-ray images obtained from Itrax scanning. The images were imported into Clip Studio Paint, a graphics software that allowed for precise, manual analysis. Counting was performed up-core, perpendicular to the bedding plane, to ensure consistency in layer interpretation.

A moveable, self-drawn scale bar was calibrated with the scale provided in the X-ray images and used to measure individual varve thicknesses. The varves were delineated based on the criteria described in section 2.2.: a varve was defined as one light layer grading into one dark layer, terminated by a sharp boundary to the next light layer. To increase the accuracy of the count, each core was analyzed twice along the central axis, where varve preservation was generally the best due to less coring disturbance and minimal plastic content interference from the core splitting process. An example of the process can be seen in Figure 5. Only layers with clearly defined varve couplets were included; ambiguous or indistinct sequences were excluded from the final count to minimize interpretative bias. However, they were still noted down for future discussion.

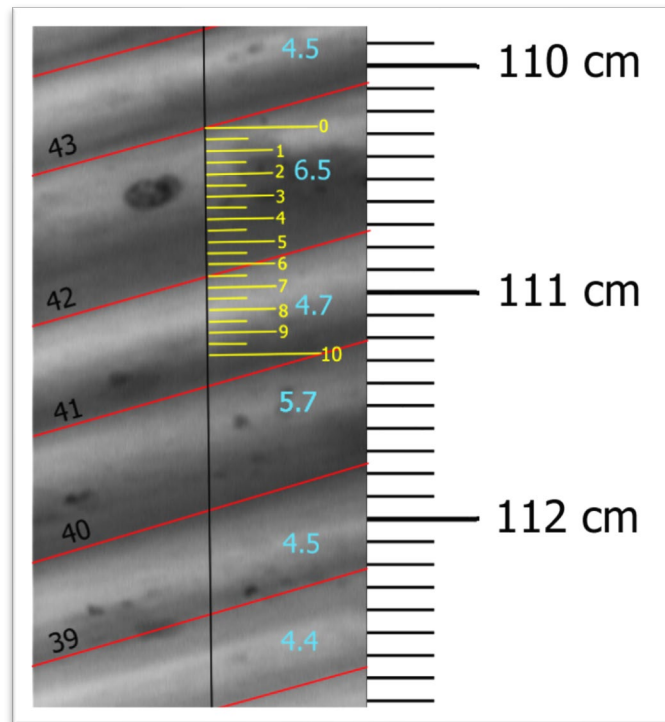


Figure 5. An example of the varve counting and measuring process, including the use of a moveable scale (yellow) and delineation method (red). Varve thickness (in mm) is displayed in blue, and the corresponding varve number in black.

2.4. Correlation between marine cores

To determine whether a consistent and robust varve chronology across the three selected cores (04-GC01, 06-GC02, 08-GC01) can be achieved, a pattern-matching ('wiggle-matching') approach was used. Varve thickness profiles for each core were constructed by plotting measured varve thickness (mm) against varve number in Microsoft Excel. These profiles were then visually compared to identify matching trends, marker varves, and overall patterns of the varve sequences.

The correlation was based primarily on the identification of distinctive features such as unusually thick varves (large 'spikes', treated as potential markers), the number of varves between marker horizons (preferably a difference of less than 10 varves to account for miscounting), and the overall trends of increasing or decreasing thickness up-core. Cross-correlation allowed for the recognition of coherent sequences and the alignment of equivalent varves across the cores, even where minor misalignments were present. This approach enabled the construction of a relative varve timeline, with overlapping intervals between the marine cores used to validate the consistency of the chronology.

2.5. Correlation with STS records

To place the marine varve sequences (04-GC01, 06-GC02, 08-GC01) within the established varve chronology, the thickness trends were compared to published varve thickness records from nearby sites within the Swedish Time Scale, documented by Strömberg (1989). Sites used were '313 a Alnön a' and '289 Björkö' (Fig. 1). Strömberg (1989)'s diagrams were digitized in two steps: first, by freehand tracing in Clip Studio Paint to capture the general structure of the lines, followed by redrawing using straight-line tools to ensure consistent alignment and facilitate the

scale adjustments. This was necessary because the original diagrams by Strömberg (1989) were likely hand-drawn and presented at varying scales.

The marine varve thickness plots (plotted as described in section 2.4.) were then visually compared to the digitized STS diagrams. Correlation focused on identifying parallel trends in varve thickness, matching distinctive marker varves, and overall ‘wobble matching’ and ‘stacking’ of the thickness lines. This pattern-matching approach enabled a relative alignment of the marine cores to the varve-year scale defined in the STS. Chronological anchoring was refined by assessing the number of varves between correlated markers and evaluating the degree of match across sequences. Where uncertainties occurred, they were noted and considered in the final interpretation.

3. Results

3.1. Core descriptions

3.1.1. Visual core analysis: 04-GC01

EL24-IGV02-04-GC01 (Fig. 6) is 150 cm long and shows continuous, well-defined light and dark laminations typical of varves. Overall, the sequence appears relatively undisturbed, apart from slight deformations near the base (lowermost 30 cm). There is a trend of coarsening up-core toward the middle of the core, then toward the top the grain size becomes finer, while varves typically thicken down-core (mm-scale to cm-scale). The distinction between the coarse summer and fine winter layers is not that noticeable to touch due to the very small scale (mm) of the varves, however it becomes more apparent upon inspecting larger (cm-scale) varves down-core. There is a distinct thick, dark layer at approximately 57.6-58.7 cm with a sharp lower boundary. A color shift occurs at approximately 78.2 cm: brownish (2.5y 3/2) varve tint changes to a more grayish (5y 3/1) hue up-core. Localized iron sulphide (FeS) and rust (reddish-orange discoloration between layers) are evident in the upper section of the core.

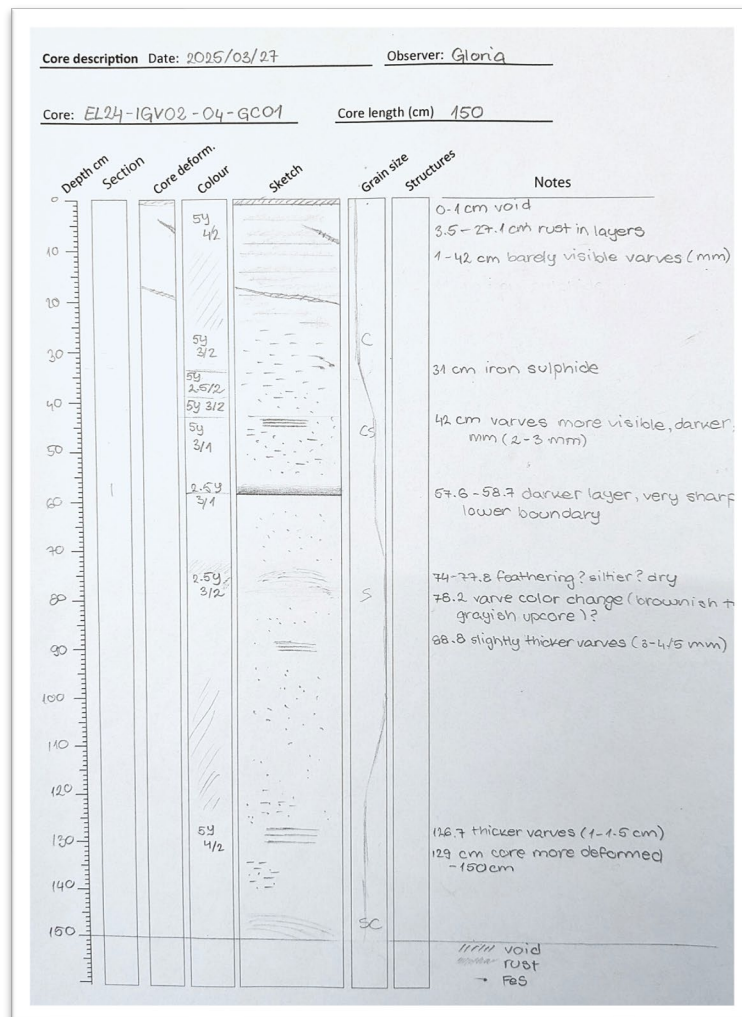


Figure 6. Visual core description (log) of core EL24-IGV02-04-GC01, created immediately after core splitting. The log is based on direct observations of the core surface and includes a hand-drawn sketch of the core alongside notable visual and textural features (color, grain size, initial varve thickness measurements, etc.). Observations were made before high-resolution imaging and are used as a preliminary reference for subsequent analysis.

3.1.2. X-ray core analysis: 04-GC01

The X-ray image of EL24-IGV02-04-GC01 (Fig. 7) confirms the presence of annual laminations, visible as alternating light and dark bands with a strong contrast (Fig. 8). The varves are generally consistent throughout the length of the core, with clearly defined boundaries, minimal tilting and negligible disturbance at the very base of the core. However, in the upper section, the laminations become faint and significantly thinner, making individual couplets more difficult to distinguish. There is an overall trend of fining-up core, evident by the layers becoming gradually lighter (finer) toward the top. A notable marker varve can be seen near the upper middle section of the core (Fig. 9) at 56-57.2 cm. The internal contrast of this varve (gradation) is also clearer than the surrounding varves. The small discrepancy between the location of the marker varve in the visual log and X-ray image is due to the 1 cm void at the core top (see Fig. 6), which was omitted during Itrax scanning.

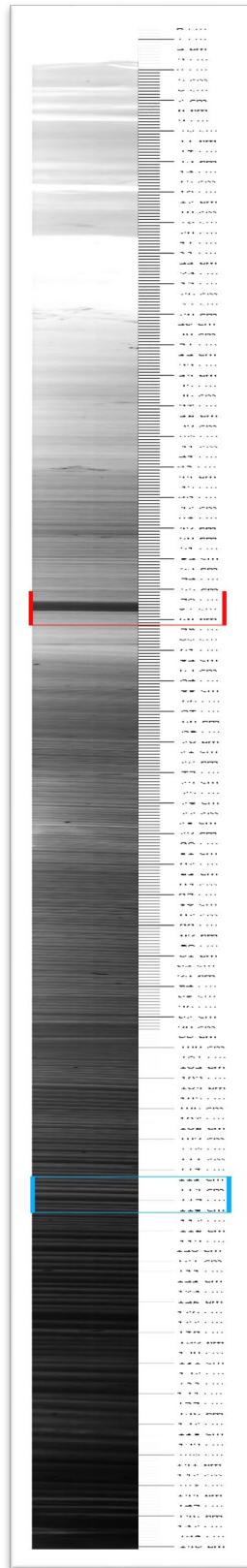


Figure 7. High resolution X-ray image of core EL24-IGV02-04-GC01 generated using the Itrax core scanner. Contrast was enhanced and the image vertically scaled for improved visibility and formatting. The varve couplets are clearly visible through most of the core. Extremely bright units at 0-3 cm and 20-28 cm were not interpreted as varved sediment. Blue box shows a section of the core with very distinct varves (closeup in Fig. 8). The suspected marker varve is shown in the red box (closeup in Fig. 9).

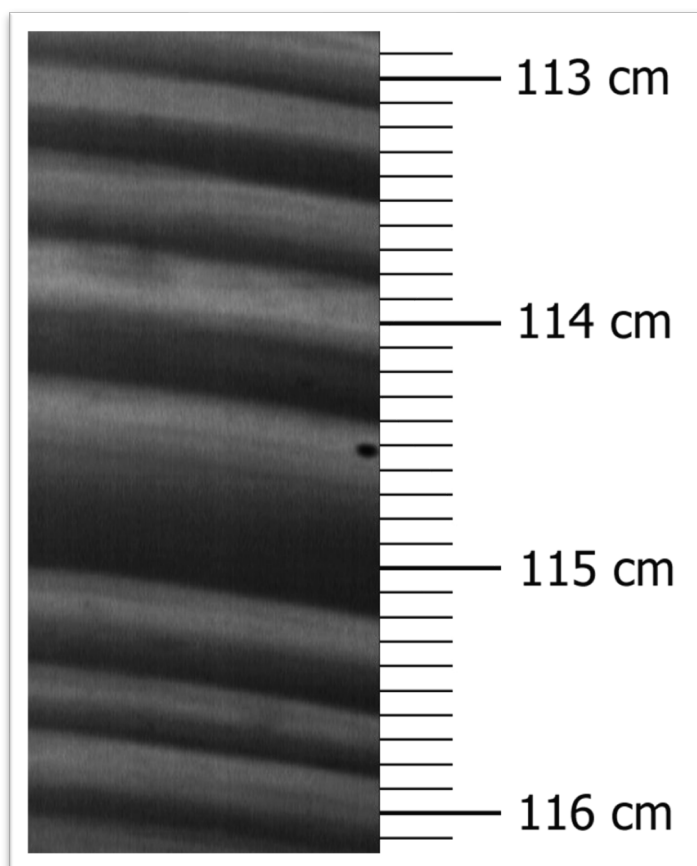


Figure 8. Closeup of the X-ray image (marked in blue on Fig. 7) on the rather distinct and contrasted varves in core EL24-IGV02-04-GC01. Varve thickness visibly varies from year-to-year, even if it is on a smaller scale. The average thickness of the varves visible here is 4.2 mm. Slight tilting is observed.

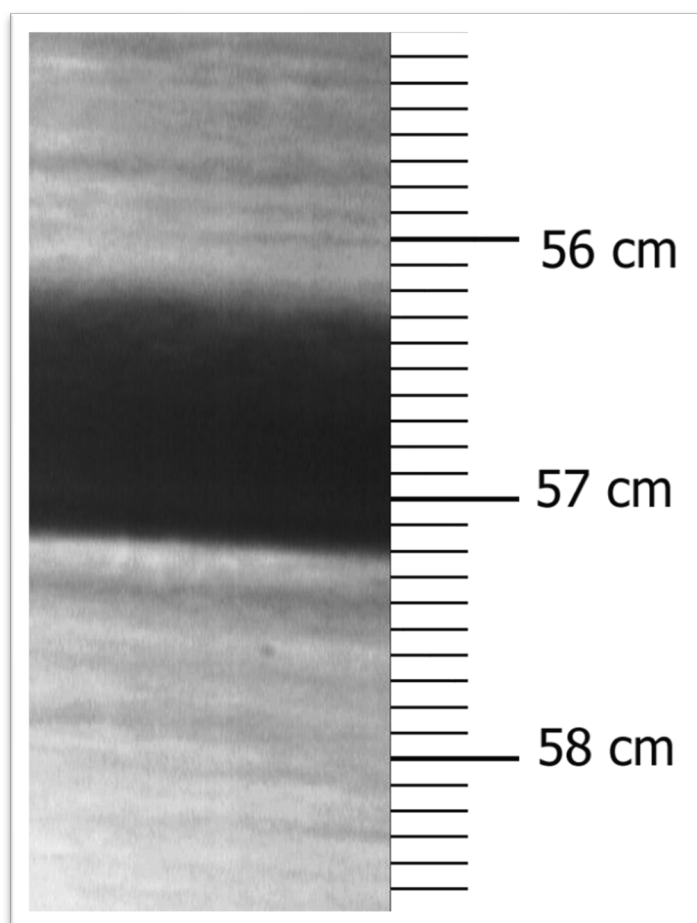


Figure 9. Closeup of the X-ray image on the marker varve in core EL24-IGV02-04-GC01 (marked in red on Fig. 7). There is a clear, sharp lower boundary at core depth 57.15 cm, from the previous light layer into the dark, marker layer. This is followed by a gradation which terminates at the next sharp boundary at core depth 56 cm – albeit less visible because the surrounding varves are barely 1 mm thick. Towards the bottom of this figure (beneath core depth 58.25 cm), varves become more difficult to identify due to their tiny (<1 mm) size.

3.1.3. Visual core analysis: 06-GC02

EL24-IGV02-06-GC02 (Fig. 10) is 147.2 cm long and has very well-defined varves, especially near the base of the core (up to 1.1 cm). Throughout most of the core, the sequence is slightly tilted, however this does not impact varve visibility. Core EL24-IGV02-06-GC02 has a larger void (12 cm) at the top than the other cores. The upper section of the core is very sandy; it feels rubbery to touch and is compact. There is localized iron sulphide (FeS) beneath the sand layer, but no rust. A prominent dark band (39-42 cm deep) composed of silty clay is evident, and down-core from this marker, varves are large enough to see with the naked eye (1-2 mm). There is a color shift at 72 cm from a brownish (2.5y 3/2) to a greyish (5y 2.5/2) hue up-core. A plausible dropstone can be seen at the very base of the core.

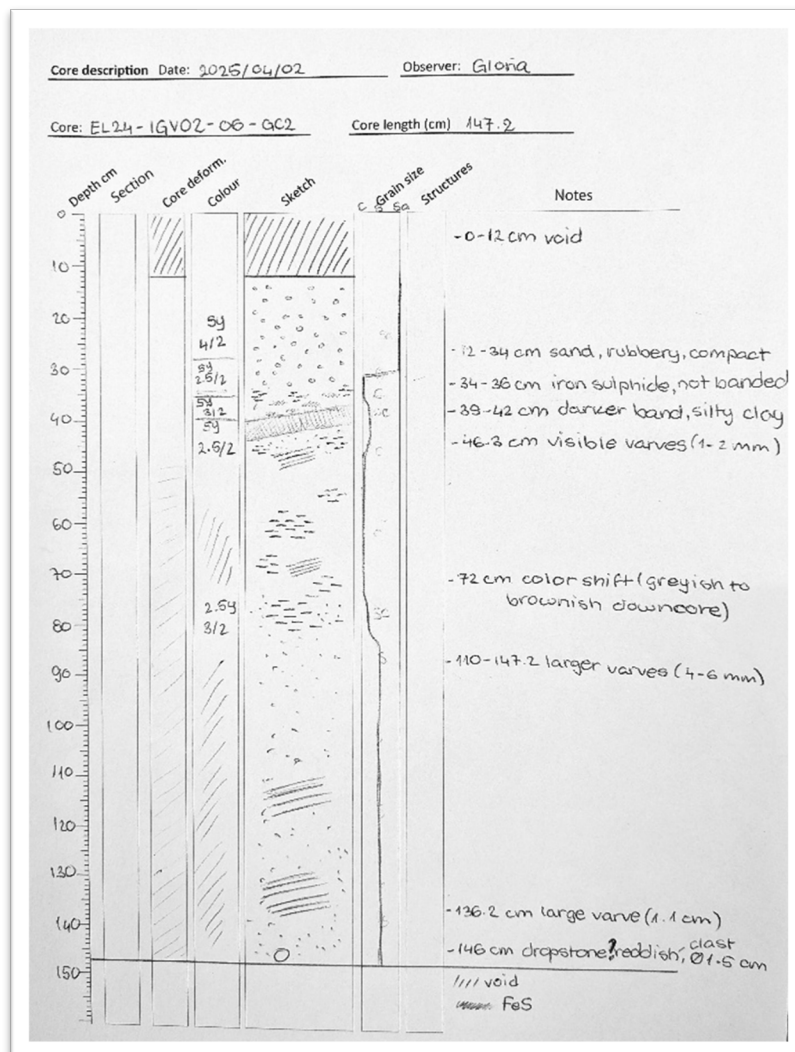


Figure 10. Visual core description (log) of core EL24-IGV02-06-GC02, created immediately after core splitting. The log is based on direct observations of the core surface and includes a hand-drawn sketch of the core alongside notable visual and textural features (color, grain size, initial varve thickness measurements, etc.). Observations were made before high-resolution imaging and are used as a preliminary reference for subsequent analysis.

3.1.4. X-ray core analysis: 06-GC02

The X-ray image of EL24-IGV02-06-GC02 (Fig. 11) reveals a continuous sequence of very distinct glaciolacustrine laminations throughout the whole length of the core. The contrast between the layers is moderately strong toward the base and middle of the core, allowing for easy identification of individual varves. In the uppermost section, the contrast weakens, and the laminations appear more compressed (generally around 1 mm in thickness). Varves can still be identified, though with greater difficulty. There are no significant signs of core deformation, apart from slight tilting which does not interfere with the sequence. The uppermost and lowermost sections of the core are very dark and contain no varves, which is consistent with the visual core log; the upper unit is sandy, and the lower unit is coarse-grained and even contains a possible dropstone (Fig. 12). A prominent varve is visible in the upper section of the core and shown in closeup in Figure 13. It has a sharp lower contact, an upward gradient and notably increased thickness relative to surrounding layers. Between the supposed marker varve and the uppermost dark section is a light layer with visible sandy grains within.

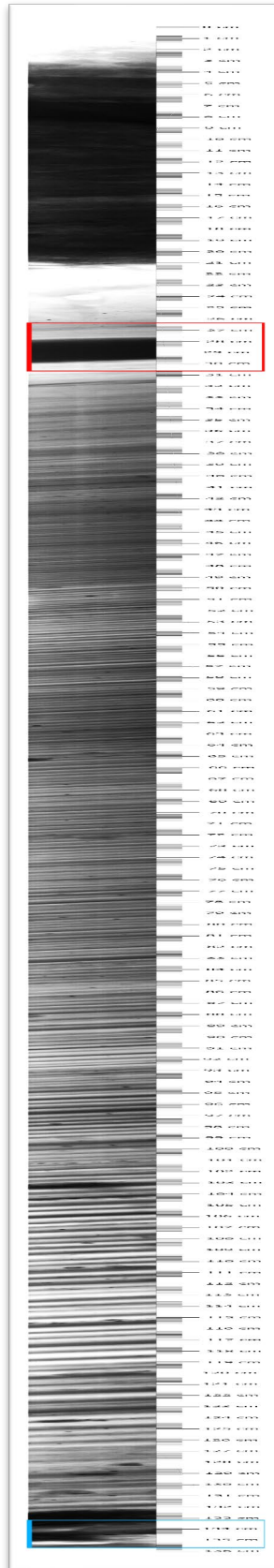


Figure 11. High resolution X-ray image of core EL24-IGV02-06-GC02 generated using the Itrax core scanner. Contrast was enhanced and the image vertically scaled for improved visibility and formatting. The varve couplets are distinct through most of the core; the primary exception being from 0-27 cm, where no varves were identified. Blue box shows the position of the suspected dropstone (Fig. 12), and the red box shows the distinct marker varve (Fig. 13).

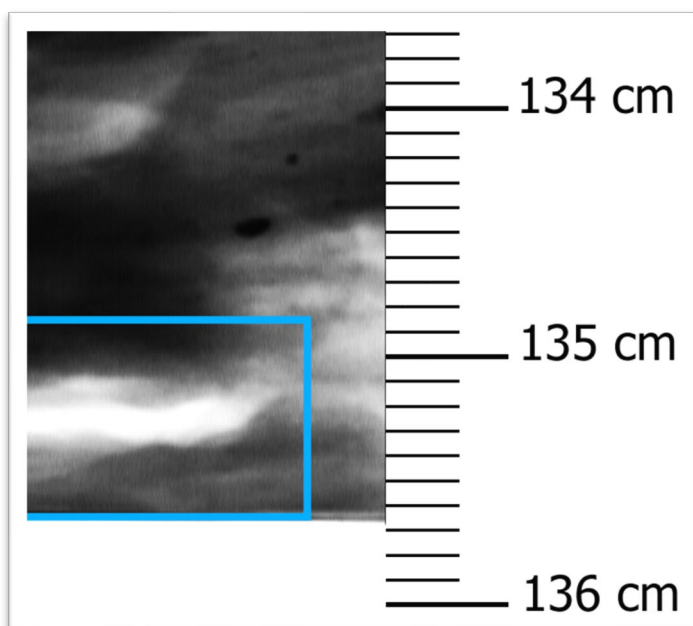


Figure 12. Closeup of the X-ray image on the suspected dropstone (blue box) in core EL24-IGV02-04-GC01 (also marked in blue on Fig. 11). Its approximate position (taking the void into consideration) and size align with the visual log (Fig. 10), although the boundaries are not clearly defined as would be expected from a clast. It is inconclusive whether this is a dropstone based on the X-ray image, but due to high likeliness, it will be included as a speculation during discussion.

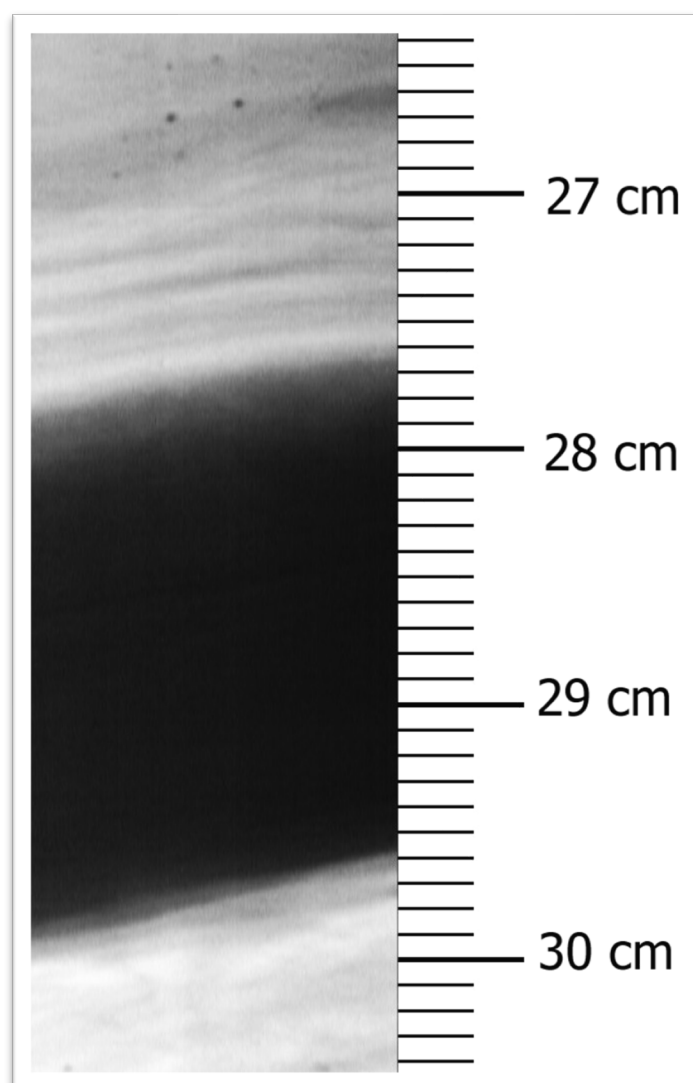


Figure 13. Closeup of the X-ray image on the suspected marker varve in core EL24-IGV02-06-GC02 (shown in red in Fig. 11). There is a sharp lower boundary at core depth 29.7 cm from a light-colored layer into the thick, dark varve up-core. A gradient and the boundary to the next dark layer is clear at core depth 27.6 cm, despite the small scale (~1 mm) of the varves on top. At approximately 26.9 cm depth starts a fine-grained layer with sand grains within that continues up to core depth 21.1 cm. Above this (not in image) is a compact sand layer.

3.1.5. Visual core analysis: 08-GC01

EL24-IGV02-08-GC01 (Fig. 14) is 96.2 cm long and has moderately defined laminations, with sections that are visually fainter when compared to the previous two cores. Approximately half of the core length has relatively well-defined varves (bottom section), while varves appear more faded and it is harder to definitively delineate them up-core. No notable deformations can be seen. The lowermost section of the core is sandy silt (visible feathering), with a gradational fining up-core; the exception is the uppermost section containing sand grains. The core also portrays a color shift at approximately 32 cm, from a brownish (2.5y 3/2) to a more greyish (5y 2.5/2) hue up-core. Localized rust is evident in the sandy section near the top of the core.

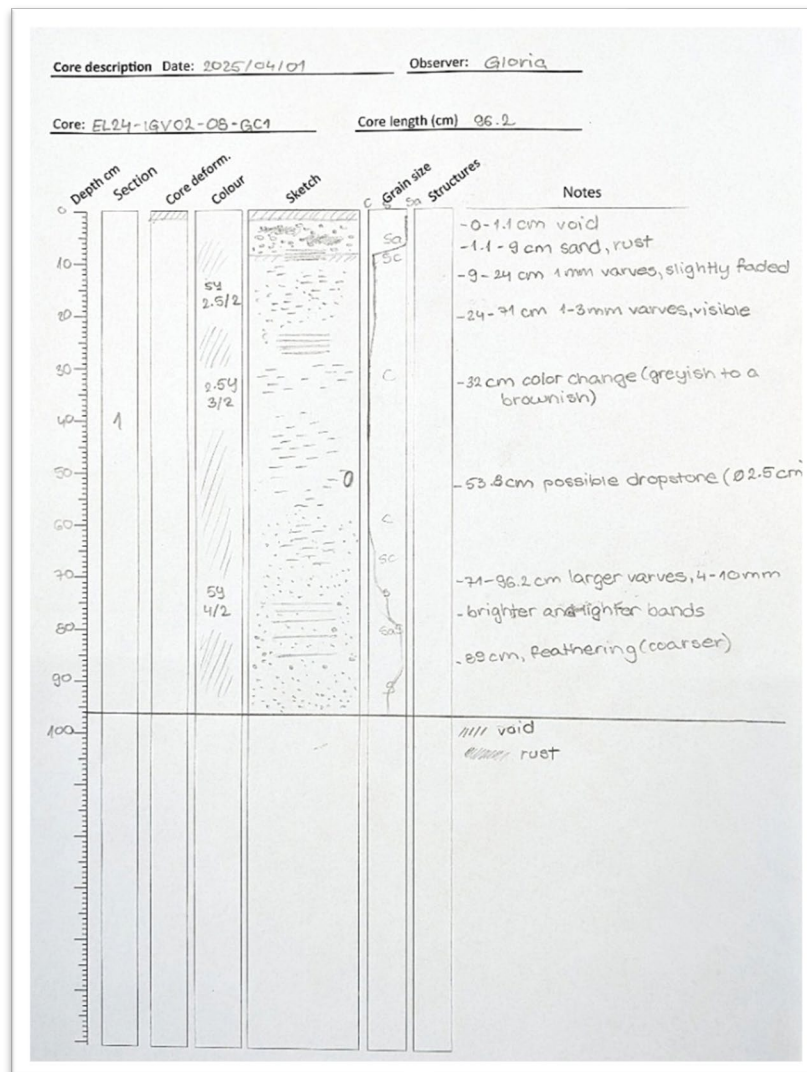


Figure 14. Visual core description (log) of core EL24-IGV02-08-GC02, created immediately after core splitting. The log is based on direct observations of the core surface and includes a hand-drawn sketch of the core alongside notable visual and textural features (color, grain size, initial varve thickness measurements, etc.). Observations were made before high-resolution imaging and are used as a preliminary reference for subsequent analysis.

3.1.6. X-ray core analysis: 08-GC01

X-ray image of core EL24-IGV02-08-GC01 (Fig. 15) shows well-defined annual laminations, particularly in the lower half of the core, where the contrast between the seasonal layers is very clear. In the middle section, the varves become progressively thinner but remain distinguishable and continuous until further up-core (see Fig. 16). In the uppermost section of the core (down to core depth 8.7 cm), a thick, dark layer is evident (Fig. 17), which corresponds to the sand unit noted in the visual core log (Fig. 14). Within this unit is an even darker layer that visually resembles a varve; however, considering this is sandy sediment, it is unlikely to be varved. This unit could instead be an erosional feature; the laminations below the unit are horizontal, but some have been truncated by the angled contact. This reinforces the interpretation of an erosional event. No distinct marker varves were found in the core, which could possibly be due to the erosional contact. The lowermost section of 08-GC01, at core depth 90.8 cm to core base at 94.9 cm, features deformed but identifiable varves (Fig. 18). The varves appear to be undulating – some truncate into the ones below, while others warp upward. This deformation could be linked to deformation during core drilling, or possibly related to slope instability, which could have resulted in such slumping.

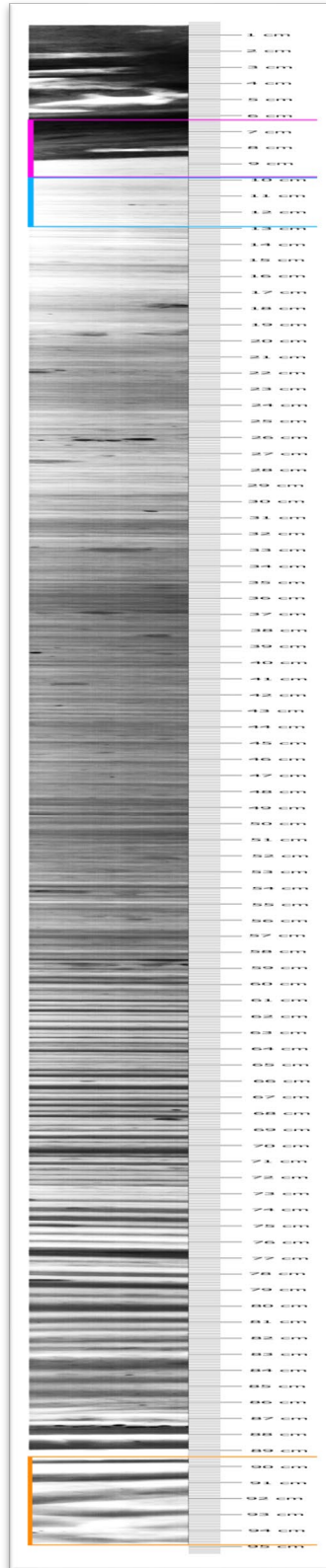


Figure 15. High resolution X-ray image of core EL24-IGV02-08-GC01 generated using the Itrax core scanner. Contrast was enhanced and the image vertically scaled for improved visibility and formatting. The varve couplets are distinct through most of the core; exceptions include the top of the core down to a depth of 8.7 cm, where a sandy unit terminates into a sharp lower boundary, likely erosional (marked by the pink box; Fig. 16); the indistinct finer-grained section beneath the sandy unit, from the core depth 8.7 cm to 10.64 cm (marked by the blue box; Fig. 17); the lowermost section which experienced clear disturbance from core depth 90.8 cm down to the base (marked by the orange box; Fig. 18).

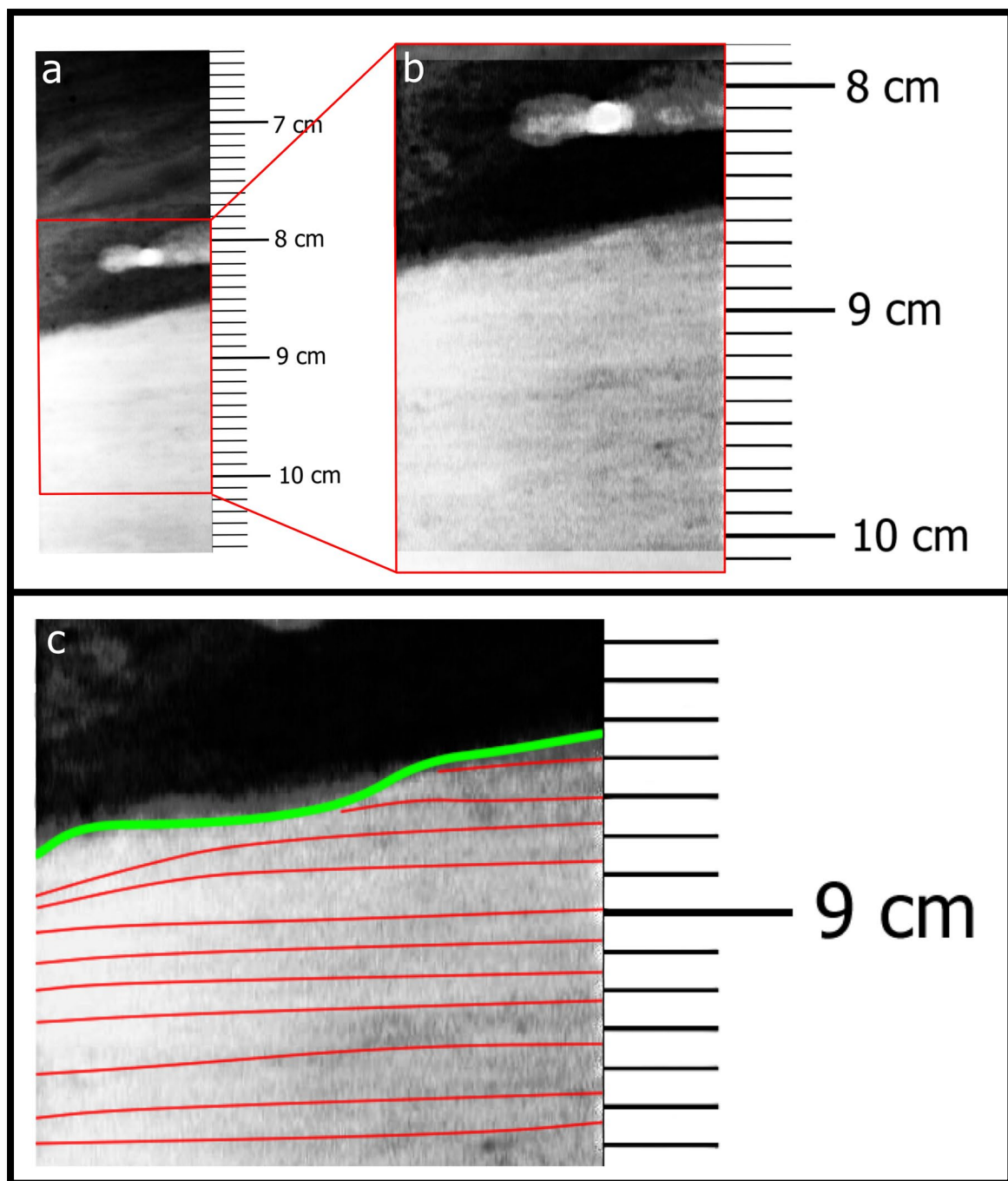


Figure 16. Closeups of the X-ray image on the erosional contact in core 08-GC01 (marked by the pink box in Fig. 15). a) Section of the core portraying the upper sandy unit that terminates at core depth 8.7 cm. Below this unit is finer-grained sediment. Small-scale laminations are vaguely visible. b) Enlarged image of the contact region. Contrast was enhanced in order to examine the faint laminations below the sandy unit. They appear to begin immediately after contact and are horizontal. The contact itself is angled and has truncated the laminations up until core depth 9 cm, supporting the idea of an erosional contact. c) Closeup of the contact, delineated in green. The laminations are drawn in red to clarify the interpretation of originally horizontal laminations being truncated by an erosional contact.

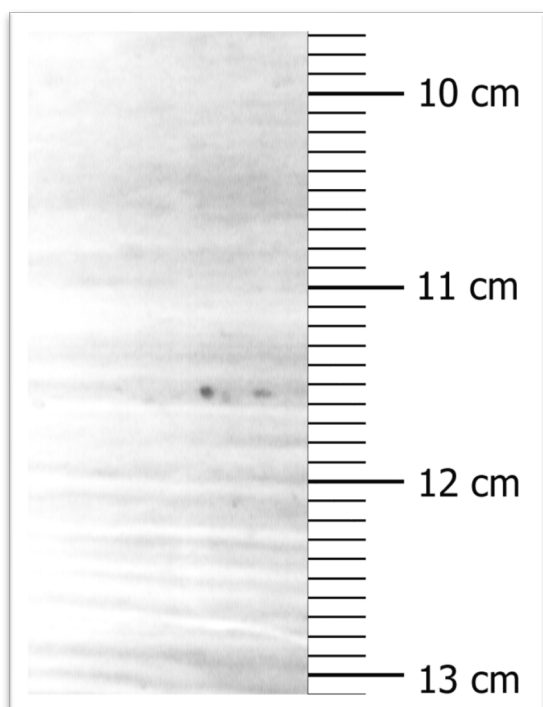


Figure 17. Closeup of the X-ray image on the upper section of EL24-IGV02-08-GC01 and continuation down-core from Fig. 16.a, where it becomes difficult to distinguish individual varves (marked by the blue box in Fig. 15). From core depth 10.64 cm, where the winter layer of the last recognizable varve ends, to the bottom of the image (and extending further down-core), varves can be identified despite their small size (approximately 1 mm each). Above 10.64 cm, the layers are much more indistinct. Delineations cannot be confidently made without greatly increasing the contrast (as was done in Fig. 16.b), and even that yields weak visibility when compared to varves beneath core depth 10.64 cm

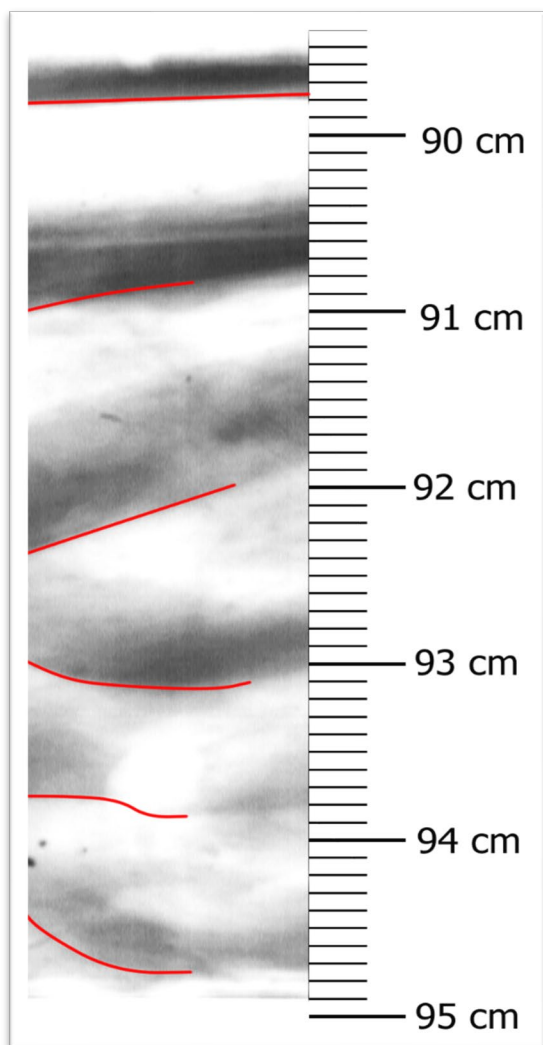


Figure 18. Closeup on the disturbed section in core EL24-IGV02-08-GC01 (marked by the orange box in Fig. 15). While the varves below core depth 90.8 cm (down to the core base at 94.9 cm) are deformed, they can still easily be distinguished as true varves: summer and winter layers are clearly present. Instead of lying horizontal, these varves display an almost undulating pattern (delineated in red for visibility). Above core depth 90.8 cm, the varves are horizontal.

3.2. Varve measurements

3.2.1. EL24-IGV02-04-GC01

A total of 370 varves were identified in core EL24-IGV02-04-GC01 (Fig. 19). Despite the slight deformation towards the base of the core, the varves were preserved well enough to include in the final count. The minimum varve thickness is 0.4 mm, while the maximum varve thickness is 12.7 mm. The mean thickness is 2.5 mm. The suspected marker varve is number 303, and its thickness is 11.5 mm. There was a general varve thickening trend toward the base of the core.

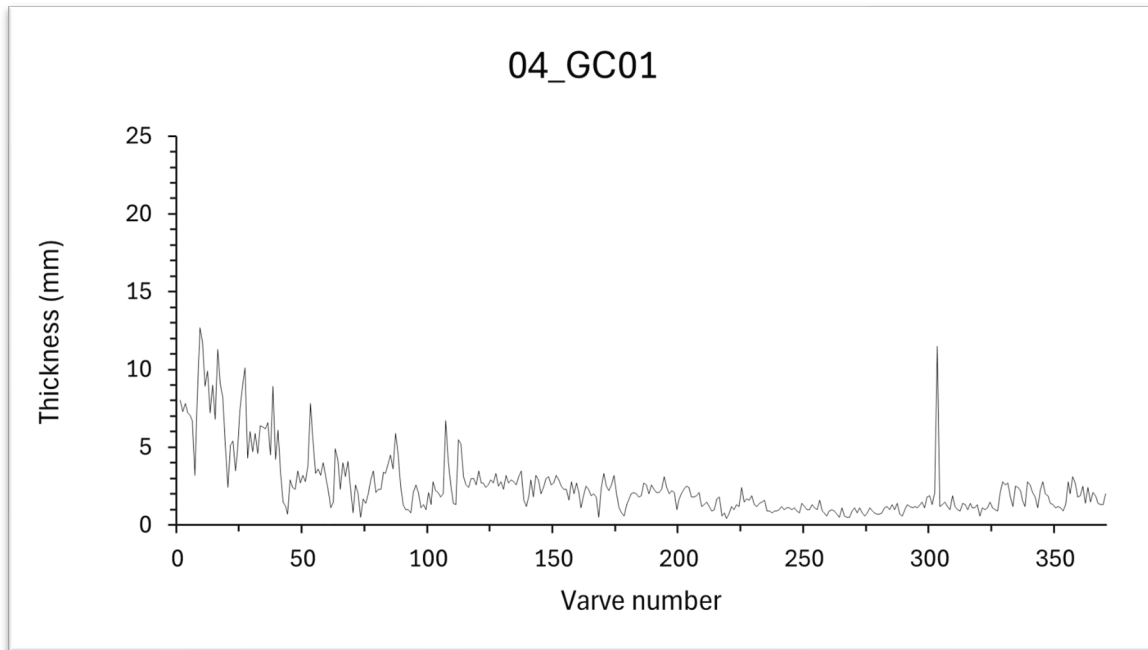


Figure 19. Varve thickness plot for core EL24-IGV02-04-GC01. Varve thickness (in mm) is plotted on the y-axis against varve number on the x-axis, with the core base (oldest varves) on the left, and the core top (youngest varves) on the right.

3.2.2. EL24-IGV02-06-GC02

Due to better overall varve visibility throughout core EL24-IGV02-06-GC02, the total varve count is slightly higher than in the other two cores: 391 distinct varves were identified (Fig. 20). The varve thickness ranged from a minimum of 0.3 mm to a maximum of 21.2 mm, and a calculated mean of 2.6 mm. The suspected marker varve is number 386 and is 21.2 mm thick. The thicker varves were generally more concentrated towards the base of the core.

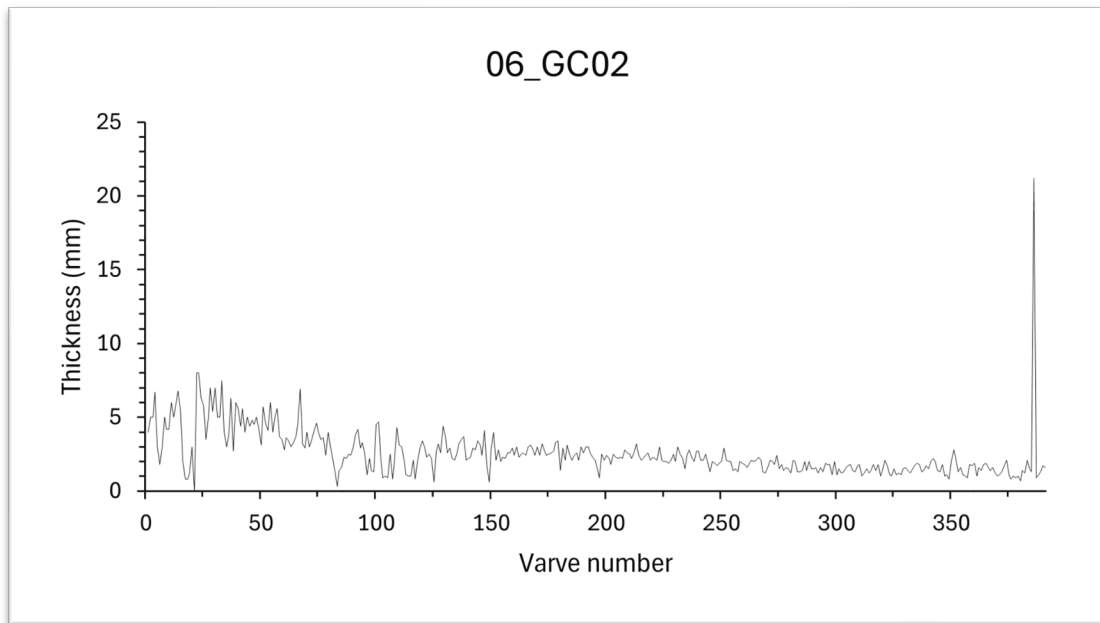


Figure 20. Varve thickness plot for core EL24-IGV02-06-GC02. Varve thickness (in mm) is plotted on the y-axis against varve number on the x-axis, with the core base (oldest varves) on the left, and the core top (youngest varves) on the right.

3.2.3. EL24-IGV02-08-GC01

Core EL24-IGV02-08-GC01 (Fig. 21) had a total varve count of 351. There were more ambiguous layers than in the previous two cores, predominantly toward the top. However, the varves were still distinguishable to an extent. The minimum varve thickness was measured at 0.4 mm, and the maximum at 11.5 mm. The mean was calculated to be 2.06 mm. The unlikely marker (see Fig. 16) is 11.2 mm thick. Varves gradually get thinner toward the top.

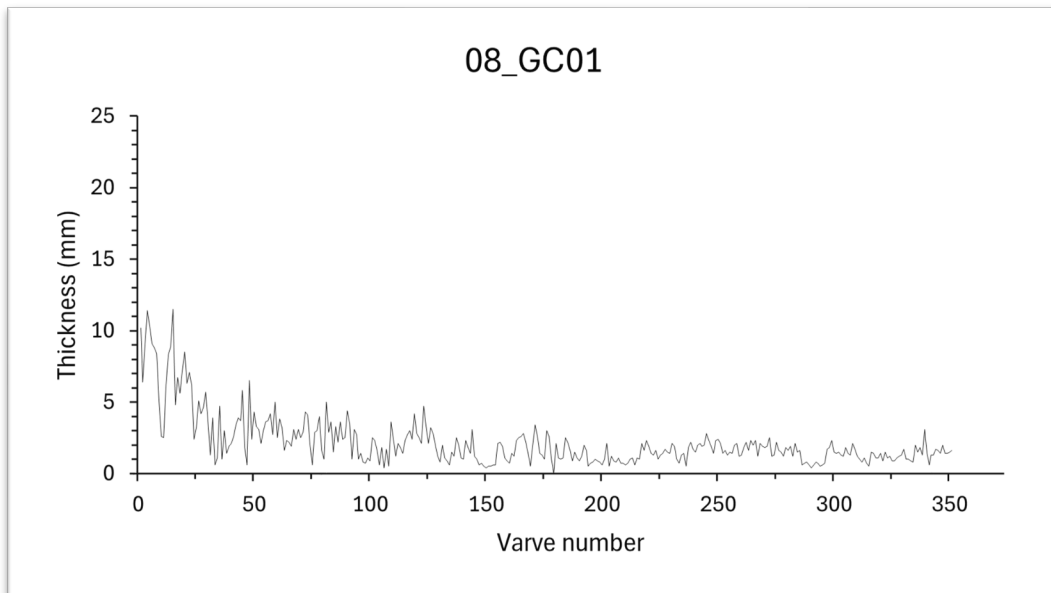


Figure 21. Varve thickness plot for core EL24-IGV02-08-GC01. Varve thickness (in mm) is plotted on the y-axis against varve number on the x-axis, with the core base (oldest varves) on the left, and the core top (youngest varves) on the right. The unlikely marker lamination was not included.

3.3. Correlation between marine cores

The varve thickness diagrams of cores EL24-IGV02-04-GC01 (Fig. 19), EL24-IGV02-06-GC02 (Fig. 20) and EL24-IGV02-08-GC01 (Fig. 21) were stacked to assess their correlation based on thickness patterns. Cores 04-GC01 and 06-GC02 were correlated using the marker varve identified in both sequences (indicated by a red line in Fig. 22). Their general thickness trends align well throughout majority of the stacked plot. However, core 04-GC01 shows more thickness variability than 06-GC02, thus some larger peaks present in 04-GC01 are not as pronounced in 06-GC02. Varves surrounding the marker varve (number 386 in core 06-GC02 and 303 in 04-GC01) match in their wiggle pattern enough to be considered confident. In contrast, core 08-GC01 could not be correlated with the other two this way as the supposed marker varve was uncertain. Instead, its alignment was established through visual wiggle matching of varve thickness patterns to the other two cores, using prominent shared thickness trends as reference points. Sections of 08-GC01 that matched clearly to at least one of the other cores are highlighted in yellow in Figure 22.

Overall, a consistent pattern of thickness variation was observed across the cores: varves at the base of the cores are thicker and display larger thickness variations. Moving up-core, the thickness variations become smaller, and the varves gradually grow thinner. Slight misalignments of up to a few varves are present and are likely due to miscounting or small-scale depositional differences between sites (see Fig. 1).

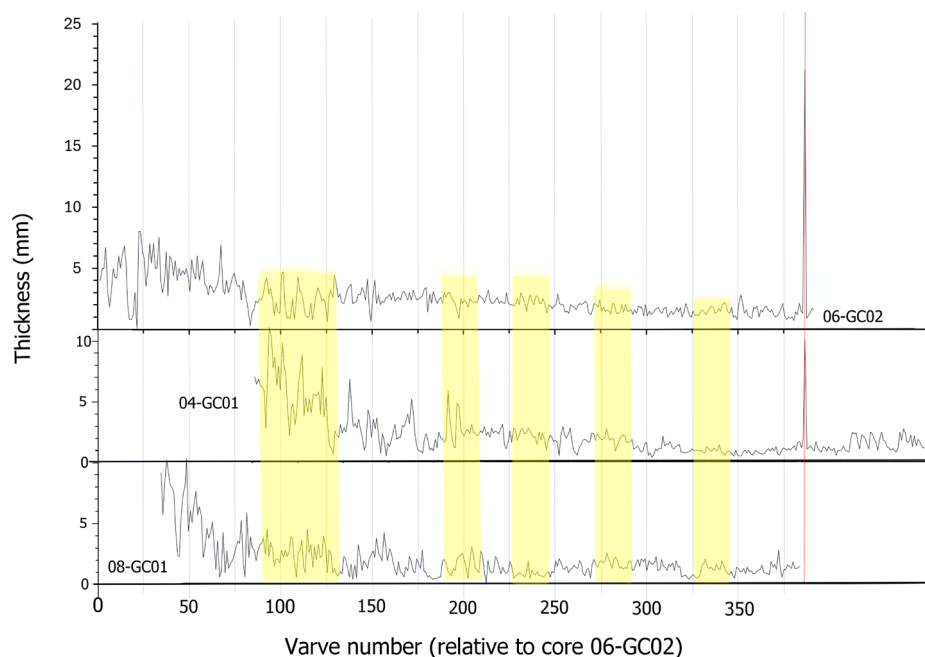


Figure 22. Varve thickness plots of cores EL24-IGV02-04-GC01 (Fig. 19), EL24-IGV02-06-GC02 (Fig. 20) and EL24-IGV02-08-GC01 (Fig. 21) plotted on a single graph. The y-axis shows varve thickness (in mm) for each core separately. Because the cores were correlated using a marker varve (in this case, varve number 386 in core 06-GC02), varve numbers for cores 04-GC01 and 08-GC01 were adjusted. The varve number relative to core 06-GC02 is displayed on the x-axis. Marker varve alignment is shown in red, and sections of core 08-GC01 which align with at least one other core are shown in yellow.

3.4. Correlation with STS records

To correlate the marine varve sequence with the Swedish Time Scale, thickness diagrams from two key STS sites – 313 a Alnön a and 289 Björkö (Fig. 1) – were digitized based on the published figures in Strömberg (1989). Due to differences in scale between the published

records and the marine core plots, the x- (varve number) and y- (thickness) axes of the digitized data were adjusted to match the marine core plots (Fig. 22); because Strömberg (1989) presented the STS sites at 10 varve year intervals, the x-axis of individual core thickness plots had to be compressed to match the 50 varve year interval assigned to the marine cores. Strömberg (1989)'s varve thickness measurements were mostly to scale, but some were presented as reduced or enlarged (e.g. 50% reduction, 500% magnification, etc.). To account for this, each occurrence of scale alteration was adjusted by digitally resizing the indicated varve(s) to a more uniform scale. Additionally, the STS plots were presented with proximal varves to the right and distal varves to the left, which contradicts with the varve counting method employed in this thesis – varves were counted from the base up-core, thus larger varve numbers correspond to younger varves. Because of this, the digitized STS plots were also mirrored.

Correlation between the records was tested by first aligning the marker varve in cores 04-GC01 and 06-GC02 (varve number 386, previously used for cross-correlation between marine cores: Fig. 22) with the marker varves present in the digitized Strömberg (1989) sites (varves 0, -48, and -68: Fig. 23). Surrounding sequences were wiggle-matched to test whether varve 386 (core 06-GC02) corresponded to any of the marker varves in the STS. Correlation using varve 0 as a reference yielded minimal matches, with only a few possible alignments observed near the bases of the cores. Using varve -68 as the shared marker produced better results, particularly in the lower sections of the cores; however, correspondence in the middle and upper sections was more limited. As such, the overall alignment was insufficient to support a confident correlation. In contrast, alignment using varve -48 demonstrated a strong match throughout the cores (Fig. 24). While minor mismatches were present, the overall pattern suggested a high degree of correlation. Considering only the varve sequence from core 04-GC01 properly continued beyond the marker varve, it was used to reinforce the alignment on the right side of the plot. Additionally, the zero varve – indicated in Strömberg (1989)'s thickness plots (Fig. 23) and originating from De Geer's original calibration – coincidentally aligned with a varve in core 04-GC01, the only marine sequence extending far enough to capture this. The zero varve correlation is indicated with a green line in Figure 24. Core 08-GC01, which did not have a marker varve, was additionally checked against the STS sites in the same way as described in section 3.3. to further affirm the alignment. This yielded additional matches, making the overall correlation of the offshore cores with the STS highly likely.

The varves in cores 04-GC01, 06-GC02 and 08-GC01 can now be expressed in absolute varve years (also shown in Fig. 24) with a subjectively assigned error margin of ± 5 varve years to account for potential miscounts. De Geer's zero varve in the STS, identified in both Alnön and Björkö (Strömberg, 1989; see Fig. 23), corresponds to varve 355 in core 04-GC01. The marker varve (number 386 relative to core 06-GC02) used for cross-correlation (red line in Fig. 24) corresponds to varve -48 in the STS chronology (Strömberg, 1989).

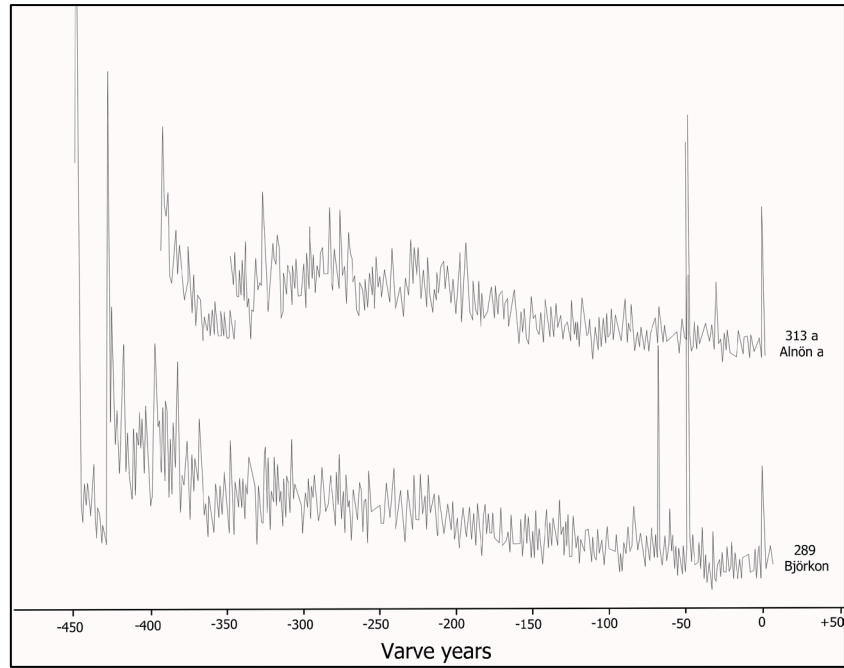


Figure 23. Compressed and mirrored digitized version of Strömberg (1989)'s varve thickness plots for sites 313 a Alnön a (top) and 289 Björkon (bottom) plotted as absolute varve years. The trend of gradual thickening toward the base of the core (left) can be seen in both Alnön and Björkon cores, and there are multiple thick varves toward the top (right) that stand out from the surroundings. These formed the basis for cross-correlation with the marine cores, specifically the marker varve at -48 varve years.

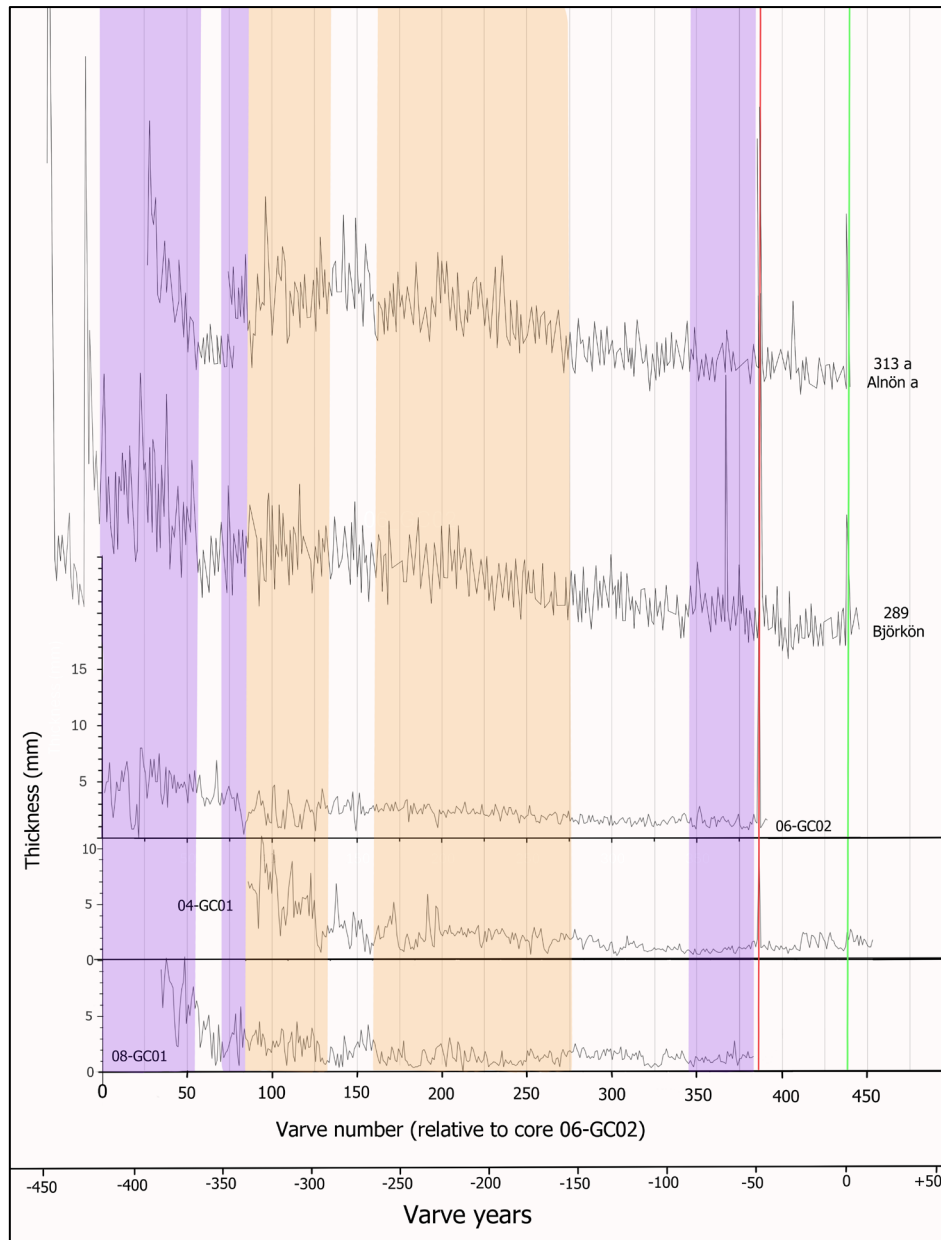


Figure 24. Stacked plot for correlation of marine varve thickness records with the Swedish Time Scale. The stacked marine sequence (from cores 04-GC01, 06-GC02 and 08-GC01: see Fig. 22) plotted alongside digitized STS thickness records from sites 313 a Alnön a and 289 Björkönen (Fig. 23). The original marker varve (red line), used to align 04-GC01 and 06-GC02, was further correlated with the STS cores. The zero varve from the STS record was correlated with core 04-GC01 (green line). Orange highlights indicate varve sequences previously correlated across the marine cores (shown in yellow in Fig. 22) and now also matched to the STS. Purple highlights denote newly identified notable matches based on visual correspondence with the STS. Uncoloured portions are left where no robust match to the STS could be established for certain.

3.5. Summary of key results

To summarize the core observations and correlation efforts, the key varve data for each core are compiled in Table 1. These results demonstrate consistent varve preservation across all three marine cores, with successful STS alignment using marker varves and varve thickness pattern matching. Correlation with the STS records allowed for chronological anchoring of the marine sequence to an absolute timescale.

Table 1. Summary of key varve measurements, marker varve positions, and correlation results for all marine cores.

Core id	Total varve number	Mean thickness (mm)	Marker varve number	Marker varve thickness (mm)	STS correlation
EL24-IGV02-04-GC01	370	2,5	303	11,5	Very likely
EL24-IGV02-06-GC02	391	2,6	386	21,2	Very likely
EL24-IGV02-08-GC01	351	2,06	Not observed	Not observed	Likely

4. Discussion

4.1. Varve interpretations

4.1.1. Varve count and Thickness trends

Predominantly well-preserved and conspicuous varves were identified in marine cores 04-GC01 (Fig. 7), 06-GC02 (Fig. 11), and 08-GC01 (Fig. 15). There was minimal disturbance throughout the cores, which allowed for confident counting and measuring of varve thicknesses. The distinct annual layering enabled the construction of high-resolution varve thickness profiles for each site (Fig. 19; Fig. 20; Fig. 21), facilitating cross-correlation and comparison. Instances of ambiguous layers were noted (e.g. Fig. 16; Fig. 17), but since they did not follow the criteria for varve identification, they were not included in the measurements. Variations in varve occurrence and preservation, specifically the pronounced sandy units in cores 06-GC02 and 08-GC01 which overlie varved units, can be interpreted as evidence of post-depositional erosion of the more distal varves by processes responsible for the sand deposition. Based on the contact angle in core 08-GC01 (Fig. 16.a), the visible truncating of lower laminations following that same angle, and the laminations being horizontal beneath the unit (Fig. 16.b; 16.c), an erosional event is well-supported. Alternatively, there might have been a complete hiatus in varve deposition – possibly a period when meltwater channels rerouted, leaving only parts of the basin isolated (considering core 04-GC01 had well-preserved distal varves and no sandy upper unit); a short-lived water-level change which altered circulation; or a halt in sediment input to the ice sheet. The pause would then be followed by a shift in depositional conditions that allowed for sand deposition. While this remains a possibility, it can then be speculated that similar would be observed in the legacy STS sites, which is not the case, unless the hiatus was in effect strictly offshore. Based on available evidence, the erosional event is the most probable cause of the missing varves.

The discrepancy between varve counts and core lengths is interpreted in relation to coring limitations, sediment characteristics, and deglaciation patterns in Sundsvall Bay. Ice margin positions (isochrons) based on onshore varved sites (Strömberg, 1989) and the plausible NNE-SSW orientation of the ice margin show that not all sites in Sundsvall Bay would have deglaciated at the exact same time: site 06, which is located farther SW in the basin (Fig. 1) would have likely deglaciated first (at approximately -460 varve years: Strömberg, 1989). Site 08, located in the NE portion in the basin (Fig. 1), would possibly be next (at approximately -440 varve years: Strömberg, 1989). Site 04, NW in the basin (Fig. 1) would deglacierate last (at approximately -420 varve years: Strömberg, 1989). Therefore, the bottom varve at site 06 would be older than the bottom varve at site 08 by 20 varve years, which would be older than site 04 by another 20 varve years. Core 06-GC02 has 391 varves. Core 08-GC01, despite being only 96.2 cm long, contains 351 varves. Because it is expected to be 20 varve years younger, it is estimated to be missing roughly 15 varves at its base to align with core 06-GC02 (Fig. 22). This is consistent with the fact that the bottom of the varved sequence was not reached in core 08-GC01, as varves remain visible down to the very base without evidence of a bottom (which is not the case for core 06-GC02: see section 4.1.2.). The increasing silt content down-core likely reduced the penetration efficiency of the gravity corer, preventing recovery of deeper sediments and accounting for the shorter core length and missing proximal varves. Additionally, core 08-GC01 is missing the marker varve itself, but includes varves extending nearly up to the expected marker position, which match well with the corresponding upper varves in the other marine cores (Fig. 22). The missing distal varves thus account for the remaining discrepancy. Core 04-GC01 contains 370 varves, and since it is expected to be 40 varve years younger than core 06-GC02, it is missing approximately 40 proximal varves to align with core 06-GC02. However, the

X-ray image (Fig. 7) shows evidence of disturbance at the base, with laminations possibly present but not distinct enough to confidently identify as varves. This suggests the presence of deeper varves which were not recovered. Notably, core 04-GC01 contains 62 additional varves after the youngest varve in core 06-GC02. This effectively balances the overall varve count between the two cores. Together, these observations indicate that differences in core length and varve counts are primarily a function of coring depth limitations, sediment composition, and varve preservation, rather than counting inaccuracy.

The varve thickness profiles across the studied marine cores display a general trend of decreasing thickness up-core (Fig. 22), consistent with expectations during deglaciation; thicker varves are typically deposited when the ice margin is closer to the core site and sediment supply is higher (Saarnisto & Ojala, 2009). This would be the case for the varves near the base of the studied cores. Thinner varves are typical of distal margins and reduced influx of sediment (Saarnisto & Ojala, 2009), which is applicable for the middle and upper sections of the cores. This is also observed in the STS sites (Fig. 23). The higher annual variability in thickness of proximal varves, observed in both the marine cores and the STS sites, possibly reflects repeated changes in the hydrological system and sediment availability, likely related to ice margin instability. In contrast, the distal varves exhibit more consistent thickness trends, indicating more stable meltwater regimes and reduced sediment input as the ice margin retreated farther.

An exception to the general thickness trends is the marker varve identified in cores 04-GC01 (Fig. 9) and 06-GC02 (Fig. 13). This marker is a single varve of notably greater thickness than its adjacent layers (see Table 1). In core 04-GC01, where the sequence fines up-core all the way to the top, the marker varve is silty; slightly finer than the underlying units, but coarser relative to the overlying section. In core 06-GC02, the marker varve is comparatively siltier (but still clayey) than surrounding varves, excluding the overlying sandy unit. The anomalous thickness and texture of this varve may be interpreted as a brief episode of enhanced sediment input to the ice margin, increased melting rates which resulted in a larger meltwater output, or a drainage event of an ice-dammed lake.

4.1.2. Bottom Varve

Considering the ice front was located in Sundsvall Bay at around 10.4 cal. kyr BP (Greenwood et al., 2017), and that De Geer's zero varve has been assigned the age $10,008 \pm 87$ cal. yr BP (Regnéll et al., 2025), a sequence of approximately 400 annual varves could be expected between the bottom varve and De Geer's zero varve from the Sundsvall Bay sites. This estimate is also based on the total varve count in Strömberg (1989)'s legacy STS sites (see Fig. 24). Core 06-GC02 contains a total of 391 identifiable varves, which is close to the reasoned complete sequence number. Directly beneath the oldest counted varve is a silty unit containing a plausible dropstone (noted in the visual log: Fig. 10), which potentially supports the interpretation of it being the bottom (till). However, it could constitute a 'false bottom', where icebergs transported till ('till raft': De Geer, 1940, as cited in Strömberg, 1989) which deposited onto pre-existing varves, effectively hiding them. This interpretation possibly aligns with the Bothnian Sea ice stream collapse (Greenwood et al., 2017), which – if restricted timewise by the 'spot-zone', a section of carbonate-rich varves (Strömberg, 1989; Greenwood et al., 2017) – would have occurred when the ice margin was nearing Sundsvall Bay (10.5 cal. kyr BP: Greenwood et al., 2017). Since the collapse featured mass iceberg calving, icebergs would have been released into the Bothnian Sea at around 10.5 cal. kyr BP, and thus the presence of a till-raft deposit forming a false bottom is a possible alternative to a true bottom varve in the Sundsvall Bay cores. However, presuming the dropstone at the base of core 06-GC02 represents a true bottom, or at least that the bottom was nearly reached, the deglaciation

timing of the other Sundsvall Bay sites can be restricted. If varve 1 in core 06-GC02 is (close to) the bottom, it would represent the first deglaciated area (first deposition of varved sediments) from the studied cores due to its SE position in the basin (Fig. 1). That would mean that deglaciation of the NE part of the basin, site 08, occurred approximately 20 varve years later, and deglaciation of the NW part, site 04, 40 varve years after the SE portion (discussed also in section 4.1.1.).

4.1.3. Color change

In all three marine cores, a color change was observed (visual core logs: Fig. 6, Fig. 10, Fig. 14), from a brownish to a greyish hue up-core. Similar was noted in Brunnberg (1995) and interpreted as a saline-water signal in relation to the drainage of the Baltic Ice Lake ($11,570 \pm 97$ cal. yr BP; Regnéll et al., 2025). This does not apply for Sundsvall Bay, however, as it was not located inside the lake, nor were varves depositing in the bay at this time as it was still covered by ice (see section 1.4.). The colour change seems to occur around the time the varves start to become thinner and less variable. It also happens at near the same depth in cores 04-GC01 and 06-GC02 (78.2 and 72 cm, respectively), while in core 08-GC01 it happens much shallower in the sequence (at 32 cm). The relation to the local basin setting (with site 08 being less ‘sheltered’ than sites 04 and 06; see Fig. 1) and subsequent differences in meltwater flow or sediment input type could be hypothesized. In core 08-GC01, varve number 87 ± 10 corresponds to this depth (± 10 , because the transition seems to occur over multiple varves with more diffuse contacts). In core 06-GC02, varve number 148 ± 10 corresponds to the color shift. In core 04-GC0, varve number 146 ± 10 corresponds to this depth. These are approximately equivalent to -280 varve years in the STS chronology (Fig. 24) and around 10.3 cal. kyr BP, excluding core 08-GC01. Considering the first drainage event of the Central Jämtland Ice Lake was recorded by varve -48 (Regnéll et al., 2025), the colour shift is unlikely to be related, as it is too far down in the sequence. No definitive limestone fragments, which could imply a color-change related to the ‘spot zone’ (that can include a brown to grey clay transition: Strömberg, 1989) were noted in the transition section. Prior to the color shift, the ice margin was still located relatively close to Sundsvall, and by 10.3 cal. kyr BP, it had retreated much farther inland (Regnéll et al., 2025). A hypothesis could be that the brownish portion of the core corresponds to locally sourced bedrock material; eroded and subsequently deposited via glacial meltwater as varved sediments in the basin. Transition to a more greyish hue could thus imply a change in sourced material as the ice margin retreated landward. The composition of the different colored sections would have to be examined in the future to provide clarity on the origin. Although, according to Brunnberg (1995), there was no change in composition between the studied brownish and greyish clays. Another cause could be a change in organic content burial (considering the retreat timing of the ice sheet) or ionization (as was speculated in Brunnberg, 1995), but further analysis would be necessary to determine for certain.

4.2. Correlation of the marine sites

Comparison between the cores was mainly based on the presence of the distinct marker varve (Fig. 9; Fig. 13) that stands out due to its unusual thickness and relative stratigraphic position. This varve is observed in both cores 04-GC01 and 06-GC02, and displays a strong pattern match in adjacent varves, which supports the interpretation that it was a synchronous depositional event across the basin. As mentioned before, core 08-GC01 is the exception. However, the absence of a marker varve can be explained by the clear erosional contact observed at the transition to a sandy layer up-core (Fig. 14; Fig. 16). The abrupt shift from silty

clay to sand indicates post-glacial erosion and deposition events, where high-energy flow eroded part of the varved sequence and allowed for sand deposition. Similar is observed in core 06-GC02 (see Fig. 10), where distinct varves above the marker varve (Fig. 9) abruptly terminate into a sandy layer. However, the contact here appears more diffuse, indicating possible sediment mixing rather than sharp erosion. Given that core 06-GC02 is located farther south in the bay (Fig. 1), it is plausible that the short-term event responsible for erosion and sand deposition in core 08-GC01 had slowed by the time it reached site 06. Alternatively, because the upper section of core 06-GC02 is composed of fine clay rather than silt, the resulting compactness (as noted in Fig. 10) between the grains and subsequent resistance to erosion would explain the more diffuse contact.

The last confidently identified varve in core 08-GC01 is very close up-core to the erosional contact (varve 351: 384, relative to core 06-GC02). Figure 22 and Figure 24 show that if there was a marker varve in core 08-GC01, it was only a few varve years away from the youngest identified one. While somewhat speculative, the data strongly suggests that this is the case. Additionally, there is a lack of a sandy layer or signs of erosion in the upper part of core 04-GC01, despite relative proximity to site 08 (Fig. 1). It preserves a long, uninterrupted varve succession above the marker varve, extending all the way to and beyond De Geer's zero varve (Fig. 24). This suggests that the event responsible for the erosion of varves in cores 06-GC02 and 08-GC01 did not affect site 04. It is likely that the flow path of this event bypassed the inner part of the bay where core 04-GC01 was drilled, possibly due to shielding by coastal features or basin topography, or both. For example, in Figure 25 below, an esker can be seen (dashed green line) positioned in the NW-SE direction between sites 04 and 08, effectively separating site 08 from the rest of the basin. Bottom currents (Fig. 25) following the outline of the coast, or currents coming north of site 08, could be deflected by the esker away from site 04 (and site 06). Moreover, the esker itself could have been the source of the sand that deposited onto varved sediments. Along the SW part of the basin, the shape of the coast potentially prevents southward currents from reaching site 04.

Other sections of the marine cores (particularly for core 08-GC01) had to be pattern matched to ensure accuracy beyond the marker. Figure 26 below shows the stacked thickness patterns of the marine cores which were closely observed to identify correlations. While some portions do not match perfectly, a correlation can be made (Fig. 22) based on the general patterns of the wiggles, rather than by matching absolute thicknesses – especially when taking into consideration the distance and differences in basin topography between the sites (see Fig. 25). Despite the challenges posed by erosion and local thickness variations, the overall correlation between the marine cores is well supported.

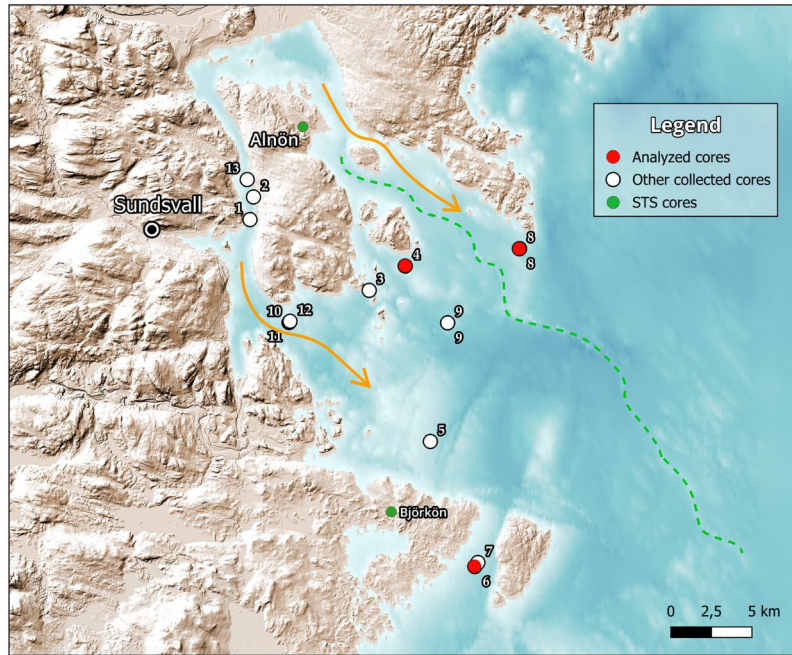


Figure 25. Sundsvall Bay Area. An esker is traced with a dashed line in green. The hypothesized currents travelling along the coastal features and the esker, which could have reached sites 06 and 08 while bypassing the inner bay area (site 04), are indicated with orange arrows.

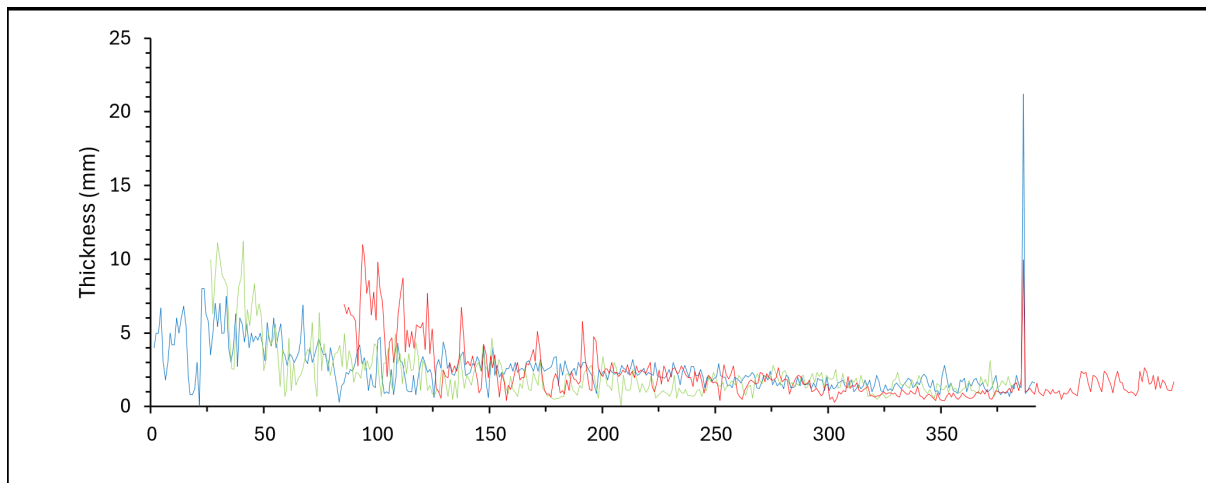


Figure 26. Process of correlation via stacking thickness patterns of cores 06-GC02 (blue), 04-GC01 (red) and 08-GC01 (green) with relation to the marker varve. The trend of decreasing thickness up-core (right) can be well aligned in all three sites, with more variation in the proximal varves (left). Wiggle-matching the middle and upper portions of the cores yielded satisfactory results, while more general pattern-matching (due to large differences in thickness) of the lower portions of the cores was necessary.

4.3. Correlation with the STS records

Due to a general lack of marine records in the Swedish Time Scale (Wohlfarth et al., 1997; see section 1.1.3.), the cross-correlation of the Sundsvall Bay varve sequences with the STS offers a valuable opportunity to extend the time scale offshore. This not only enhances the spatial resolution of deglacial reconstructions in the area, but also provides the means to integrate marine sedimentation dynamics into broader chronologies of ice retreat. Offshore records are thus needed to achieve a robust varve chronology for Fennoscandia (Avery et al., 2021). The most effective way to reliably correlate any varve series is to compare the drainage varves found

in equivalent positions within an area (Strömberg, 1989). This is because distinctive drainage varves are practical for anchoring the varve sequence in absolute time by relating it to lake drainage events. Without these markers, correlation is based primarily on small-scale thickness pattern changes, as is the case with many varve records from all around Sweden, which can result in less reliable results. STS sites 313 a Alnön a and 289 Björkö were chosen for correlation efforts because they were located very close to the marine sites (Fig. 1) and contained one of the most useful drainage varves for correlations (-48: Strömberg, 1989). The marker varve in the marine cores was speculated to represent a drainage event, prior to cross-correlations. This was because Sundsvall Bay served as the eastern outlet for the drainage of the Central Jämtland Ice Lake, so it was reasonable to expect a drainage varve in these sequences. Moreover, the -48 marker varve in the STS sites has been identified as the first and most prominent marker of the Central Jämtland Ice Lake drainage event (Regnéll et al., 2025). Therefore, the marine marker varves were aligned with the STS varve -48 from Alnön and Björkö, based purely on a hypothesis at first. Marker varves 0 and -68 (Fig. 23) were also checked, but the correlations yielded lesser degrees of match. In both Alnön and Björkö cores, varve -48 is siltier than the surrounding varves (Strömberg, 1989). This aligns with the marker varve compositions in marine cores 06-GC02 and 04-GC01 (see Fig. 6; Fig. 10), reinforcing their possible correlation. The rest of the sequence was then pattern-matched, which produced a decent alignment (see Fig. 24). Previous correlations between marine sites (Fig. 22) were thus reinforced by the new links with the STS. While a few sections remain somewhat less certain, the overall alignment is satisfactory.

Curiously, the second marker varve in 289 Björkö (approximately varve -67) was not prominent in core 06-GC02, despite the relative proximity between the sites (see Fig. 1). This is likely due to onshore and offshore topographical differences. The zero varve, which is also a remnant of the Central Jämtland Ice Lake drainages (Regnéll et al., 2023; Regnéll et al., 2025), aligns with varve 355 in core 04-GC01. Varve 355, although prominent when compared to the general thickness of the upper core, did not stand out like a drainage varve in the X-ray image (Fig. 7). It is possible that the drainage flow which deposited the zero varve slowed down upon reaching the basin, considering the whole upper sequence of core 04-GC01, including the zero varve, is fine-grained. Regardless, if the count and the correlation is correct, core 04-GC01 captured two distinct drainage events of the Central Jämtland Ice Lake: the first, and the second to last (Regnéll et al., 2023; Regnéll et al., 2025).

4.4. Reflections on the methods

The varve counting process adhered to the established definition of annually laminated sediments; however, it remains an interpretive method subject to error. Varve boundaries were identified based on visual contrast between the summer (silt-rich) and winter (clay-rich) layers, but faint transitions and very thin varves introduced the potential for miscounts. While thickness measurements provide a more objective dataset, they are still contingent on where varve boundaries are drawn – making them equally reliant on interpretive accuracy. Additionally, contrast enhancements applied to the X-ray images of the cores, while helpful in delineating layers, may have introduced artefacts or erased more subtle features. To minimize potential errors, the core sequences were each analyzed twice, with counts conducted along the same central axis perpendicular to the varves. Thickness measurements were also double-checked during this process. Overall, the results can be considered reliable, as the methodological consistency and agreement between the cores – including comparable mean varve thicknesses, similar pattern trends, and interpretation of missing varves – supports the validity of the measurements.

Correlation between the cores was primarily based on the presence of a marker varve, but beyond that, matching relied largely on visual alignment of thickness patterns – an inherently subjective process. In line with approaches used in reference studies, pattern matching was prioritized over absolute thickness values, especially where depositional environments likely varied due to distance between sites, differing meltwater pathways, etc. Where patterns aligned clearly, correlations were considered robust. Where they aligned weakly, correlation remained tentative but plausible due to other, more confident alignments. Digitization of the Swedish Time Scale data (Strömberg, 1989) posed additional challenges. The original plots were presented with inconsistent scales (e.g. reduction or magnification of certain sections), and though the resolution was sufficient, post-digitization rescaling likely distorted true thickness values, with peak amplitudes being particularly exaggerated. To address this, multiple digitization attempts were carried out using different software programs and approaches to minimize scaling errors. Despite these efforts, some degree of distortion remained. The final plot (Fig. 23) likely represents the best achievable result within the constraints of this digitization method.

Given the objective of this thesis, the geographic context of the study area, and the lack of continuous marine varve records in the STS, the chosen methods were appropriate. The goal was not to construct a definitive, fool-proof chronology, but to evaluate whether correlations can be made between the offshore records and the legacy STS sites. In that context, visual pattern matching anchored by a well-supported marker varve provided a reasonable and practical approach for these interpretations.

5. Conclusion

This thesis has aimed to investigate the possibility of cross-correlation between the marine cores from Sundsvall Bay and the established Swedish Time Scale records. Using strict criteria for varve identification, the sequences were counted, measured, and subjected to visual thickness pattern analysis. Identification of a key marker varve in the marine cores and within the STS sites, interpreted as a synchronous depositional event linked to the catastrophic drainage of the Central Jämtland Ice Lake, provided a key stratigraphic anchor for cross-core correlation. Thickness pattern matching, although inherently subjective, allowed for fairly confident and reliable interpretation of the sequences. The results demonstrate a satisfactory degree of correlation across the studied cores.

The findings support the potential for extending the STS offshore, thus contributing important insights to regional paleoclimatic reconstructions, and improving the understanding of deglaciation processes in Sundsvall Bay. Although some uncertainties remain, the methodological consistency and agreement between the cores lend confidence to the overall chronology. To improve the results presented in this thesis, further research should aim to confirm correlation with more refined digitization techniques, incorporate additional cores from the area to broaden spatial coverage and solidify the degree of match, and apply multi-proxy analysis and radiocarbon dating techniques to validate correlations.

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References

- Avery, R. S., Greenwood, S. L., Schenk, F., Morén, B. M., Armstrong McKay, D. I., Brunnberg, L. and Wohlfarth, B. (2021). 'A 725-year integrated offshore terrestrial varve chronology for southeastern Sweden suggests rapid ice retreat ~ 15 ka BP'. *Boreas*. 50(2). pp. 477-496. <https://doi.org/10.1111/bor.12490>
- Brunnberg, L. (1995). 'Clay-varve chronology and deglaciation during the Younger Dryas and Preboreal in the easternmost part of the Middle Swedish Ice Marginal Zone'. *Quaternaria. Ser. A*. <https://urn.kb.se/resolve?urn=urn:nbn:se:su:diva-153259>
- Demezhko, D. Y., Gornostaeva, A. A. and Antipin, A. N. (2020). 'The Fennoscandian ice sheet during the Late Weichselian: geothermal evidence'. *International Journal of Earth Sciences: GR Geologische Rundschau*. 109(6). pp. 1941–1955. doi:10.1007/s00531-020-01881-1.
- Feldens, P. & Schwarzer, K. (2012). 'The Ancylus Lake stage of the Baltic Sea in Fehmarn Belt: Indications of a new threshold?'. *Continental Shelf Research*. 35. pp. 43-52. <https://doi.org/10.1016/j.csr.2011.12.007>.
- Greenwood, S. L., Avery, R. S., Gyllencreutz, R., Regnéll, C. And Tylmann, K. (2024). 'Footprint of the Baltic Ice Stream: geomorphological evidence for shifting ice stream pathways'. *Boreas*. 53. pp. 4-26. <https://doi.org/10.1111/bor.12634>
- Greenwood, S. L., Clason, C. C., Nyberg, J., Jakobsson, M. & Holmlund, P. (2017). 'The Bothnian Sea ice stream: early Holocene retreat dynamics of the south-central Fennoscandian Ice Sheet'. *Boreas*. 46. pp. 346-362. doi: 10.1111/bor.12217.
- Hall, A. and Van Boeckel, M. (2020). 'Origin of the Baltic Sea basin by Pleistocene glacial erosion'. *GFF*. 142(3). pp. 237-252. doi: 10.1080/11035897.2020.1781246
- Holmquist, B., & Wohlfarth, B. (1998). 'An evaluation of the Late Weichselian Swedish varve chronology based on cross-correlation analysis'. *GFF*. 120(1). pp. 35–46. <https://doi-org.ezp.sub.su.se/10.1080/11035899801201035>
- Hughes, A. L. C., Gyllencreutz, R., Lohne, Ø. S., Mangerud, J. and Svendsen, J. I. (2015). 'The last Eurasian ice sheets – a chronological database and time-slice reconstruction, DATED-1'. *Boreas*. 45 (1). pp. 1-45. <https://doi.org/10.1111/bor.12142>
- IPCC (2022). 'Climate Change 2022: Impacts, Adaptation and Vulnerability'. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H. -O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. *Cambridge University Press*. Cambridge, UK and New York, NY, USA. doi:10.1017/9781009325844.
- Krauß, N., Kenzler, M. and Börner, A. (2025). 'Geochronological investigations at the maximum extent of the Fennoscandian Ice Sheet during the Late Weichselian glaciation in northern Germany'. *Boreas*. 54(2). pp. 246–257. doi:10.1111/bor.12695.
- NordNordWest (2008). Scandinavia location map. [Online image]. Available at: https://en.m.wikipedia.org/wiki/File:Scandinavia_location_map.svg Accessed: 2025-06-17

- Ploeg, K. and Stroeve, A. P. (2025). 'History and dynamics of Fennoscandian Ice Sheet retreat, contemporary ice-dammed lake evolution, and faulting in the Torneträsk area, northwestern Sweden'. *The Cryosphere*. 19(1). pp. 347–373. doi:10.5194/tc-19-347-2025.
- Regnéll, C., Becher, G. P., Öhrling, C., Greenwood, S. L., Gyllencreutz, R., Blomdin, R., Brendryen, J., Goodfellow, B. W., Mikko, H., Ransed, G. and Smith, C. (2023). 'Ice-dammed lakes and deglaciation history of the Scandinavian Ice Sheet in central Jämtland, Sweden'. *Quaternary Science Reviews*. 314. doi: 10.1016/j.quascirev.2023.108219
- Regnéll, C., Greenwood, S. L., Gyllencreutz, R., Peterson Becher, G., Regnéll, J., Öhrling, C., Hardeng, J., Johnson, E., Bakke, J. and Cederstrøm, J. M. (2025), in press. 'Anchoring the Swedish Time Scale to the radiocarbon time scale: An absolute age for De Geer's zero varve'. *Geology*. doi: 10.1130/G53280.1.
- Saarnisto, M. and Ojala, A. E. K. (2009). 'Varved Sediments'. *Encyclopedia of Paleoclimatology and Ancient Environments, Dordrecht: Springer Netherlands*. doi:10.1007/978-1-4020-4411-3_226.
- Simon, M. H., Rutledal, S., Menviel, L., Zolles, T., Haflidason, H., Born, A., Berben, S. M. P. and Dokken, T.M. (2023). 'Atlantic inflow and low sea-ice cover in the Nordic Seas promoted Fennoscandian Ice Sheet growth during the Last Glacial Maximum'. *Communications Earth & Environment*. 4(1). pp. 1–11. doi:10.1038/s43247-023-01032-9.
- Soulet, G., Ménot, G., Bayon, G., Rostek, F., Ponzevera, E., Toucanne, S., Lericolais, G. and Bard, E. (2013). 'Abrupt drainage cycles of the Fennoscandian Ice Sheet'. *Proceedings of the National Academy of Sciences of the United States of America*. 110(17). pp. 6682–6687. <https://www.jstor.org/stable/42590499>
- Stroeve, A. P., Hättestrand, C., Kleman, J., Heyman, J., Fabel, D., Fredin, O., Goodfellow, B. W., Harbor, J. M., Jansen, J. D., Olsen, L., Caffee, M. W., Fink, D., Lundqvist, J., Rosqvist, G. C., Strömberg, B. and Jansson, K. N. (2016). 'Deglaciation of Fennoscandia'. *Quaternary Science Reviews*. 147. pp. 91-121. doi: 10.1016/j.quascirev.2015.09.016
- Strömberg, B. (1989). 'Late Weichselian deglaciation and clay varve chronology in East-Central Sweden'. *Sveriges geologiska undersökning. Serie Ca. Avhandlingar och uppsatser I 4:0*, (73). pp. 3-70. <http://pascal-francis.inist.fr/vibad/index.php?action=search&terms=4559240>
- Wohlfarth, B., Björck, S., Cato, I. and Possnert, G. (1997). 'A new middle Holocene varve diagram from the river Ångermanälven, northern Sweden: indications for a possible error in the Holocene varve chronology'. *Boreas*. 26(4). pp. 347-353. <https://doi-org.ezp.sub.su.se/10.1111/j.1502-3885.1997.tb00860.x>