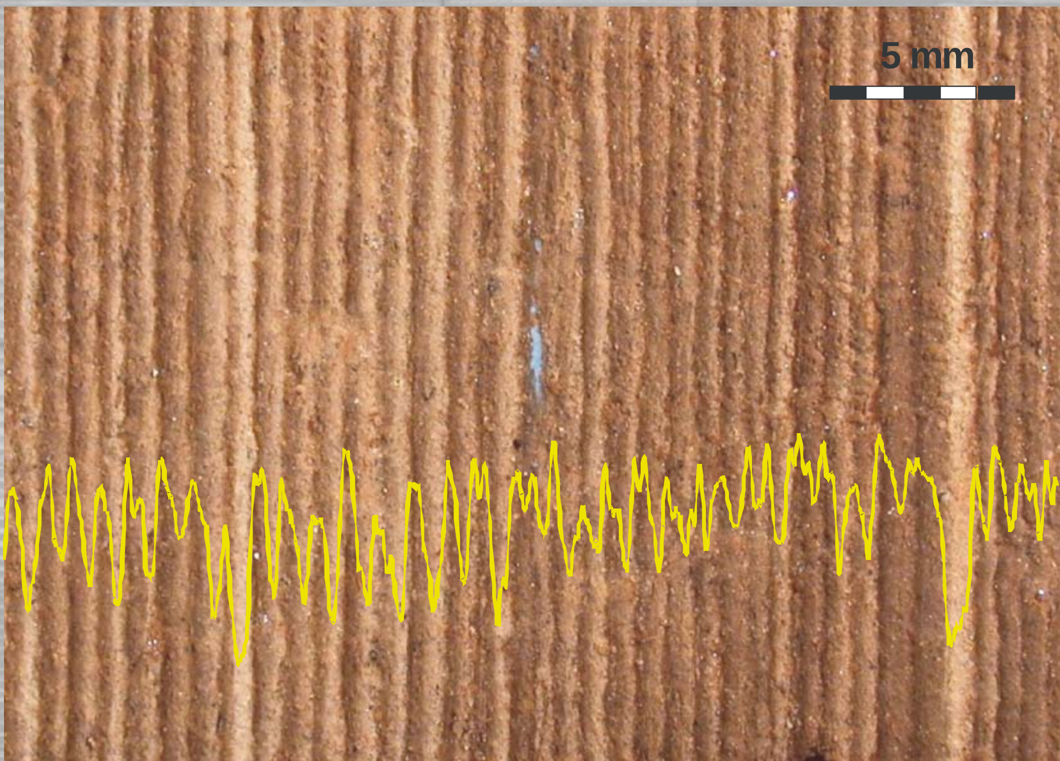
First workshop of the PAGES Varves Working Group

April 7-9, 2010
Palmse, Estonia



PROGRAMME AND ABSTRACTS

Edited by Ojala, A.E.K. & Kosonen, E.

The workshop is supported by PAGES

PAGES
PAST GLOBAL CHANGES

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The Varves Working Group (VWG) is a working group under the frame of the PAGES Cross Cutting Theme 1 "Chronology". The purpose of the VWG is to gather the varve community together and to bridge the gaps between people working with sedimentary varves and other communities dealing with annually resolved records.

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The workshop is supported by PAGES
http://www.pages-igbp.org/science/varves/varves2010.html

Geological Survey of Finland
Espoo, Finland
2010

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Scientific program

Wednesday 7.4.2010

13:45- Registration

14:00-15:00 LUNCH

15:00-15:15 Welcoming words

Session I: "Varved sites, environments, sedimentology and geochemistry"

15:15-16:00 **KEYNOTE: Wojciech Tylmann**: How to find varves? - Examples from Poland

16:00-16:50 **Poster presentations,** Part 1 (Posters 1-13)

16:50-17:15 COFFEE BREAK

17:15-17:40 **Mona Stockhecke**: Insights into the annual particle and sedimentation cycles of Lake Van (Turkey) by combining remote sensing data and sequential sediment trap analysis

17:40-18:05 **Scott Lamoureux**: The environmental signal contained in nonglacial Arctic varves: lessons from seven years of intensive lake and watershed process research

18:05-18:40 PAGES Varved Working Group: foundations, objectives, final products

18:40-19:00 **Poster presentations**, Part 2 (Posters 14-19)

19:00- **POSTER SESSION (Ice breaker and buffet)**

1. **Behl et al.**, Extending an intermittently varved record of abrupt and millennial-scale climate and ocean change through the Pleistocene in Santa Barbara Basin, California USA
2. **Corella et al.**, Climate fluctuations in Western Mediterranean during the last 1.5 ka: the varved record of Lake Montcortès (NE Spain)
3. **Darin and Kalugin**, Geochemical indicators of climate change in lacustrine varves Central Asia.
4. **Delaney**, The Potential for Constructing Varve Chronologies and Reconstructing Ice Dynamics using MIS Stage 2 Ice-Contact Lake Deposits in Ireland and Great Britain, Delaney
5. **Enters and Zolitschka**, Proposal for an online varve image library - removing misconceptions about varves
6. **Fortin et al.**, Investigating the presence of varved lake sediments in the Boreal Québec-Labrador region
7. **Francus and Nobert**, An integrated computer system to acquire, process, measure and store images of laminated sediments

8. **Heinsalu**, Different aquatic ecosystem response to the 8.2 ka cooling event: two diatom-based high-resolution case studies of varved sediments in southern Estonia and central southern Finland

9. **Kosonen et al.**, Using micro X-ray fluoresence (XRF) method to analyze clastic-biogenic varves from Lake Nautajärvi (Southern Finland)

10. **Martín-Puertas et al.**, Mid-Holocene climate variability from Meerfelder Maar (Western Europe)

11. **Moller et al.**, Consistent centennial scale climate signals, revealed by high resolution sediment chemistry in a fully laminated, expanded S5 Sapropel from the eastern Mediterranean

12. **Ojala et al.**, Studies of Lake Nautajärvi varved sediment record – chronology and environmental interpretations

13. **Palmer et al.**, Microfacies analysis of clastic laminated sediments and the discrimination of clastic varves using thin section micromorphology: examples from Lochaber, Scotland

14. **Renberg et al.**, Review of recent studies and work in progress on varved lake sediments in northern Sweden

15. **Schlolaut et al.**, Suigestu Varves 2006: An automated algorithm for varve interpolation

16. **Simola et al.**, Spectral imaging of sedimentary pigments in varved sediments – method and applications

17. **Tavernier et al.**, High-temporal resolution reconstruction of East Antarctic climate changes based on a varve analysis

18. **Van Daele et al.**, Impact of landscape changes on the sedimentary record of lakes in South-Central Chile

19. **Veski et al.**, Annually laminated lake sediment record from Rõuge Tõugjärv, southern Estonia – implications for paleoclimatic and palaeoenvironmental reconstructions

Thursday 8.4.2010

7:30-8:15	BREAKFAST

Session II: "Chronology"

8:15-9:00	**KEYNOTE: Ian Snowball**: Refining a varve chronology using independent dating techniques: a Swedish case study
9:00-9:25	**Irka Hajdas**: Varve chronology of lake Soppensee (CH) compared with the age-depth model based on the high resolution ^{14}C chronology
9:25-9:50	**Mark Besonen**: AMS ^{14}C dates and the reworking of terrestrial macrofossils as deduced from a varve chronology
9:50-10:10	COFFEE BREAK
10:10-10:35	**Adrian Palmer**: Developing an annually-resolved record for the Lateglacial period in the UK: the challenges and progress
10:35-11:00	Session discussions
11:00-12:00	PAGES Varved Working Group: aims and how to continue
12:00-13:00	LUNCH

Session III: "Exploring analytical and numerical methods and tools"

13:00-13:45	**KEYNOTE: Achim Brauer**: Combing varve micro-facies analyses and µ-XRF element scanning
13:45-14:10	**Michael Marshall**: Suigetsu Varves 2006: utilising µXRF and X-radiography for varve counting
14:10-14:35	**Michael Weber**: New tools for the varve community: laminae recognition (BMPix), fully automated counting (PEAK), and evolutionary spectral analysis (ESA-Lab)
14:35-15:00	**Arndt Schimmelmann**: Optical scanning of water-wet and epoxy-embedded sediment mini-slabs for structural documentation of laminated unconsolidated sediment: Energetic turbidites erode underlying varves in Santa Barbara Basin, California
15:00-15:30	Session discussions
15:30-15:50	COFFEE BREAK

Session IV: "Environmental and climate history (case studies)"

15:50-16:15	**Christian Wolff**: East African monsoon and ENSO variability since the last glacial
16:15-16:40	**Daniel Aritztegui**: Annually resolved environmental history of Lake Butrint (Albania) for the last 300 years
16:40-17:05	**Mathias Trachsel**: Assessing the potential of varved sediments of Lake Silvaplana (South-Eastern Switzerland) for high-resolution quantitative climate reconstruction
17:05-17:30	Session discussions
17:30-	DINNER + tour in the Palmse Manor House
19:00-	Sauna

Friday 9.4.2010

7:30-8:15	BREAKFAST
8:15-8:50	**Ingemar Renberg et al.**: Review of recent studies and work in progress on varved lake sediments in northern Sweden
8:50-9:15	**Cathy Delaney**: The Potential for Constructing Varve Chronologies and Reconstructing Ice Dynamics using MIS Stage 2 Ice-Contact Lake Deposits in Ireland and Great Britain
9:15-9:40	**Bernd Zolitschka**: Climatic and human control on lacustrine depositional processes: Evidences based on varved sediments from Lake Łazduny, Masurian Lake District (north-eastern Poland)
9:40-10:00	COFFEE BREAK
10:00-10:25	**Richard Behl**: Extending an intermittently varved record of abrupt and millennial-scale climate and ocean change through the Pleistocene in Santa Barbara Basin, California USA
10:25-10:50	**Jennifer Pike**: Late Quaternary marine varves from the Antarctic Margin: diatom silica oxygen isotope records
10:50-11:15	**Alan Kemp**: Palaeoclimatic and palaeoceanographic variability from Late Cretaceous marine varve records
11:15-11:30	Session discussions
11:30-12:15	LUNCH BREAK
12:15-14:00	PAGES Varved Working Group: Final discussion
14:30-16:00	Bus Transportation from Palmse to Tallinn (via airport)

ABSTRACTS

KEYNOTE

Combing varve micro-facies analyses and µ-XRF element scanning

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Annually laminated sediments are precise recorders of climate and environmental variability because they provide both, accurate chronologies based on varve counting and various proxy data at decadal to seasonal resolution. Therefore, varved lake records have been identified as key palaeoclimate archives on the continents and numerous efforts have been undertaken in the last decade to better exploit the high potential of lacustrine archives. On one hand, a large number of new annually laminated varved lake records have been discovered, partly by applying systematic surveys. On the other hand, novel non-destructive core scanning techniques have been developed to provide major element data down to 50 micron resolution. This corresponds to 10 – 20 data points for individual 0.5 – 1 mm thick varves, thus attaining even sub-seasonal resolution. In comparison, standard geochemical analyses by conventional XRF or ICP MS or AES techniques commonly is carried out on 1-cm sample intervals, *i.e.* at a time resolution of 10-20 years at most for comparable annual sedimentation rates. Despite the very high resolution of the scanning techniques, however, crucial limitations in interpreting element variations remained because of two reasons: (1) the obtained data represent relative variations of individual elements that are not easily convertible into element concentrations, and, (2) as for geochemical analyses in general, uncertainties in understanding the environmental or climatic processes for which the measured element ratios stand (*i.e.* proxy identification).

(1) Element data are commonly given in count rates which are strongly influenced by the detection sensitivity of each element. This in turn is a function of the X-ray characteristic energy of the element which is determined by the atomic number (Moseley's law) and therefore of the atomic weight. In general, heavier elements like Fe are more sensitive than lighter ones like Al and Si. Count rates of these elements with identical concentrations in the sediment may differ by a factor of approximately up to 40. Therefore, Fe count rates are very high in most records, whereas Al count rates often are close to the detection limit. These differences have major implications on element ratios, which commonly are calculated to eliminate dilution effects caused, for example, by variations in porosity, and water and organic matter contents. Therefore, intensity ratios calculated from scanner data are generally not identical to concentration ratios as obtained from quantified geochemical analyses. In particular, ratios of elements with larger differences between their atomic weights like Ca/Al are largely affected, whereas the difference between intensity and concentration ratios is nearly negligible for Fe/Mn ratios.

(2) Using element variations in sediment records as climatic proxies requires profound knowledge about element sources and reactivity. This is rather straightforward for some elements with a well-constrained geochemical signature like Ti, which is corrosion-resistant and hardly soluble and thus commonly considered as proxy for detrital minerogenic matter. For other elements, however, this is more ambiguous. Fe, for example, commonly is considered as proxy for redox conditions but can be also related to detrital matter fluxes. Another example is Ca, which occurs in dolomite (detrital proxy), endogenic calcite (productivity proxy) or aragonite (evaporation

proxy). The sources for individual elements element may change in time and thus vary within one record, thus preventing from establishing standard interpretation schemes valid for all lake sediments. Some limitations in interpreting high-resolution element scanner data can be reduced ba adding complementary data.

Such data at comparable resolution can be derived from micro-facies analyses that have been proven a powerful tool to understand seasonal deposition changes and interprete these in terms of climatic and environmental processes. This method provides very detailed optical information about sediment composition and depositional structures. There are, however, limitations in quantification and visualisation of these data except for varve and seasonal layer thickness. Therefore, a combination of micro-facies analyses with high resolution element scanning has a great potential to aid both, better visualisation and quantification of optical data and improve interpretation of element variations. Combining microscopic and scanner data sets at required precision has two main preconditions (1) precise depth control of both thin section samples and scanner profiles and (2) inhomogeneities within the sediment body should be avoided by realising both types of analyses on the same intersection plane of the sediment. Therefore, after splitting a sediment core one half should be first used for scanning and thereafter for thin section preparation. Alternatively, element scanning can be carried out on the same impregnated epoxy samples produced for thin sections using a vacuum scanning device instead of a core scanner. This guarantees a direct match of scanner data and microscope images. Compared to core scanning this method requires more lab time because the length of epoxy samples is limited to 10 cm, so that overlapping profiles have to measured and reassembled to composite profiles. Another problem is the occasional appearance of micro-cracks in the epoxy samples due to the preparation procedure which have to be removed from the data series. The advantage of epoxy samples is their durability which assures reproducibility compared to fresh cores which alter through oxidation and drying even when stored under best possible conditions at 4°C in a cold room.

In summary, modern scanning techniques substantially increased the resolution of major element data from sediment records but applying these techniques only for minimising analyses time does not meet the requirements. The great potential of this method can be much better exploited by complementation with micro-facies analyses which, however, requires additional efforts and time. The recompense is a very powerful tool to trace the dynamics particularly of abrupt climatic and environmental changes at unprecedented precision. Two examples from European maar lakes will be presented, (1) the transition into the Younger Dryas in the Meerfelder Maar record and (2) the demise of the last interglacial in the Monticchio record.

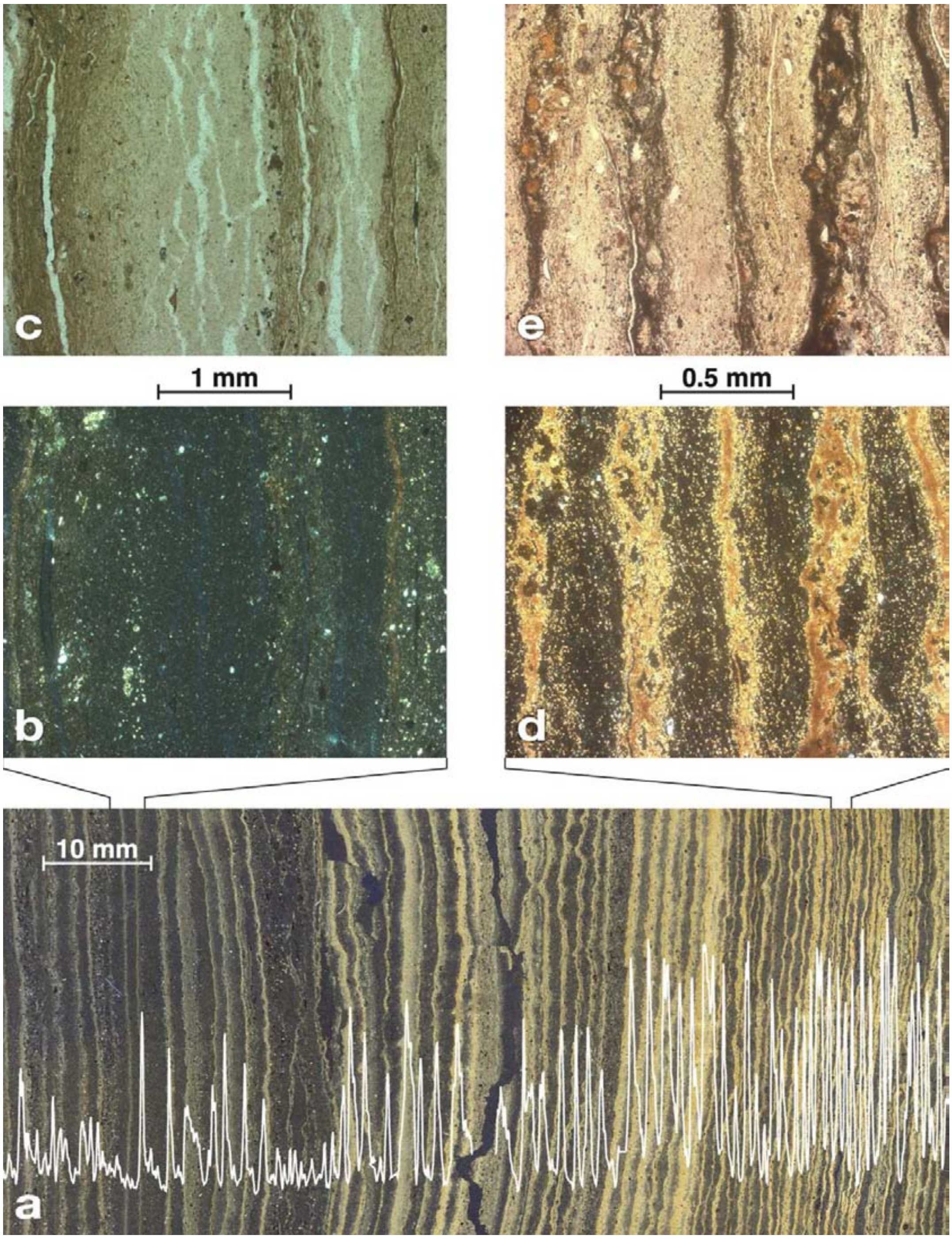

Fig. 1. Climatic-triggered changes in varve micro-facies at the Allerød/Younger Dryas transition 12,700 years ago (Brauer et al., 2008): (a) Thin section scan with polarised light; white curve shows Fe counts mainly reflecting siderite layers measured by element scanning. (b-c) microscopic images of Younger Dryas varves; (d-e) microscopic images of Allerød varves; (b, d) images with polarised light.

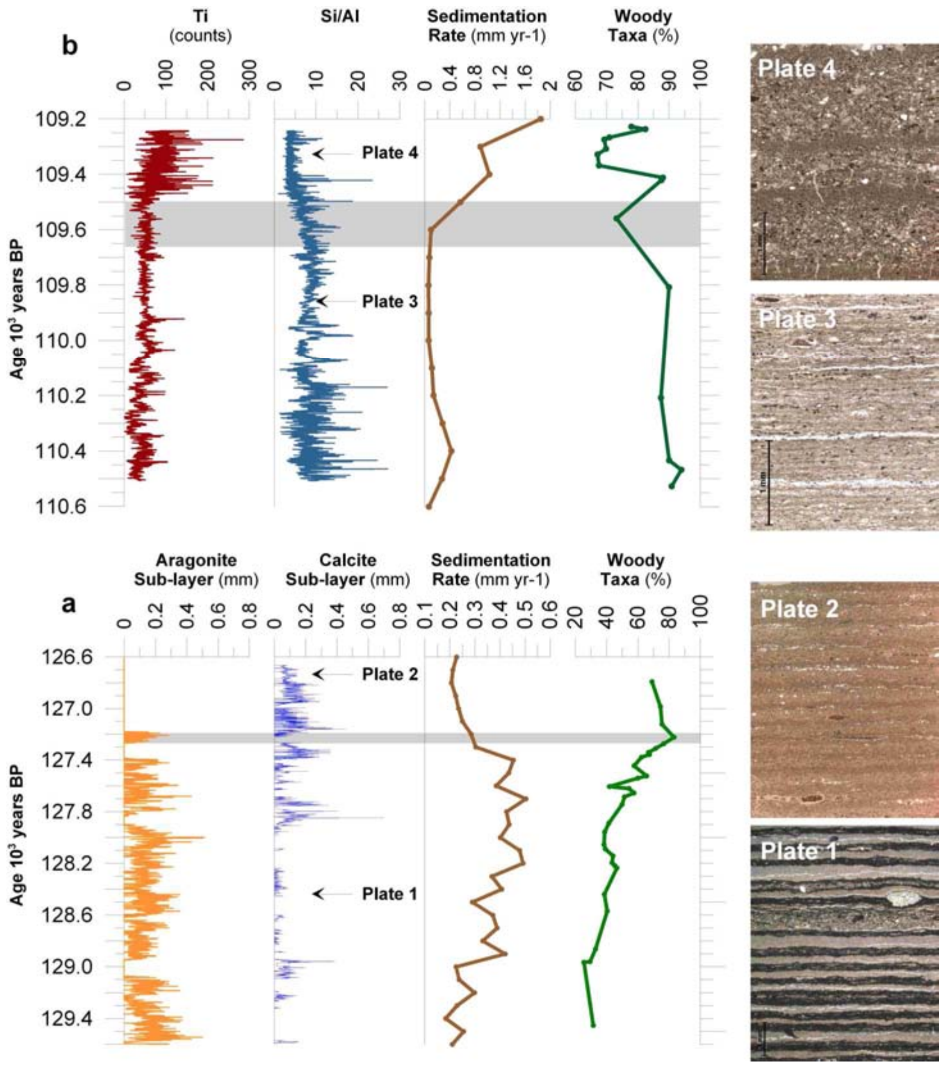

Fig. 2. Rapid onset and end of the last interglacial at Lago Grande di Monticchio (Brauer *et al.*, 2007). (a) Onset of the last interglacial) with gray bar marking the distinct transition in varve micro-facies. Inset plates show microscopic images of varves prior to (Plate 1) and following (Plate 2) the rapid onset of the last interglacial. Plate 1 (polarised light): regular light-greyish aragonite layers. Plate 2 (partly polarised light): thin bright layers of calcite included in some varves. (b) Termination of the last interglacial with gray bar indicating the transition in varve micro-facies. Inset plates show microscopic images of varves prior to (Plate 3) and following (Plate 4) the abrupt end of the last interglacial. Plate 3: regular very thin organic-diatomaceous varves. Plate 4: thick minerogenic-detrital varves.

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Refining a varve chronology using independent dating techniques: a Swedish case study

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Eleven years ago we carried out systematic reconnaissance to detect annually laminated (varved) lake sediments in the Swedish province of Värmland. Immediately after the last deglaciation the relatively low areas of Värmland formed part of the Yoldia Sea, which was succeeded by the Ancylus Lake and finally the large Ancient Lake Vänern. During these stages the areas below the highest coastline were covered by thick deposits consisting of clay and silt. The presence of this fine grained Quaternary cover is one of the prerequisites for varve formation in the many smaller lake basins that formed due to isostatic rebound and subsequent isolation from the Ancient Lake Vänern. Additional prerequisites include seasonal contrasts in climate and hypoxic conditions in the deepest parts of the basins, which restrict bioturbation and allow varves to be preserved.

Our search for suitable sites revealed three lake basins in which varves had formed continuously since their isolation approximately 9000 years ago (Fig. 1). These basins lie on a transect that spans the so-called *Limus Norrlandicus*, which is a vegetation and climate transition zone. The Boreo-Nemoral forest exists to the south of this zone and the South Boreal forest exists to the north of it.

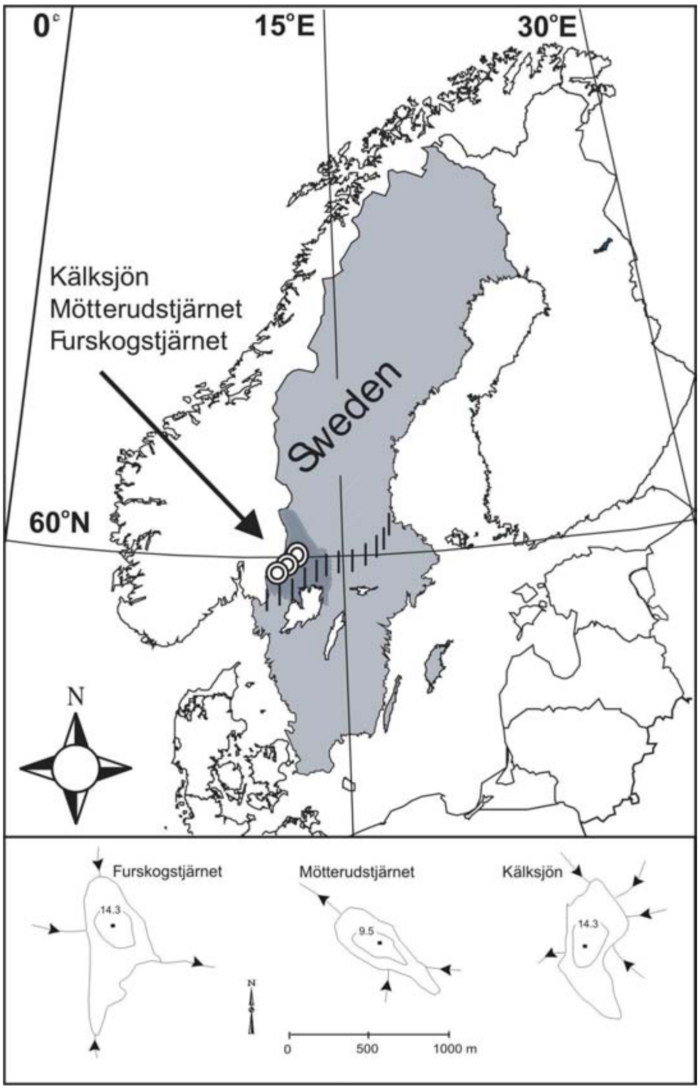

Fig. 1. Map showing the location of the study sites in the province of Värmland (dark shade). The dashed zone shows the *Limus Norrlandicus* vegetation and climate transition zone.

Human disturbance of the landscape over the past few hundred years often caused the deposition of a relatively thick clay layer (~10 cm thick) in which varves are difficult to indentify. Most of the errors in our visual varve counts are due to the problems associated with this layer and immediately below it, where the varves are thin with less distinct spring detrital layers.

In this presentation we focus on Lake Kälksjön, which is the site with the highest sediment accumulation rate (an average varve thickness of 0.7 mm since isolation). To test and correct the Kälksjön varve chronology we have applied independent methods; (i) historically dated lime layers and ^{137}Cs, (ii) palaeomagnetic secular variations (PSV), (iii) tephrochronology, (iv) atmospheric lead pollution isochrones and (v) two independent radiocarbon "wiggle matching" excercises.

A statistical comparison between the Kälksjön palaeomagnetic data and the PSV master curve for Fennoscandia (FENNOSTACK - Snowball et al., 2007) reveals a systematic offset in the ages of PSV features, with the Kälksjön features approximately 270 years younger than expected (Stanton et al., under revision). Similarly, two distinct troughs in $^{206}Pb/^{207}Pb$ that can be assigned to the known Greco-Roman and Mediaeval pollution peaks (Renberg et al., 2001) appear in Kälksjön varves that are approximately 250 years younger than expected. We distributed 270 additional years within the portion of the original varve chronology that lies between the AD 1963 bomb peak and the AD 1000 Mediaeval lead pollution peak because our palaeomagnetic data and lead data indicate that varves are missing between these levels. To obtain agreement with the PSV master curve we also removed 230 years (evenly distributed) from the portion of the original varve chronology older than 8000 cal. yr BP, when multiple interannual layers probably formed as a result of an uncolonised landscape that was particularly sensitive to individual precipitation events. These adjustments resulted in a corrected varve chronology, which extends to 9193 ± 186 cal. yrs BP.

As improved statistical methods for comparing radiocarbon ages to the IntCal calibration curve have become available (e.g. Bronk Ramsey et al., 2001; Bronk Ramsey, 2009) we have undertaken two independent wiggle matches of the Kälksjön sediments by using bulk sediments (terrestrial macrofossils are rare and cannot be found at the required stratigraphic levels). The first study concentrated on a series of nine samples (each containing 10 varves) spaced at 50-year increments across a distinct anomaly in the Kälksjön sediment sequence, which is characterised by low amounts of organic carbon. We adjusted the reservoir age applied to the ^{14}C ages to obtain the best wiggle match using Bayesian modelling, which anchored the 450 sequence of varves to the tree-ring derived radiocarbon calibration curve. The best agreement implies a reservoir age of 350 ^{14}C years at c. 8000 cal. yr BP. The GRIP and NorthGRIP ice-cores were also matched to the same absolute timescale by comparing ^{10}Be data and tree-ring $\Delta^{14}C$. By placing the ice-core and varve proxy climate data sets on the same absolute timescale we conclude that the abrupt onset of increased winter precipitation in west-central Sweden started at least 50 years after the onset of the "8.2 kyr cold event" as defined by oxygen isotope data from the Greenland ice cores (Snowball et al., in press).

In a second radiocarbon wiggle matching exercise we used a series of 11 bulk sediment measurements spaced at different levels in the original varve chronology. Their calibrated ages were significantly older than their equivalent ^{14}C ages corresponding to the original varve chronology (ranging between 170-960 ^{14}C years) and the corrected varve chronology (123-750 ^{14}C years). We applied the reservoir ages inferred from the corrected varve chronology and produced a Bayesian time-depth model using the P-sequence routine available in OxCal v4.1 (Fig. 2). We also applied the inferred reservoir ages according to the corrected varve chronology to a V-sequence, which produced excellent agreement indices. This model implies a bulk sediment reservoir age of 360 ^{14}C years at approximately 8000 cal. yr BP, which agrees well with the 350 ^{14}C years determined independently by Snowball et al. (in press). Thus, we have obtained estimates for a variable radiocarbon reservoir age during the Holocene, which appears to be largest (600-700 ^{14}C years) during the Holocene Thermal Maximum between 7500 and 4500 cal. yr BP (Snowball et al., 2004).

Our studies highlight the need to validate certain varve chronologies with complementary dating techniques because chronological uncertainties can be reduced. The detection of regional isochrones and the use of the globally applicable radiocarbon wiggle matching method increase the value of the vast number of proxy-environmental indicators that varved sediments contain.

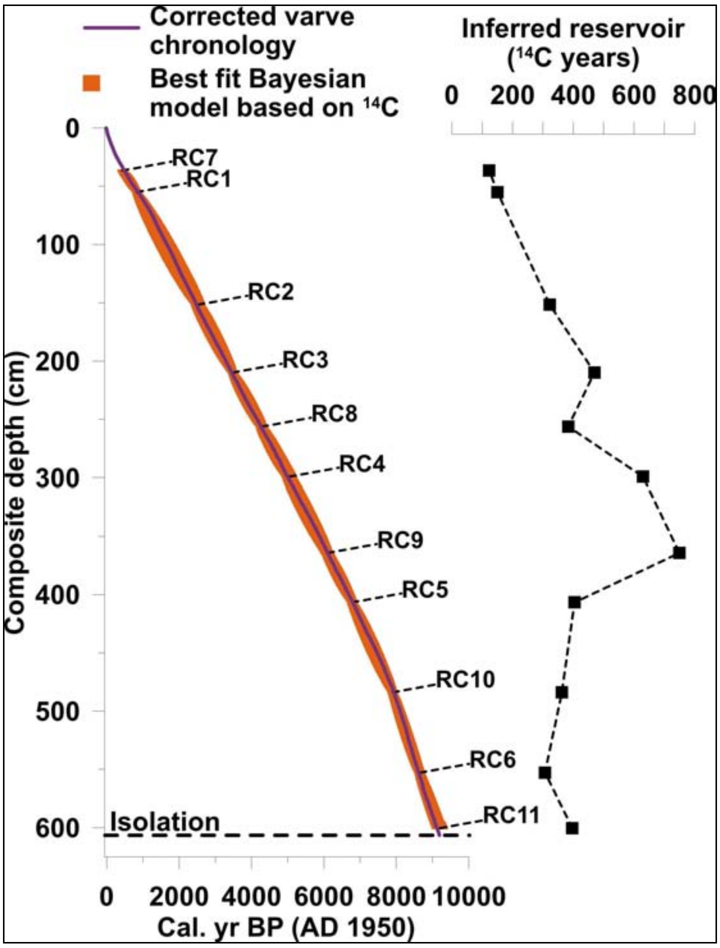

Fig. 2. The time depth curve to the left shows the corrected varve chronology (purple line), with radiocarbon dated levels indicated by RC's (1-11). The orange ribbon shows the 95.4% confidence range of calendar year ages produced by the P-sequence routine available in OxCal v4.1, which fits the reservoir age corrected ^{14}C ages to the tree-ring derived radiocarbon calibration curve. The inferred reservoir ages that were applied to produce this time-depth curve are shown to the right.

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How to find varves? - Examples from Poland

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Annually laminated lake sediments are formed as the result of seasonal variability of biological productivity in the lake and changes in supply of allochthonous components from the catchment area. General conditions favorable to the formation and preservation of varved sediments are already known, however a number of localized sites with continuous varved sequences is rather small. The good example is northern Poland with more than 7000 lakes of various morphometric features, hydrological regime and trophic status, and only one varved record covering the entire Holocene (Lake Gościąż) which had been investigated so far. Thus, systematic research was undertaken in order to find new varved records in northern Poland which can provide high-resolution environmental and climatic data for this part of Europe.

The pre-selection of potential sites was based on a hypothesis that morphometric features of a lake (size, shape, depth and morphology of lacustrine basin) are the most important parameters that determine whether varves have been formed and preserved. Previous research revealed that varved sediments were most common in relatively small-sized and deep lakes. Following this assumption, analysis of bathymetric charts was done for three areas with greatest density of lakes per 100 km^{-2} in Poland: the Land of Great Masurian Lakes, the Suwałki Lakeland and the Kashubian Lakeland. The assumed maximum depth of the targeted lakes exceeded 15 meters and maximum length was less than 1 km, with a few exceptions of larger lakes with isolated deep basins, which can contain varved sequences as well. From a total of several hundred bathymetric maps available for the investigated areas, 85 sites were selected according to the assumed morphometric criteria (table 1).

Table 1. Short statistics of the investigated lakes dataset

	Kashubian Lakeland (n=25)				Great Masurian Lakes (n=27)				Suwałki Lakeland (n=33)			
	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
altitude (m a.s.l.)	115.8	205.0	158.6	23.5	116.0	147.0	127.6	9.1	122.0	246.8	153.9	29.7
Surface area (ha)	10.2	51.2	20.0	9.9	10.6	291.6	68.1	64.9	10.4	228.2	48.3	43.8
max. length (km)	0.5	1.3	0.8	0.2	0.4	3.9	1.5	0.7	0.5	3.3	1.4	0.8
max. depth (m)	15.0	39.8	21.8	7.1	16.8	42.5	25.5	7.8	15.1	49.6	27.1	10.3
mean depth (m)	3.3	13.4	7.5	2.3	5.0	12.9	7.5	2.1	3.5	17.4	8.0	2.9

The field strategy was based on taking short gravity cores, which is logistically easy operation and not very time consuming. This enables surveying a large group of lakes, which would not be possible in the case of taking complete sequences of sediments. Systematic field work was carried out in the years 2005-2009. Coring was in each case conducted at the deepest point of the lake using gravity corer. Topmost 50-90 cm of sediment were collected and split lengthwise in the field. Uncovered surfaces were subjected to a more detailed analysis for the occurrence and quality of preservation of laminae. A detailed photographic documentation of the collected cores containing varved sediments was also made at laboratory conditions.

More than 30% of the surveyed group (28 lakes) contains sediments with distinct alternations of pale and dark laminae. Most of them were laminated throughout the recovered topmost section, whereas several sites display laminations only for the upper 20-30 cm. The highest efficiency was obtained in the Land of Great Masurian Lakes, where 15 out of the 27 checked lakes contained laminated sediments. In case of Suwałki Lakeland this was 9 out of 33 and in the Kashubian Lakeland 4 lakes out of the 25 checked contained laminated sediments.

Visual inspection at laboratory conditions and smear slides analysis suggest that in all cases biochemical varves were developed with pale spring/summer layers composed of autochthonous carbonates and dark fall/winter layers made of organic and minerogenic detritus. This was confirmed by microstratigraphic analysis of thin sections done for selected sediment records.

Varve thickness varies significantly between lakes (fig. 1), with average values about 2-3 mm. However, sediments of some lakes show very fine laminations (<1 mm) and in case of one site (Lake Żabińskie) varves were extremely thick, exceeding 10 mm. As 110 cm-long core from this lake contains 136±6 varves, it seems to be very promising record for calibration-in-time approach, i.e. transforming biogeochemical sediment proxies into quantitative climate variables through modeling based on statistical relationships between time series of sediment proxies and time series of meteorological observations.

From the obtained results it is clear that the undertaken approach was efficient in localizing new sites of varved sediment records and can be used in other postglacial areas.

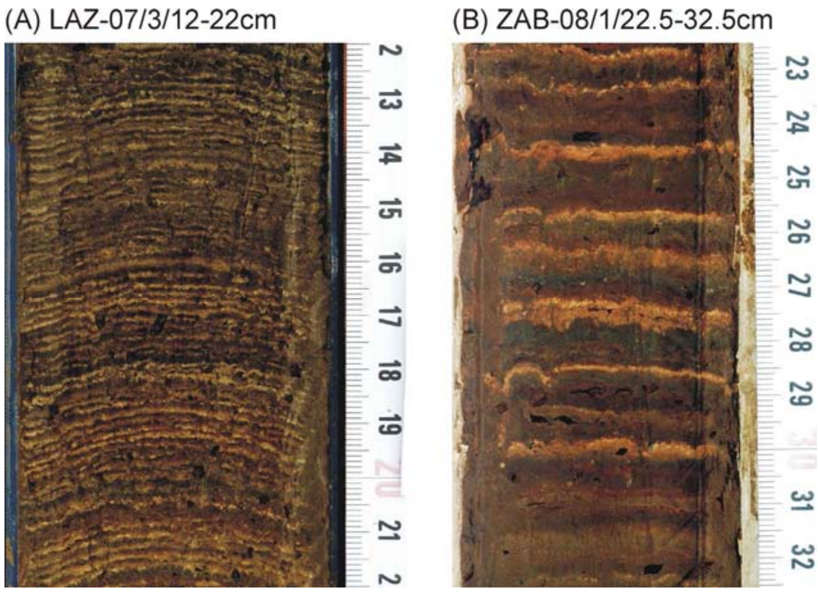

Fig. 1. Examples of varved sediment records from northern Poland. The presented sections show different varve thickness, i.e. 1-2 mm at Lake Łazduny (A) and 8-10 mm at Lake Żabińskie (B).

Acknowledgements

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ORAL AND POSTER PRESENTATIONS

Annually resolved environmental history of Lake Butrint (Albania) for the last 300 years

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Laminated sequences hold unique information on the rate of change of natural environments as well as the recurrence of events. They further provide key information to understand the contribution of the different forcing functions on the Earth system. Relative to the ocean, lakes respond very rapidly to environmental change providing a means to trace a high-resolution history of biotic/abiotic interactions, and these interactions are themselves dependent on changing climatic and hydrologic factors.

The origin of rhythmic laminations, however, is often a confronting problem between researchers since the combination of *"lakes and rhythms"* immediately invokes images of varved glacial clays. Yet biological productivity and seasonal changes in lake chemistry are also excellent triggers for lamina formation. Modern lakes in historically populated areas often contain this kind of laminated sequences that can be calibrated against historical information providing ideal records to develop multiproxy time series.

A sediment core from Lake Butrint in southwestern Albania contains a varved sequence covering the last ~300 years (Ariztegui et al., *in press*). It provides thus an exceptionally well-dated time series to study past climate-driven environmental changes, as well as anthropogenic perturbations along the coast of the Ionian Sea. These annually laminated sediments are composed of organic-rich carbonate couplets and detritus-dominated clay layers. Existing water column data indicate that the first are deposited during spring-to-fall, and reflect the chemistry of the lake, which, in turn, is sensitive to 1) the relative importance of marine versus freshwater inputs, 2) relative evaporation rates, and 3) the productivity cycle within the lake. The detrital laminae are deposited during winter, reflecting precipitation and runoff conditions during the wet season. The age of the most recent sediments was constrained using the ^{137}Cs gamma-counts showing maximum Cs activity at 15.5 cm that has been assigned to the climax of atmospheric nuclear bomb testing in 1963 (Appleby, 2001). A somewhat smaller activity peak at 5.5 cm can be assigned to the 1986 Chernobyl accident. A comparison of the ^{137}Cs-based chronology with information gained from the visual assessment of the laminae confirm that the laminae couplets (occasionally triplets) are of annual origin, signifying that the age model can be extrapolated from the upper part of the core through varve counting. A computer-assisted image analysis provided the thickness of each individual lamina and supported the established varve-based age model. Furthermore, these individual laminae as well as the thick homogeneous intervals are also clearly defined using ultra high-resolution µX-ray fluorescence. Thus, once the homogeneous intervals were virtually "removed" from the record, the lamination provides a continuous, robust age model covering the last 259 years. Further support of the established age model originates from a series of well-defined homogeneous layers throughout the basin that are interpreted as earthquake-induced mass wasting events (Anselmetti et al., in prep.). The varve-based ages of these event layers fit well with historically reported earthquakes (1794, 1811, 1872, 1917), reaffirming the validity of the age model and the annual resolution of this sediment core.

A 2-3‰ stable carbon isotope ratio shift in both bulk organics and authigenic carbonates has been attributed to increasing eutrophication towards the end of the 20th century, and validated by historical and instrumental data. An increase in the $\delta^{18}O$ of authigenic carbonates by more than 8 ‰ indicates the progressive salinization of the lake, which can primarily be attributed to man-made perturbations that reduced the freshwater input to the lake and/or enhanced the exchange with seawater from the nearby Ionian Sea. A recent increase in the relative evaporation versus precipitation rates may have additionally contributed to the observed ^{18}O enrichment in the Lake Butrint carbonates. The interdecadal cyclicity in the thickness of the detrital laminae seems to be at least partially controlled by NAO and/or ENSO-like phenomena that modulate precipitation patterns in the eastern Mediterranean. Thus, this study demonstrates the potential of combining microstratigraphic and stable isotopic tools to disentangle anthropogenic and natural environmental changes in Lake Butrint, validated by historical records. It further offers new insights into the causal processes behind varve formation in a coastal lacustrine milieu, providing valuable information concerning tectonic, climate and human impact in the catchment. Further retrieving of long cores in Lake Butrint will furnish a potentially varved section of environmental change punctuated by historic anthropogenic impact, covering the late Holocene period on a decadal and even annual scale. In particular the construction of a few-km long channel, already initiated during the ancient Greeks and maintained during Roman and later periods (Hounslow and Chepstow-Lusty, 2004), connected the antique City of Butrinti and the lake to the Mediterranean Sea and must have significantly influenced the depositional processes in the lake.

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Extending an intermittently varved record of abrupt and millennial-scale climate and ocean change through the Pleistocene in Santa Barbara Basin, California USA

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Santa Barbara Basin provides one of the highest-resolution paleoclimate records of the latest Quaternary recovered from the world's oceans. Over much of the basin, sediment accumulated rapidly (70-130 cm/kyr) and with minimal disturbance by bioturbation due to persistent suboxic to anoxic bottom-water and sediment conditions in a silled, marginal setting. These conditions are sufficient to obtain data at sub-decadal sample intervals, permitting analysis of the rate of change and climate/ocean phasing at human time scales.

As part of an integrated seismic acquisition and piston coring campaign in 2005, we acquired thirty-two 2-11 m long piston cores that provide ~2-9 kyr high-resolution windows into past climate behavior. High-frequency climatic oscillation is recorded in 8 of these cores by variations in massive to varved or laminated sedimentary fabric, oxygen and carbon isotopes, % total organic carbon, % carbonate, % biogenic silica, abundance of redox and productivity sensitive elements, or planktonic foraminiferal assemblages. These data contain evidence for abrupt ocean/climate change and millennial-scale oscillations distributed through the past ~735 kyr. In general, warm interstadials are represented by varved, organic-rich sediment deposited under highly productive surface and dysoxic bottom waters. During this interval, rapid decadal-scale climatic/oceanographic transitions occur within different climatic base states, such as, MIS 3-like intermediate conditions, deglacial transitions, and glacial episodes. To date, no Dansgaard-Oeschger-like interstadials have been found to occur during otherwise fully interglacial conditions. These results indicate that the California margin has been sensitive to climatic forcing and experienced rapid climatic fluctuations since at least the Mid-Pleistocene Transition when predominance of 41-kyr climate cycles shifted to a 100-kyr climate cycle regime.

We obtained these cores by identification of distinctive seismic stratigraphic horizons related to climatic and sea-level fluctuations existing multichannel seismic (MCS) data and in high-resolution MCS and towed chirp data acquired during 2005 and 2008 research cruises. These horizons were mapped in 3D to seafloor outcrop, where they are accessible to piston coring. Ages of horizons and cores were determined by interpolation between ODP Site 893, a previously published 1-Ma horizon, dated tephra, biostratigraphic markers, and climate states and transitions identified from oxygen isotope records from the recovered cores. We are using this data to support a proposal for continuous coring by the Integrated Ocean Drilling Program to at least 1.2 Ma to cross the Mid-Pleistocene Transition.

AMS ^{14}C dates and the reworking of terrestrial macrofossils as deduced from a varve chronology

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Terrestrial macrofossils dated by the AMS radiocarbon method are generally considered to provide accurate ages of deposition for the sediment horizon in which they are encountered. This is especially true when compared to bulk sediment samples which often contain fine-grained, reworked organic matter that skews dating results to values that are too old. However, terrestrial macrofossils may also be reworked, but few studies have examined this issue systematically, and many simply make the assumption that it has not occurred. Varved sedimentary records provide an opportunity to investigate this issue. Here we compare the results of 15 AMS ^{14}C analyses on seemingly ideal terrestrial macrofossils against a well-controlled varve chronology for the last millennium. We demonstrate that 60% of the macrofossils were reworked, and provided age results that are ~130-230 years older than the age of the enclosing sediment. The results also show that delicate terrestrial macrofossils such as leaves, needles, and seeds do not necessarily provide more accurate dates than woody samples as has been suggested elsewhere. Despite different storage methods before submission for dating (i.e. dry storage in a desiccator or wet storage in a refrigerated environment for extended periods of time), macrofossil samples from the same stratigraphic horizon returned identical ^{14}C age results. Of two leaf beds that were dated, one returned an accurate age result suggesting it was from primary deposition following vegetation stripping due to a hurricane event, and a second returned results that were too old suggesting that it resulted from reworking. We do not suggest that results from this well-controlled example are necessarily applicable to all systems. But we believe it may provide a explanation for discrepancies seen in other records which use a small number of ^{14}C ages for chronological control even if the ^{14}C samples that were used were seemingly ideal terrestrial macrofossils.

Climate fluctuations in Western Mediterranean during the last 1.5 ka: the varved record of Lake Montcortès (NE Spain)

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Permanent anoxic hypolimnetic conditions in the meromictic Lake Montcortès (Pre-Pyrenean Range, NE Spain) have favored the preservation of finely annually laminated sediments in central-distal areas of the lake basin. The sedimentary sequence of karstic Lake Montcortès constitutes the first annually laminated multi-proxy record from northern Spain spanning the last 3500 cal yrs BP. A detailed sedimentological study of the upper sections of Kullenberg cores retrieved from the deepest part of Lake Montcortès provides detailed reconstructions of the paleohydrological variability, climate fluctuations and human settlement phases in the Northern Iberian Peninsula during the last 1.5 ka.

Three different microfacies (MF) can be distinguished in the 528 cm studied interval from Lake Montcortès sedimentary sequence (Fig 1); varve MF 1 and 2 and graded coarse detrital layers MF 3.

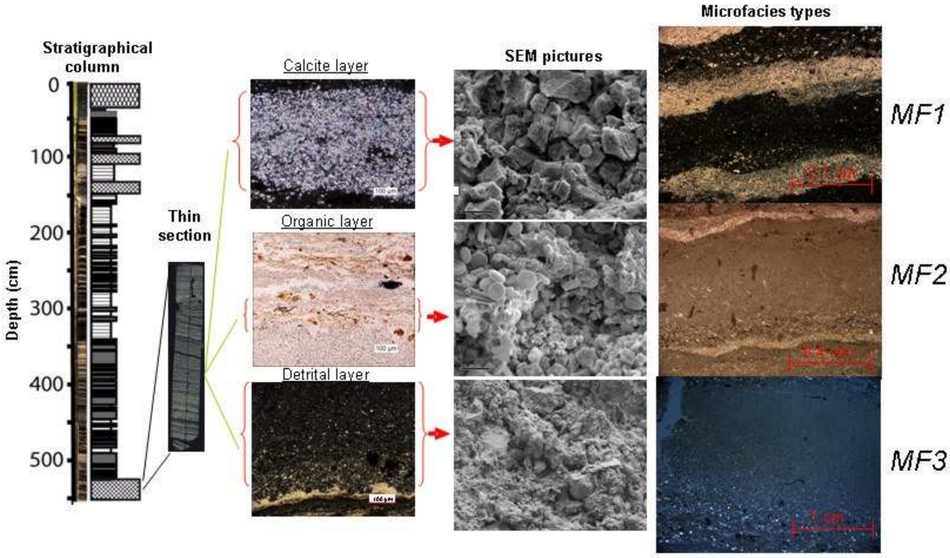

Fig.1.

Microfacies 1 are biogenic varves composed of a couplet of white (calcite) and brownish (organic) layers with no discrete detrital layers. The calcite layer is the result of endogenic precipitation in the epilimnion during spring/summer while the organic-rich layer represents deposition in Lake Montcortès after the period of calcite precipitation, which likely includes summer and winter. Calcite layers display different sublayering types depending on the texture, reflecting different settling velocities. Microfacies 2 is characterized by the presence of an additional clastic layer besides the calcite and organic laminae. Microfacies MF 3 occurs as 0.8 mm to 12 cm thick grey detrital layers characterized by a normal grading and abrupt lower boundaries. They show a discrete coarser basal sublayer. These layers would be deposited during shortlived events (days to weeks) in which the sediment accumulated in the catchment would be transported into the lake by ephemeral streams and run – off. The coarse basal layer and the erosional surface may be the result of underflow current processes.

A robust age model for the upper 1500 yrs BP has been established through varve counting on petrographic thin sections combined with radiocarbon and ^{210}Pb dating. The good correlation of the varve counting with the ^{14}C AMS dates underlines the annual nature of the lamination. Comparison of the detrital layer time series with historical data and climate reveals an increase in allochtonous detrital input into the lake related to higher anthropic pressure over the catchment and to arid periods. The small catchment of Lake Montcortès increases the importance of human activities as a trigger factor for the generation of the detrital layers. Thus, an abrupt increase of the sedimentation rate is parallel to the human occupation of the area after the VI century and also to periods of higher occupation of the watershed (Low Medieval times, late 19th century). On the other hand, a direct relation between increased clastic input and more arid conditions have also been observed.

The interpretation of the rapid oscillations observed in the thickness of calcite layers, although complex seems to respond to two factors; i) Changes in the nutrient supply to the lake and iii) increasing summer temperatures. During the Medieval Climate Anomaly (MCA) calcite layer thickness increased as both factors increased during this period. Higher clastic delivery to the lake during this interval correlates with an increase of farming activities in the area, conducive to increase nutrient supply to the lake. An abrupt decrease of the clastic input in 1330 AD coincides with a significant depopulation of the Pyrenees and a cooling related to the beginning of the Little Ice Age (LIA). During the LIA, the observed calcite thickness decrease may respond to cooler conditions. Furthermore, internal sublayering of calcite layer may indicate delayed warming during spring. Fluctuating but lower clastic input during this period is coherent with a lower land use in the catchment. The end of the LIA coincides with an abrupt increase of the sediment input to the lake between 1830-1874, which is also coincident with the peak in population in the Pyrenean Mountains during the late 19th and early 20th centuries. The 20th century displays thicker calcite laminae possibly related to warming temperatures and a decrease in clastic input due to an abandonment of the land (decrease in farming activities), particularly since the 1950s.

The sedimentary record of Lake Montcortès demonstrate a clear hydrological impact of recent climate fluctuations (MCA, LIA and 20th century), in agreement with other nearby records and a significant impact of farming activities in the area. The interplay between climate and human factors affecting sedimentation in Lake Montcortès is complicated and further research will address this issue.

Geochemical indicators of climate change in lacustrine varves Central Asia

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Purpose: search geochemical indicators of climate change in lacustrine sediments; finding of the quantitative relationship between the content of trace elements in sediments and instrumental meteorological observations (temperature, precipitation); reconstruction of climate change in Central Asia over the last millennium with an annual resolution.

Objects. Investigate a number of bottom sediments of lakes in Central Asia: Kucherla (Gorny Altai), Shira (Khakassia), Telmen (Mongolia), see Fig. 1 and Table 1.

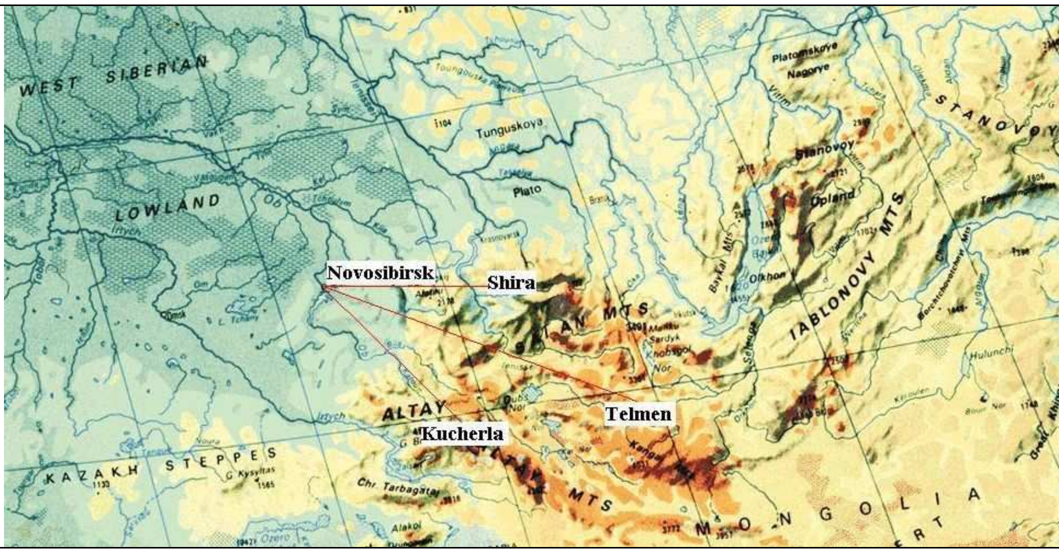

Fig. 1 Localization of lakes.

Table 1. Objects of research

Object	Coordinates	asl, m	Dimensions, km	Max depth, m	Depth of the sampling, m	The length of core, m	Varvy thickness, mm
Lake Kucherla	49°52’N 86°24’E	1690	4,7x0,8	55	40	0.2	2.3
Lake Shira	54°30’N 90°10’E	352	9,5x5,3	22	20	1.4	1.3
Lake Telmen	48°49’N 97°18’E	1790	27x12	25	22	1.4	0.75

Sample preparation. Cores were cut in the laboratory. Were prepared slabs size 170x30x20 mm. Samples were dried in the freezer and impregnated with epoxy resin. For the analysis were prepared the plate thickness of 2 mm.
Analysis. Geochemical studies have been made using a scanning X-ray fluorescence analysis using synchrotron radiation. Measurements were carried out in the Siberian Synchrotron Radiation Center at station X-ray microanalysis [Darin et all, 2005]. For scanning the excitation energy on 18 and 24 keV were used, scanning step 100 and 200 microns. Table 2 presents a set of analyzed elements and limits of detection.

Table 2. Set of analyzed elements and limits of detection.

Element	LD (ppm)	Element	LD (ppm)	Element	LD (ppm)
K	500	Cu	2	Y	1
Ca	300	Zn	2	Zr	1
Ti	150	Ga	1	Nb	0.5
V	70	As	1	Mo	0.5
Cr	30	Se	1	Pb	5
Mn	15	Br	0.5	Th	2
Fe	10	Rb	0.5	U	2
Ni	5	Sr	0.5		

Profilograms were combined with photographs of the samples and converted into time series data on the age model (Fig. 2).

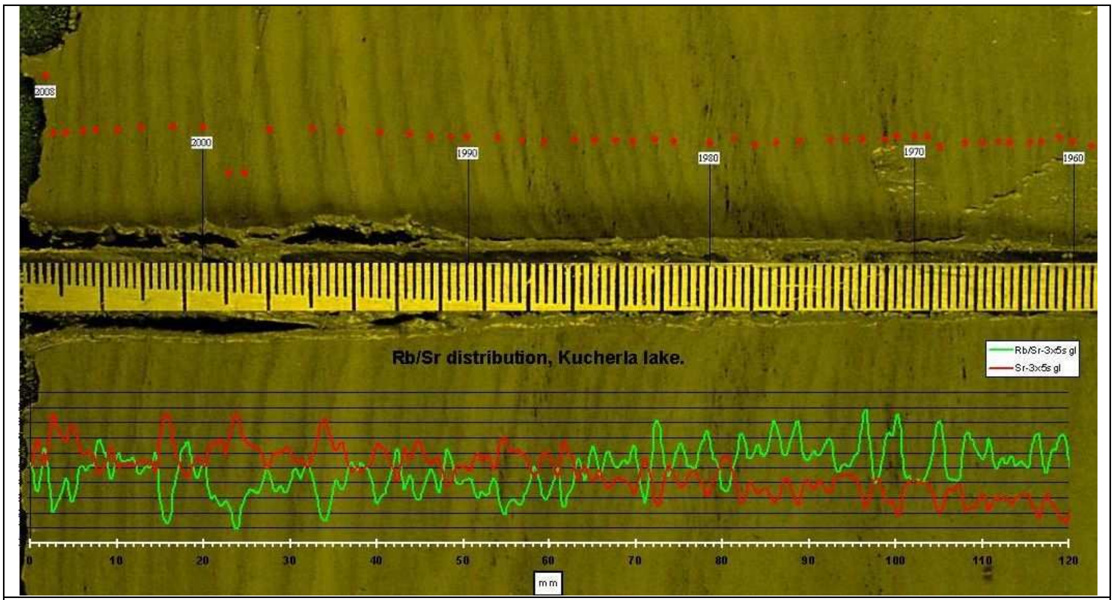

Fig. 2. Variations Sr and Rb / Sr ratio along the core Kucherla lake.

The age model is based on visual allocated layers (varves) and geochemical indicators. (Fig. 3 Telmen - geochemistry and visual layers). Table 3 presents the results for the upper 30 mm core samples of Lake Telmen.

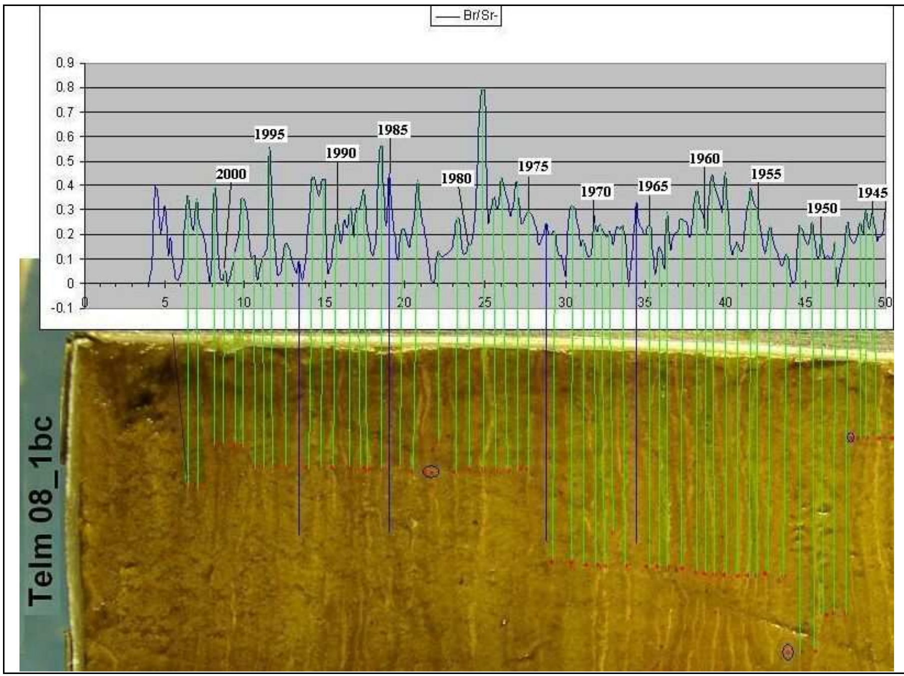

Fig. 3. Annual layers allocated across the core Thelmen lake on visual and geochemical (Br/Sr ratio) characteristics.

Table 3. The results for the upper 30 mm core samples of Lake Telmen.

Depth, mm	Thickness, mm	Year	Depth, mm	Thickness, mm	Year	Depth, mm	Thickness, mm	Year
8.7	0.6	2000	15.7	0.8	1990	24.0	0.8	1980
9.4	0.6	1999	16.6	0.9	1989	24.9	0.8	1979
9.9	0.5	1998	17.1	0.5	1988	25.6	0.8	1978
10.6	0.7	1997	17.5	0.4	1987	26.2	0.5	1977
11.1	0.5	1996	18.5	1.0	1986	27.1	0.9	1976
11.6	0.5	1995	19.0	0.5	1985	27.7	0.7	1975
12.6	1.0	1994	19.8	0.8	1984	28.8	1.1	1974
13.4	0.8	1993	20.7	0.9	1983	29.4	0.5	1973
14.2	0.8	1992	22.1	1.4	1982	30.5	1.1	1972
14.8	0.6	1991	23.3	1.2	1981	31.2	0.7	1971

Time series are created, taking into account the thickness of annual layers and contain information about the geochemical indicators and physical-chemical properties of sediment.

Comparison with weather data produced by instrumental meteorological data for the region of study. Length of series meteorological observations from 130 to 55 years. Choosing geochemical indicators of climate change produced by a significant correlation coefficient.

Transfer function to create by method of multiple regression. Reconstruction is performed at the depth of testing (fig.4).

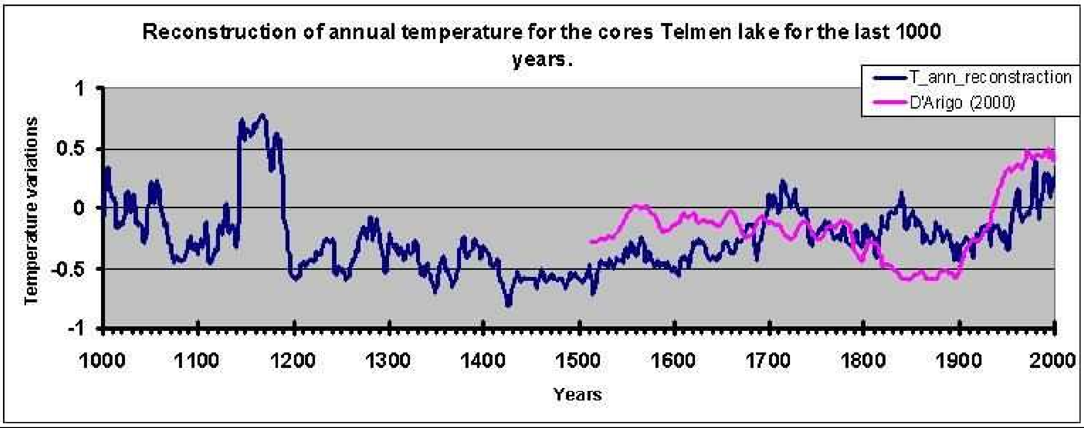

Fig. 4. Reconstruction of annual temperature by the cores Telmen lake for the last 1000 years (blue line), dendrochronological data, D'Arigo et all, 2000. (red line)

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The Potential for Constructing Varve Chronologies and Reconstructing Ice Dynamics using MIS Stage 2 Ice-Contact Lake Deposits in Ireland and Great Britain

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Integrated varve chronologies covering the last deglaciation (Marine Oxygen Isotope Stage 2 (MIS 2)) using sediments from former ice-contact proglacial lakes have been in existence since the early 20th century, the best known being the Scandinavian and New England chronologies. Some of these integrated chronologies have been revised more recently and have been used to provide high-resolution dating of ice recession across large areas, and to correlate the pattern of recession and associated dynamics with other records, particularly ice core and marine records (e.g. Boulton *et al.* 2001). However, new integrated chronologies are not being developed, despite the potential existence of suitable sites in Europe and N. America. Single-site chronologies from ice-contact lakes dating from MIS Stage 2 are also rare, although single site chronologies which provide records of meltwater/sediment inputs and ice dynamics do exist for the Holocene.

This paper considers the potential for establishing two varve chronologies for the British-Irish Ice Sheet (BIIS) during MIS 2, one in Ireland and one in NW England, presents initial results from both sites and considers the sort of information they may supply.

In Ireland glaciolacustrine sediments are known to occur under most raised bogs, indicating that proglacial lakes were widespread across the Irish Midlands during glacial recession. In order to assess the potential of using these deposits to establish an integrated chronology, a series of cores were retrieved from one lake, Paleolake Riada, central Ireland. This lake, which existed at some point between 20-14.5kyr BP, covered much of the central midlands and is associated with formation of the large esker system in this area. It has been suggested that a major readvance possibly associated with Heinrich Event 1 occurred along the NW margin of the lake during ice recession; however, the timescale between recession and readvance is disputed (e.g. Clark and Meehan 2001, Delaney 2002, McCabe 2008).

Boreholes retrieved from north of an area of hummocky moraine interpreted as the readvance margin and within the area thought to have been covered by the readvance, contain up to 3m of inorganic, laminated silt and clay underlying Holocene peats and lacustrine carbonate deposits. The basal 1.5m of the sequence is rhythmically laminated, with internally laminated coarser, pale silts alternating with thin, dark clay laminae (Delaney 2007). Microscale logging and S.E.M. analyses of grain fabric and surface textures show that the characteristics of the clay laminae are consistent with winter layer deposition, while silt layers were deposited as both single grain and flocculated aggregates from a combination of density current and suspension deposition and contain much wind-blown material, consistent with summer deposition. The varves could be correlated over a distance of 500m parallel to the ice margin, using varve thickness or internal characteristics of individual rhythmites. Errors caused by the presence of false varves are easily identified across cores. Varve thickness reduces upwards rapidly through the sequence. Varved sediments are overlain conformably by a 1.2m thick bed of laminated clayey silts without distinct clay laminae, which are overturned in places. These sediments are interpreted as multiple underflow deposits and are thought to have formed during lake drainage events which occurred during ice recession.

Boreholes beyond the suggested readvance margin are more variable. Borehole records suggest that glaciolacustrine sediments thicken eastwards towards the River Shannon. Boreholes taken immediately SE of the readvance moraine contain thin sequences of pre-Holocene sediments only and bottom on diamictons. Glaciolacustrine sediments consist of basal rhythmically laminated silt and clay overlain by more diffusely laminated sandy silts. However, boreholes closer to the Shannon were not bottomed (max depth 13m) and contain at least 5m of glaciolacustrine sediments. In the deepest boreholes the lowest sediments retrieved were rhythmically laminated silts and clays in which thick, winter layers contained multiple coarse silt laminae, interpreted as a evidence of multiple winter melt events and indicating possible climatic controls on varve characteristics. Overlying laminated sediments are less clearly rhythmically laminated and contain reactivation surfaces, shear planes, faults and downward-injected microscopic dykes. The unit is overlain by a sequence of highly deformed silt and clay laminae with occasional thin diamictons. Sediments contain evidence of folding, soft sediment deformation, faulting and possible thrust planes. This deformed unit is thought to have formed during ice readvance, immediately in front of the ice margin. It is overlain by a unit of sandy, diffusely and rhythmically laminated sandy silts and clays; it is not clear if these sediments are varved and they cannot be correlated with the nearest varved sequences. The lateral variation in stratigraphy, the disruption of possible varved sediments and the evidence for a likely readvance in this area indicate that construction of an integrated chronology for the Irish Ice Sheet would not be straightforward, and would require a considerable number of cores beyond those used to construct the chronology. However, these sediments also have the potential to constrain timescales for recession and readvance and cast considerable light on ice dynamics in this area.

The second site considered here is in the Rossendale Plateau, southern Pennines, England. Recent work by Crofts (2005) has confirmed that the advance of ice from the Irish Sea basin and NW England at Glacial Maximum (c. 21kyr BP in this area) dammed a series of lakes between the Manchester and Cheshire Plains and the southern end of the Pennines. In the Rossendale Plateau, ice to the north and south is thought to have ponded a lateral ice-dammed lake along the narrow Irwell valley. Borehole records indicate that laminated silt and clay is extensive in this area. New cores retrieved from the upper part of the sequence indicate that these sediments are rhythmically laminated and likely to be varved. The potential to establish a chronology spanning the Glacial Maximum is discussed.

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Proposal for an online varve image library - removing misconceptions about varves

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Annually laminated (varved) sediment sequences are regarded as one of the most important paleoenvironmental archives because they offer (1) accurate „internal" age information in calendar years combined with (2) exceptional high temporal resolution down to a subannual timescale. Although the paleoscientific community is aware of the advantages provided by annually laminated sediments in both marine and lacustrine environments, there is still some confusion or even misconception about what can be regarded as a truly varved sediment sequence. As experienced by the authors, finely laminated minerogenic sediments, for example, have been considered as varved *a priori* - although they were not, as later evidenced by the monitoring of recent sedimentation processes. Given the importance of annual layers, the null hypothesis (default assumption) must be that a laminated sequence is not annually laminated. This hypothesis has to be falsified using e.g. independent age controls such as short-lived isotopes (^{137}Cs and ^{210}Pb) or sediment trap studies.

This misconception about varved vs. finely laminated sediments might partially originate from the history of the expression "varve". The term was first used by the Swedish geologist De Geer (1912) to describe annually laminated, proglacial (i.e. minerogenic) lake sediments. Later on, the term "varve" was extended to several other sediment types such as biogenic or chemically precipitated sediments with a preserved annual succession of seasonal sublaminae. This large diversity of "varved" sediments may contribute to the conception that all finely laminated sediment sequences must be varved. A website specifically dedicated to varved sediments could assist researchers "outside of the varve community" to judge the potential of varved sequences in their sediment cores as well as to summarize and distribute the existing information about varves.

During this 1st Varve Workshop we propose to establish a website showing images of various types of varved and non-varved sediments (macroscopic and microscopic pictures) based on the contributions of the "varve community". We intend to structure this website into (1) macrostratigraphy (e.g. varved sediments, non-varved sediments), (2) microstratigraphy (e.g. regular seasonal sublaminations, event layers like tephra layers, slumps, turbidites or homogenites, and other sedimentary features), (3) sediment components (biological, minerogenic, artefacts), (4) so far unknown sediment features. Each image should be accompanied by a short description containing information about the image, study site, researcher, photographic method and possible publication. The proposed website differs from other websites describing lacustrine sediment components (e.g. the Smear Slide Page at LCR, http://lrc.geo.umn.edu/smears/smsl.html) as it shows these components in thin sections of impregnated sediments. Thus, larger components such as ostracods are visible as cross-sections only. The first draft of this website will shortly be accessible at http://www.geopolar.uni-bremen.de/varves.

Investigating the presence of varved lake sediments in the Boreal Québec-Labrador region

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The ARCHIVES multidisciplinary project has for objectives to reconstruct the hydroclimatic parameters used for modeling hydroelectric water supply and production, to analyse the spatio-temporal variability of the boreal climate of Québec over the past millennium and to compare climatic reconstructions with the outputs of the CRCM and the ARPEGE climate models. Originally centered on the La Grande rivière Hydroelectric Complex, the study area covers now nearly 600 000 km^2 or most of the boreal domain of the Québec-Labrador region.

In order to complete the intensive dendrochronologic investigations (growth patterns, density and stable isotopes in wood cellulose) made on modern and subfossils trees all over the study area, we initiated, in the summer of 2009, a search for lakes that would be suitable for high resolution paleoclimatic analyses: clastic or clastic-organic varved lakes. Of the 50 lakes visited, we cored the surface sediments of 22 and found so far the presence of laminations, potentially varves, in one of them. In this presentation we discuss our research strategy and our preliminary results, which includes X-ray fluorescence spectrometry, X-radiography and computed tomography. We also present a lake in which varve initiation that was recently triggered by land use changes and deforestation. These results show that clastic and clastic-organic laminations, which can potentially reveal critical information about past river discharge variability, can be found in the Canadian Boreal region.

An integrated computer system to acquire, process, measure and store images of laminated sediments

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Paleoenvironmental reconstructions from long (>500 years) varved sequences using image analysis techniques have a strong potential to increase our knowledge of climate variability. However, the detailed analysis of such sequences proved to be a tedious task. In this poster, we present a new software that integrates a series of tasks involved in the study of varved sediments. The first task is the semi- automated acquisition of flat bed scans of thin-sections in both plain and crossed-polarized light. The software aligns the two views in order to facilitate the identification of sedimentary facies. The second task is devoted to the marking of boundaries between laminations. The interface displays simultaneously low and high magnification images of the sedimentary facies in order to make the identification of the boundaries easier for the operator. Counts made on individual thin-section can be assembled into a composite sequence in order to build varves counts over long varved sequences. Multiple counts by multiple operators can be stored and compared. The third task is devoted to image analysis of images of thin-sections taken at the Scanning Electron Microscope (SEM). First, the user manually chose the Region of Interest (ROI) on the flat bed scan image of the thin-sections. Then, the system drives the SEM to automatically acquire backscattered images at the exact location of the ROI. A special sample holder is designed to accommodate 8 thin-sections. Finally, the acquired backscattered grey-level images can be processed using image analysis algorithms in order to transform them into black and white images, where white pixels represent the sedimentary matrix and black pixels represent the grains. From these images, textural (grain-size) and structural (orientation) measurements can be extracted.

All images (e.g., flat bed-scans of thin-sections, grey-level BSE images), data (e.g., varve thickness measurements) and metadata (e.g., algorithm used for image analysis) are stored in a customized database. It is therefore possible to examine and verify the entire processing chain that was used to produce any and all results. This software facilitates the analysis of varved sediments and intends to make long varved sequences accessible for high-resolution investigation.

Varve chronology of lake Soppensee (CH) compared with the age-depth model based on the high resolution ^{14}C chronology

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The quest for high-resolution records of past climate changes that are comparable to ice cores underlines the importance of records with laminated sediments. Despite the impressive number of sites discovered around the world that are known to have laminated or even annually laminated sediments, most archives are not laminated but are equally vital to past climate research. For these records, reliable chronologies are needed and are usually based on ^{14}C ages of deposits selected at various depths. However, it is often argued that chronologies are impaired by the complicated nature of the ^{14}C time scale and calibration of ^{14}C ages.

In this study, we present the potential of radiocarbon dating to construct high-resolution chronologies of sedimentary records that are comparable to counting annual laminations i.e. varves. To demonstrate this, we applied a *P_Sequence* model that is implemented in OxCal 4.1 (Bronk Ramsey 2008) and the updated INTCAL09 data set (Reimer et. al 2009) to obtain calendar chronology based on ^{14}C ages of macrofossils from Soppensee sediments and compared with the varve chronology of the sediment core that was sampled for ^{14}C dating (Hajdas 1993; Hajdas et al. 1993). The resulting calendar chronology is compared with the varve chronology that was built for this record in the previous study; there is a very good agreement between the two approaches. This illustrates ability of high-resolution radiocarbon dating for construction of reliable, high-resolution calendar time scale for sedimentary records. Based on the age-depth model of this study the Vasset Killian Tephra found in sediment of Soppensee has calendar age of 9291 - 9412 cal BP and the Lachersee Tephra is dated at 12735 - 12871 cal BP. Moreover such age-depth model provides timing for climatic and environmental changes observed in poorly laminated or not laminated sections of the Soppensee sediment i.e. the Late Glacial and the late Holocene.

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Different aquatic ecosystem response to the 8.2 ka cooling event: two diatom-based high-resolution case studies of varved sediments in southern Estonia and central southern Finland

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Annually laminated (varved) lake sediments possess natural archives of calendar year chronology that can deliver changes in past climate and lake environment at seasonal to decadal resolution. Many sedimentary records, especially from the North Atlantic region, provide evidence by various biological and physical proxies of a short cold event at 8200 cal yr BP that represents a unique climatic feature within the last 10 000 years.

A synthesis of negative and positive evidence from pollen-based temperature reconstructions in northern Europe indicates a spatial pattern in the 8200 cal yr BP event, with more distinct evidence of the cooling in the southern regions (Baltic countries and in southern Fennoscandia) than in the central and northernmost parts of Fennoscandia (Seppä et al. 2007). Generally consistent cooling was identified in Lake Rõuge Tõugjärv (57º44`30``N; 26º54`20``E) pollen record in southern Estonia by Veski et al. (2004). The cooling began abruptly at about 8400 cal yr BP, culminated at 8250 to 8150 cal yr BP, when the level for quantitative annual mean temperature (T_{ann}, °C) reconstruction was 0.5–1.0 °C below the modern values for the region and 2.0 °C colder than prior to the cooling, and ended with a sudden temperature rise at about 8080 cal yr BP. In contrast, the pollen-based T_{ann} reconstructions from a much northward site Lake Nautajärvi from central Finland (61º48`N; 24º41`E) show no evidence of cooling at 8300–8000 cal yr BP. Seppä et al. (2007) suggest that in the central and northernmost parts of Fennoscandia the 8.2 ka cooling was predominantly a winter and spring event that took place before the break-up of lake ice and onset of the growing season as well as pollening of the plants, and therefore the event is not recorded in these quantitative and qualitative pollen-based climate reconstructions.

An attempt was made to investigate how did lake ecosystems respond to 8.2 ka climatic reversal. Diatoms from northern locality, Lake Nautajärvi annually laminated sediment sequence, were analysed at 30 stratigraphic levels in the core section spanning a period of 500 years from 8300 to 7800 cal yr BP, each sub-sample including 3 to 8 years. Diatoms from southern site, Lake Rõuge Tõugjärv annually laminated sediment sequence, were analysed from 8700 to 7760 cal yr BP, sampling interval was after every 20 years and each sub-sample included 10 years.

In Lake Nautajärvi the base of the studied core section, covering the period from 8300 to 8160 cal yr BP, is dominated by open water species, notably *Aulacoseira subarctica* (Fig. 1). Overall, planktonic taxa are the major component of diatoms and make up 55–75% of the assemblage. Diatom accumulation rate (DAR) values that estimate the approximate productivity of the siliceous microfossils suggest relatively high planktonic diatom productivity. Diatom inferred total phosphorus (DI-TP) concentration estimates are stable during the period and range between 17–19 mg l^{-1}. Diatom composition undergoes changes from 8160 to 8010 cal. yr BP that are reflected in a decrease in planktonic diatoms, particularly *Aulacoseira subarctica*. A more frequent and diverse littoral diatom flora develops, even though most of these taxa are only minor components of the sedimentary assemblage. However, these changes in diatom species composition were not according to the nutrient preferences of the taxa as the floristic shift caused only a minor decrease in DI-TP concentration (Fig 1). Overall, total DAR and particularly plankton DAR values are very low during this time period, despite increased sediment accumulation rate. In addition, the records of other siliceous microfossils (chrysophyte cysts and scales) also suggest a change in the limnological conditions. Between 8010 and 7800 cal. yr BP, representatives of all the siliceous indicators, such as the relative abundance of planktonic diatoms, especially *Aulacoseira subarctica*, the most important contributor to diatom plankton community, recovered to the same values as pre-8160 cal yr BP sediments.

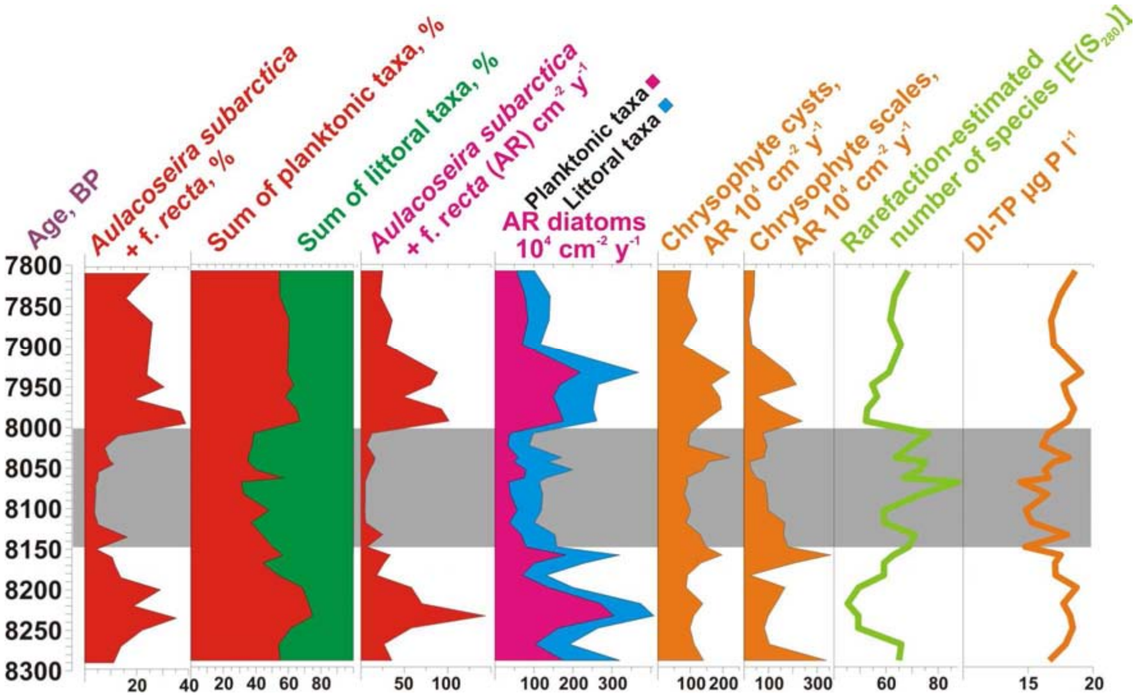

Fig. 1. Diatom stratigraphy of the dominant taxa *Aulacoseira subarctica* as relative frequency (%), proportion of planktonic and littoral taxa (%), and different diatom accumulation rates (AR), accumulation rates (AR) of chrysophyte cysts and scales, rarefaction estimated species richness and diatom-inferred epilimnetic total phosphorus concentrations (DI-TP) from Lake Nautajärvi (8300–7800 cal yr BP).

High turbulence and mixing of the water column during the long-lasting overturn in early spring are the main factors that most probably favoured the development of the *Aulacoseira* spp. dominated planktonic diatom community in Lake Nautajärvi from 8300 to 8160 cal yr BP (Fig. 2). Consequently, favourable hydrological conditions and a prolonged growing season due to the warmer climate resulted in increased pelagic productivity. However, microfossil evidence implies that in between 8160–8010 cal yr BP conditions shifted towards colder winter temperatures, prolonged duration of the ice cover, rapid development of thermal stratification in spring coupled with reduced water circulation and shorter growing seasons. During this 150 yr long period, diatom composition underwent a change from planktonic species dominance to more littoral species dominance at 8160 cal. yr BP, followed by a recovery.

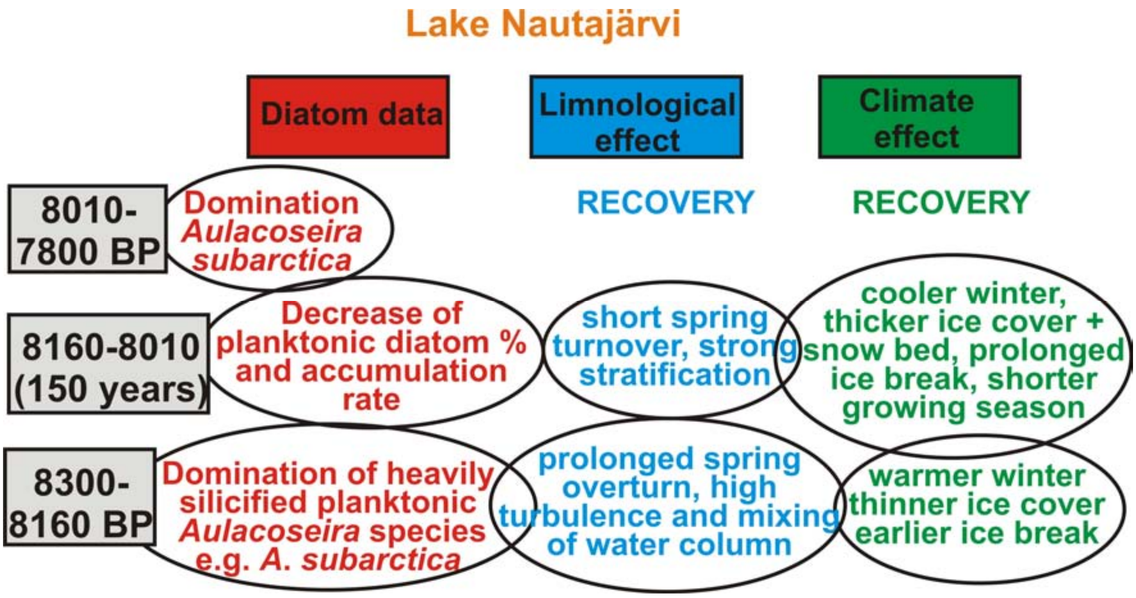

Fig. 2. Synthesis of the Lake Nautajärvi diatom data and paleoenvironmental and paleoclimatic interpretation.

In addition, according to the Lake Nautajärvi varve record, the annual accumulation of organic matter show decreased values at 8160–8010 cal yr BP, indicating lowered levels of primary production possibly caused by cooler and/or shorter summers (Ojala et al. 2008). Moreover, the period from 8090 to 8030 cal yr BP has the maximum peak of mineral matter influx, possibly induced by prolonged and severe winters that could have caused increased spring erosion due to the higher net precipitation of snow in winter (Ojala et al. 2008).

Opposite to Lake Nautajärvi, the diatoms composition and diatom-inferred epilimnetic total phosphorus concentration from varved sediments of Lake Rõuge Tõugjärv does not indicate any changes in between 8700–7800 cal yr BP. *Cyclotella* species (*C. comensis* and *C. comta*), diatoms that are tolerant to low nutrient waters, show high values and reconstructed DI-TP concentrations are low, in the range of 5–10 $\mu g\ l^{-1}$ (Fig. 3), i.e. reflecting the oligotrophic status for the lake. Although the pollen temperature reconstruction from the same sediment samples indicated abrupt climatic cooling in between 8400 to 8080 cal yr BP diatom assemblages did not react to the climate change. One explanation is the too southern location of Rõuge Tõugjärv, so that the colder winter temperature and possibly prolonged duration of ice cover did not influenced ecosystem in Lake Rõuge Tõugjärv. However, one can hint that possibly colder winters coupled with increased winter snow precipitation caused more intensive top soil erosion during higher spring melt-water discharges and consequently increased nutrient supply into the lake. One explanation to stable diatom composition and low nutrient level in Lake Rõuge Tõugjärv in between 8700–7800 cal yr BP is in the calcite composition of the varves. Intensive calcite precipitation during the spring effectively removed phosphorus transported to the lake from the catchment from the lake epilimnetic strata.

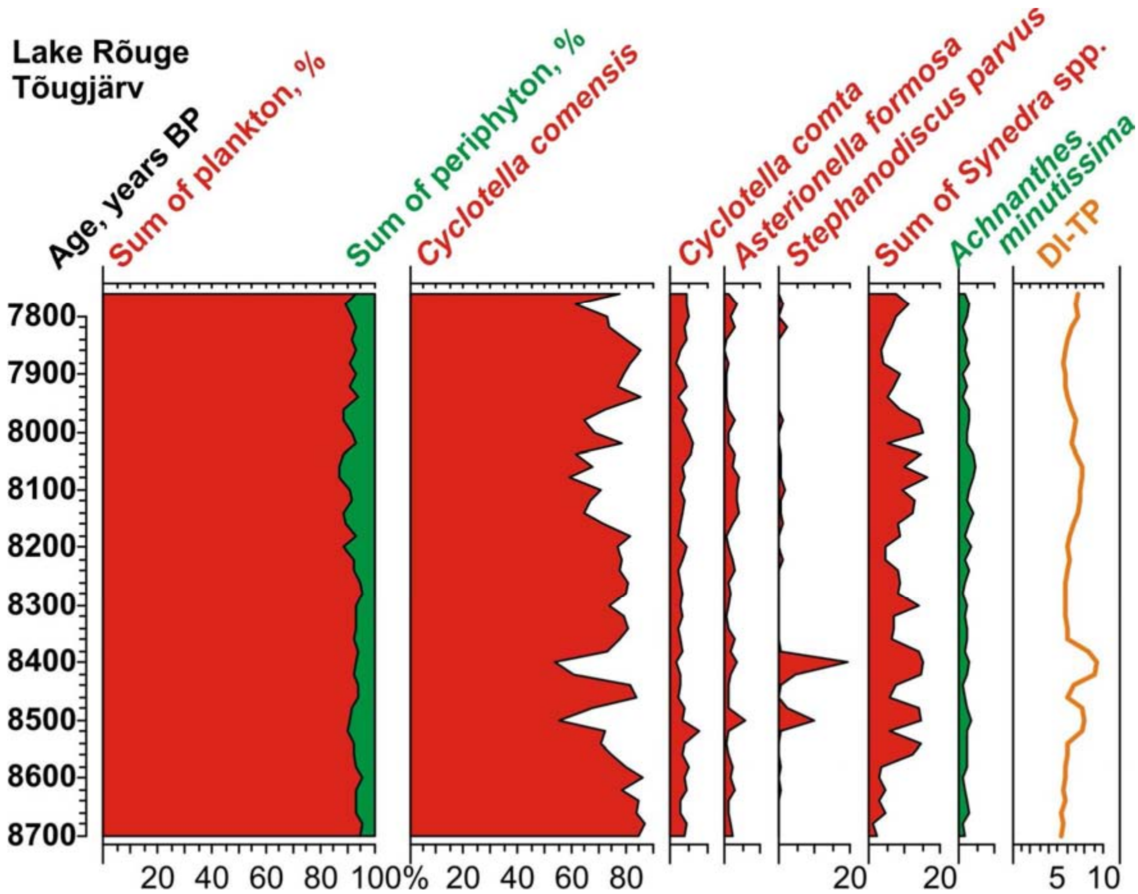

Fig. 3. Proportion of planktonic and periphytic taxa (%), main diatom taxa (%) and diatom-inferred epilimnetic total phosphorus concentrations (DI-TP) from Lake Rõuge Tõugjärv (8700–7800 cal yr BP).

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Palaeoclimatic and palaeoceanographic variability from Late Cretaceous marine varve records

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The modern Arctic Ocean is regarded as barometer of global change and amplifier of global warming[1] and therefore records of past Arctic change are of a premium for palaeoclimate reconstruction. Little is known of the state of the Arctic Ocean in the greenhouse period of the late Cretaceous, yet records from such times may yield important clues to its future behaviour given current global warming trends. A remarkabale seasonally resolved sedimentary record from the Cretaceous is located in superbly preserved, laminated marine sediments from the Alpha Ridge of the Arctic Ocean. This "palaeo-sediment trap" provides new insights into the workings of the Cretaceous marine biological carbon pump as well as the first records of Cretaceous interannual and decadal scale climate variability[8]. Seasonal primary production was dominated by diatom algae but was not related to upwelling as previously hypothesised[2]. Rather, diatom production occurred within a stratified water column, driven by concentrations of specially adapted species in blooms resembling those recently documented in the modern North Pacific subtropical gyre[3], or those indicated for the Mediterranean sapropels[4]. With elevated CO_2 levels and warming currently driving increased stratification in the global ocean[5] this stratified-adapted style of production may become more widespread. Time series analysis of records spanning 1000 years reveals strong periodicities in the quasi-biennial oscillation and El Niño – Southern Oscillation (ENSO) band as well a prominent 14 year period, all of which closely match periodicities typical of modern high latitude climate variability[6]. This supports the view that an Arctic Ocean free of permanent sea ice would be driven by similar forcing to the present state[1], implicating tropical ocean atmosphere interaction and demonstrating that stratosphere-troposphere coupling played a prominent role as has recently been established for the modern earth system[7]. On the other hand, the prominent ENSO periodicity documented in our records argues against the hypothesized link between past warm climate episodes and "permanent El Niño" states.

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Using micro X-ray fluorescence (XRF) method to analyze clastic-biogenic varves from Lake Nautajärvi (Southern Finland)

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Although annually laminated sediments provide basis for accurate paleoenvironmental interpretation, the prerequisite for reliable analysis is to have knowledge on the mechanisms controlling the sedimentation and varve formation. The enhancement in X-ray and X-ray fluorescence (XRF) instruments has opened up new applications for studies of lacustrine sediments. Recent studies with high-resolution (100 µm) XRF analysis have demonstrated good comparability between elemental profiles and characterized lake and marine sediment variations in grain-size, thickness and facies. The general objective in this work was to test whether the results from XRF chemical analysis done on epoxy embedded varve samples from Lake Nautajärvi correspond with the changes seen in varve thickness and composition. The aim was also to combine XRF element profiles with the existing X-ray densitometry data from Lake Nautajärvi.

The study site, Lake Nautajärvi in Orivesi area (24º41`E/61º48`N), is located in southern central Finland. Varves in Lake Nautajärvi are approximately 0.6 mm thick on average. Due to the high-resolution, elemental profiles can provide accurate information on annual and seasonal sedimentation. The sediment sequence, containing 187 years (701-888 BC), used in this study is prior to the human impact and land-use time in lake vicinity, therefore the sediments and the elemental values represent pristine environmental signal. In Lake Nautajärvi varves the source for allochthonous mineral matter (primarily on spring) is the hill-slope and channel bank erosion from the catchment area, and the main source for the organic matter before human influence has been the autochthonous production (Ojala and Alenius 2005).

According to Boyle (2001), main problems with reliable chemical analysis from lake sediments emerge from the lack of continuous chronology and heterogeneity in catchment area and sediment source. Therefore, the consistent varve chronology and the congruent surrounding soil and bedrock geochemistry in Lake Nautajärvi catchment area provide good basis for chemical analysis (Kujansuu et al. 1981, Sjöblom 1990, Lahermo et al. 1996).

The µ-XRF chemical analysis detected 24 elements of which Si, K, Ti, Ca, Cl, Mn and Fe showed the most relevant elemental profiles. Selected elements reveal two opposite trends that show similarities with X-ray densitometry based organic and minerogenic layer thicknesses. These opposite trends show changes seen in varve thickness and composition more accurately than the X-ray densitometry values.

Hence, the ongoing work is focused on interpreting the high-resolution elemental signals for the last 4 000 years. We are also using the sediment trap study from Lake Nautajärvi to verify the forcing mechanisms behind the sediment geochemistry and varve formation.

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The environmental signal contained in nonglacial Arctic varves: lessons from seven years of intensive lake and watershed process research

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Since the seminal varve-process study in the Canadian High Arctic by Bradley et al. (1996), efforts have continued towards developing new varve records from the Arctic, along with watershed and lake process studies to improve the environmental interpretation from varved sediments. This paper reports some of the key results culminating from a seven-year study initiated in 2003 at paired watersheds and varved lakes at the Cape Bounty Arctic Watershed Observatory (CBAWO, 74°55'N, 109°30'W), located on the south-central coast of Melville Island in the Canadian High Arctic. This comprehensive study has included snow, meteorological, hydrological, sediment transport, and limnological monitoring during the melt season each year. This ongoing research program has focused on key new elements related to the interpretation of the varves in both lakes at CBAWO and elsewhere in the region: the role of snowpack versus thermal (or temperature) controls over sediment delivery; inter- and intra-annual controls over seasonal suspended sediment delivery and characteristics (particle size); deposition of sediment in the lakes over short time scales (days) and related limnological controls; and, the impact of changing geomorphic controls over sediment availability and transport. These investigations have been undertaken in a wide range of climatic conditions, including years that represent the warmest and coldest since 1950 (when records began). Additionally, the contributions from snowmelt and rainfall have also been investigated, along with related studies of diatom community structure, microfossil records in the sediments, and biogeochemical studies from sediments and the watersheds.

Results indicate that in the non-glacial environment, where discharge and sediment transport are generated by either snowmelt or rainfall, temperature controls are apparent at daily time scales, but there is limited evidence that seasonal suspended sediment transport is affected by temperatures. By contrast, end of winter snow water equivalence (SWE) is the major control over the duration, intensity and overall sediment delivery in this system. This result is consistent with previous shorter studies elsewhere in the Arctic. Additionally, rainfall is a substantial contributor to seasonal sediment delivery and in some years may dominate overall yield from the watershed. Hence, the climatic control over suspended sediment yield may vary substantially on an interannual basis and generate non-stationary climate forcing factors over varve accumulation, particularly thickness or mass accumulation. Grain size studies at CBAWO show that substantial grain size hysteresis occurs in river and lake-bottom sediments and results in complexity in interpreting hydrological and climate controls over sedimentary grain size.

Sediment trap studies with frequent replacement intervals between 2003-9 reveal deposition in the lake bottom show consistency with river sedimentary inflows. Proximal-distal attenuation of underflows results in selective deposition from individual sedimentary inflow events, which can result in the absence of sediment from events in some cases. These results are consistent with other sedimentary studies that show high sensitivity of clastic laminae to lake dynamics, and few studies have evaluated the impact these processes have on the formation of the sedimentary record. Limnological moorings in the CBAWO lakes indicate that seasonal anoxic bottom water with slightly higher conductivity also affects sediment deposition at the crucial period when fluxes to the lake are high. Hence some decoupling between sediment inflows and deposition are apparent at CBAWO, but these do not appear to be highly problematic.

Finally, record melt season temperatures at CBAWO in 2007 resulted in extensive permafrost melt and slope disturbances. Detailed assessment of the downstream sedimentary impact of these disturbances indicates that this type of geomorphic perturbation has the potential to substantially alter the sedimentary record and constitutes a poorly constrained non-stationarity in varve records. While changing sediment sources may be revealed by detailed geochemical analyses, it is not clear that disturbances composed of sediment from background sources in the watershed can be determined by unique geochemical signatures. Ongoing work will evaluate these factors, but this type of geomorphic perturbation is an important consideration for interpreting long clastic varve records.

Long term process monitoring work at CBAWO has revealed a number of factors that should be carefully considered in the interpretation of similar clastic varve records. While these factors represent complications for paleoenvironmental records, they also point to opportunities to expand the potential information available from varves in conjunction with new analytical techniques and detailed evaluation of the sedimentary record.

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Developing an annually-resolved record for the Lateglacial period in the UK: the challenges and progress

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The publication of the Greenland ice-core records has highlighted that climatic changes have occurred on decadal timescales. Temperature fluctuations, considered to be reflected in isotopic variations, over the Lateglacial period are thought to be the product of reorganisation of ocean circulation patterns rather than longer term solar variability. Evidence from proxy climate records in terrestrial lake systems from across Europe suggest broad similarities to Greenland over this period, however traditional radiometric dating techniques do not provide the precision required in order to test the relative timing of these transitions. Annually resolved records published from sites in continental Europe demonstrate that the duration of these events can be linked to those identified in Greenland and that the transitions can be as equally abrupt. To date, few of these records have been recorded in the British Isles. As such it is critical that records of equivalent resolution are developed from this region which will enable examination of how rates of environmental response vary in terrestrial systems across Europe at a comparable resolution. This paper describes the approach taken in the development of an annually-resolved record of environmental change for the Lateglacial in the UK and presents the first results of an integrated varve and radiocarbon chronology which connects these records to the calendar timescale.

One of the key challenges in the UK is the identification of long varved records. Our starting point has been to examine two basins that formed ice contact lakes during the readvance of ice during the Younger Dryas (YD) period. The first is on the north-eastern flank of the YD ice cap in the Lochaber area of Scotland. The second is on the southern limit of the YD ice cap near Loch Lomond.

The Lochaber area of Scotland is well documented in the literature for the phenomena of the 'Parallel roads of Glen Roy'. These distinctive landforms on the valley sides are shorelines (formed at 260m, 325m and 350m) and are significant because the mapped extent of the landform provides an indication of the YD glacier limits which dammed the lakes: as ice advanced into Glen Roy successive cols were blocked causing the lake levels to rise to the next available col. When the ice retreated the cols were re-opened allowing drainage of the lake waters to the next lowest level. Annually-laminated sediments from distal locations in the lake basin have been identified using thin section micromorphology. Varve counts and varve thickness characteristics have been used to develop a varve chronology indicating that the lakes existed for 515 years. The position of the ice margin can be inferred from the varve thickness records, and allow estimations for the duration of lake levels (between 112 and 119 years), and thus the rate of shoreline development (between 5-10 cma^{-1}) and infer the rates of glacier advance (between 13.4 and $41.9ma^{-1}$). It has also been possible to infer from analysis of the summer component of the varve structure and tephrostratigraphic relationships that the ice was likely to have reached its maximum position during the latter part of the YD period.

The Loch Lomond area is the type site for the Loch Lomond (YD) Readvance in the UK and an ice dammed lake formed when ice, emerging from the highlands, blocked the natural drainage systems. Two sequences have been examined from within the basin: Croftamie, where organic sediments are overlain by glaciolacustrine, laminated clays and glacial diamicton; and Bogwood, where a 12m succession of laminated silts and clays exist. Both laminated sequences were examined using thin section micromorphology, identifying the likely annual nature of the deposits. Varve counts were made using a combination of thin section analysis and ITRAX downcore XRF scanning. The Croftamie sequence is constrained at the base by multiple radiocarbon dates on single species plant macrofossils obtained from the organic layer (short-lived leaves and terrestrial mosses) giving an age range for deposition of between 12, 115 and 11,627 cal yr BP. This is overlain by a minimum of 94 years of varved sediments. This location was then overridden by the advancing YD ice, however Bogwood remained ice free and a further 165 varve years are identified (259 in total). The Croftamie and Bogwood varve sequences are linked using marker horizons, distinctive summer component microfacies (see Palmer et al, this meeting) and total varve thickness records. This suggests that the Croftamie sequence corresponds to the lower part of the Bogwood sequence. A Bayesian *Sequence* model has integrated the two data sets to provide modelled absolute age ranges for: i) formation of the ice dammed lake after the deposition of the organic material (12,046-11,808 cal yr BP); ii) ice advance over Croftamie (11,927- 11,638 cal yrs BP) and; iii) cessation of varve deposition at Bogwood (11,762- 11,474 cal yrs BP). This study demonstrates that glacier ice reached its maximum position during the latter part of the YD, which contradicts evidence from Norway where small corrie glaciers appear to have responded more quickly and earlier to YD warming than the larger Scottish ice cap. The findings from both Lochaber and Loch Lomond will allow further refinement of glaciological models for the timing and extent of the YD ice cap. The retrodictive models underestimate the extent of the ice in the south of the ice cap, when compared to the mapped empirical limits, and vastly overestimate ice extent in the north of the ice cap, highlighting the need for improvement in the parameters used in glaciological model construction (topography, bathymetry, presence of lacustrine systems, accurate precipitation gradients amongst others).

These studies highlight the potential of glaciolacustrine systems to provide high resolution records for the Lateglacial period in the UK. Current work aims to improve the precision of Bayesian models by integrating tephrochronological data to the varve and radiocarbon at both Loch Lomond and Lochaber whilst also investigating other basins from the Lateglacial period in order to refine and extend current chronologies.

Suigetsu Varves 2006: utilising µXRF and X-radiography for varve counting

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As well as being extremely rich in terrestrial leaf fossils, providing a unique, truly atmospheric, record of radiocarbon throughout much of the period (10-50 kyr BP), the Suigetsu sediment is annually laminated for much of its depth. An earlier study of the Lake Suigetsu sedimentary archive remains one of the most comprehensive terrestrial records of radiocarbon (Kitagawa & van der Plicht, 2000), but significantly diverged from alternative, marine-based calibration datasets, due to gaps in the sediment profile and varve counting uncertainties (Staff et al., 2009). In 2006 a new core (SG06) was taken from Lake Suigetsu with complete recovery of the entire 73.5m sequence. This project aims to contribute to the international terrestrial radiocarbon calibration model, extending it to 50,000 years BP using the new SG06 Lake Suigetsu sediment core.

Together with a parallel programme of AMS radiocarbon measurement, varve counting is being carried out through the combination of two different and independent methods; (i) thin section microscopy, and (ii) high-resolution Itrax X-ray fluorescence and X-radiography. These methods have been used previously to quantitatively investigate micro-facies change through varved sequences but this study is one of the first that uses microscope analyses in unison with high-resolution XRF as a dual approach for varve counting. Initially, the two counting methods are carried out independently. The results are then compared in detail to identify the differences down to the sub-mm scale. This new approach substantially reduces internal error and results in a greater degree of accuracy than previously possible. Poor varve preservation in some sediment intervals requires an interpolation of these counts. For this a new automated interpolation-algorithm has been developed (Schlolaut et al., *this workshop*).

For the high-resolution geochemical approach to varve counting overlapping double-L channel core sections (Nakagawa, 2007), each 1 m long and continuous, were scanned at 60 μm resolution. The resulting data are analysed with *PeakCounter* (http://dendro.naruto-u.ac.jp/~nakagawa/), software specifically developed for varve counting using multi-parameter data from the Itrax scanner (Fig.1). The dominant annual geochemical signal is an end member rich in siderite ($FeCO_3$), clearly observed as peaks in Fe (and Mn) and by optically distinct, high density layers.

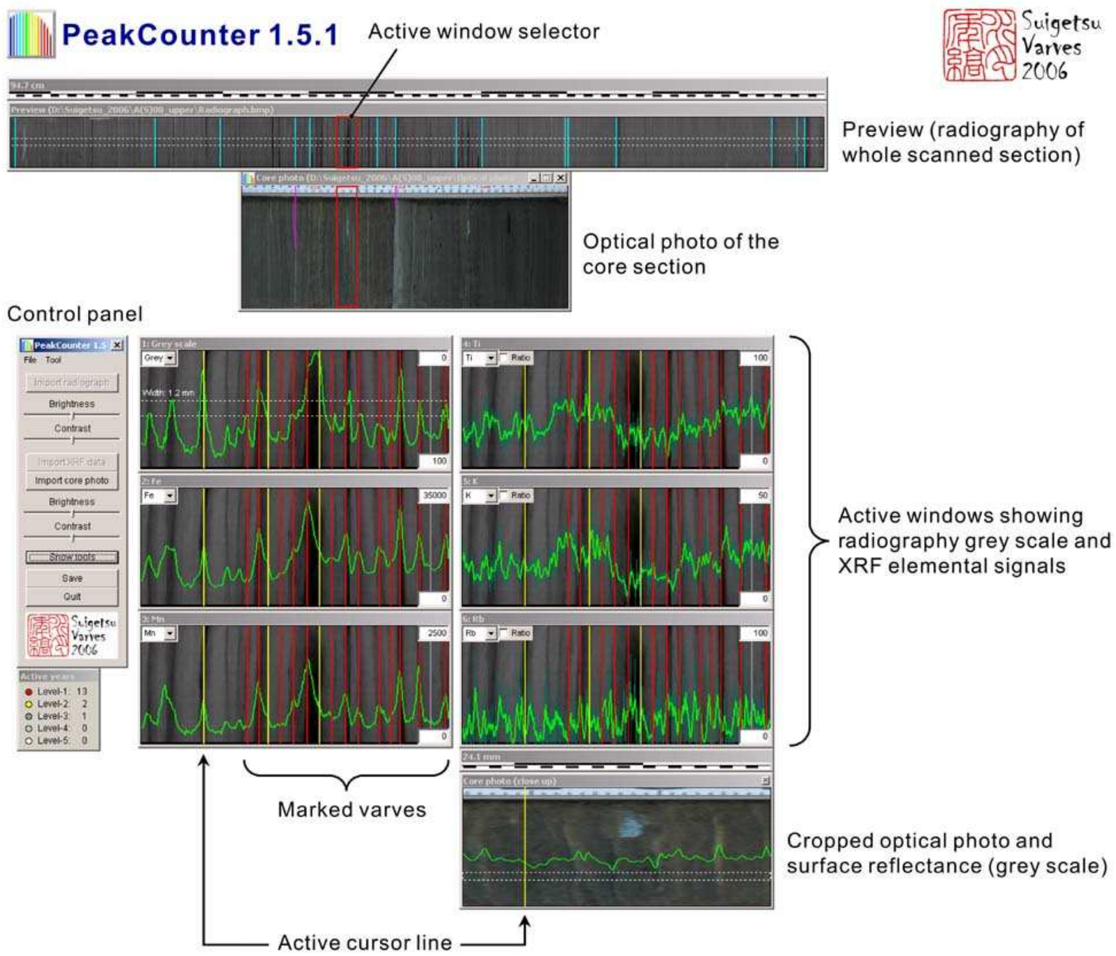

Fig. 1.

Detrital clay and tephra are clearly delineated in the data, aiding their removal prior to construction of the combined age-depth model. As well as facilitating varve counting and characterisation, the geochemical data provide crucial information about past processes in the lake and its catchment.

Results for the Late Glacial show that the raw count (before interpolation) is higher in the µXRF-derived count than in that from microscopy. This might be due to additional iron hydroxide layers picked out by the geochemical data. Adequately accounting for these differences is ongoing research. The combined varve count model (constructed using both µXRF and microscopic data) shows an improved accuracy and good agreement with the radiocarbon dates calibrated using Intcal04 (Reimer et al. 2004) and Fairbanks et al. (2005).

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Mid-Holocene climate variability from Meerfelder Maar (Western Europe)

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Abstract
Since Meerfelder Maar is one of the auxiliary stratotypes for the Lateglacial/Holocene transition (11700 cal yr BP) and studies so far mainly focussed on the Last Glacial-Interglacial transition, to continue the high resolution research through the Holocene is an unresolved task. New cores from 2009 and advances in methodology in combination with the excellent radiocarbon supported by varve chronology performed from the older cores (1996) are already being studied in order to obtain a detailed reconstruction of the Holocene climate evolution at high resolution scale. This study has been focussed on the mid-Holocene, from 4000 to 7000 cal yr BP, since this period represents the steepest part of the decreasing curve in summer insolation. First results are based on varve thickness and µ-XRF data, which are well-correlated and allow seasonal layers characterization. The Atlantic/sub-Boreal transition is clearly marked at 5850 cal yr BP, as an abrupt change in the varve thickness: from high variability and thicker varves indicating higher interannual variability; to thinner varves and low thickness fluctuation.

Keyword: varved sediments, mid-Holocene transition, Meerfelder Maar.

Introduction

Meerfelder Maar (MFM), located in the Eifel volcanic region of western Germany, contains a long annually laminated sediment record for most of the Holocene and Lateglacial (Brauer et al., 2000). Due to its particular morphological situation in a deep maar crater, it has preserved fine seasonal layers allowing for precise dating and high-resolution environmental reconstruction. Climatically, MFM is very sensitive of changes in the North Atlantic climate system due to its geographical location and, it has been classed as an excellent sedimentary climate archive together with Lake Holzmaar (Walker et al., 2009).

Previous studies have been focused on reconstruction of decadal to seasonal climate variability based on the varve chronologies during Late Glacial (14,700-11,500 cal yr BP) (e.g. Brauer et al., 2000) providing new evidence for the role of atmospheric circulation for extremely abrupt changes related to the Younger Dryas cooling (Brauer et al., 2008). Now, we aim at extending this work through a detailed reconstruction of the Holocene climate evolution at seasonal resolution applying the new methodological developments such as µ-XRF and isotope analyses, in order to identify natural climate variability in Western Europe during interglacial conditions.

Methodology

Seven new cores sequences from MFM were collected with a Livingston piston corer from the deepest part of the lake (17 m depth) in 2009. The sediments are being sampled for thin sections following the methodology described by Brauer et al. (1999), in order to carry out the varve counting and thickness measurements. The first thin sections are well correlated through a series of well-defined marks layerswith the composite profile performed from the older cores (1996). In addition, geochemical composition (Mg, Al, SI, P, S, Cl, K, Ca, TI, Mn, Fe and Sr) was studied using µ-XRF scanning (Brauer et al., 2009) at 100 µm resolution. The measurements are expressed on counts per seconds (cps).

Results and Interpretations

Figure 1 shows a high resolution floating varve chronology for the Mid Holocene (7000-4000 yr BP) anchored to the ^{14}C calibrated years on the base of 5 radiocarbon dates.

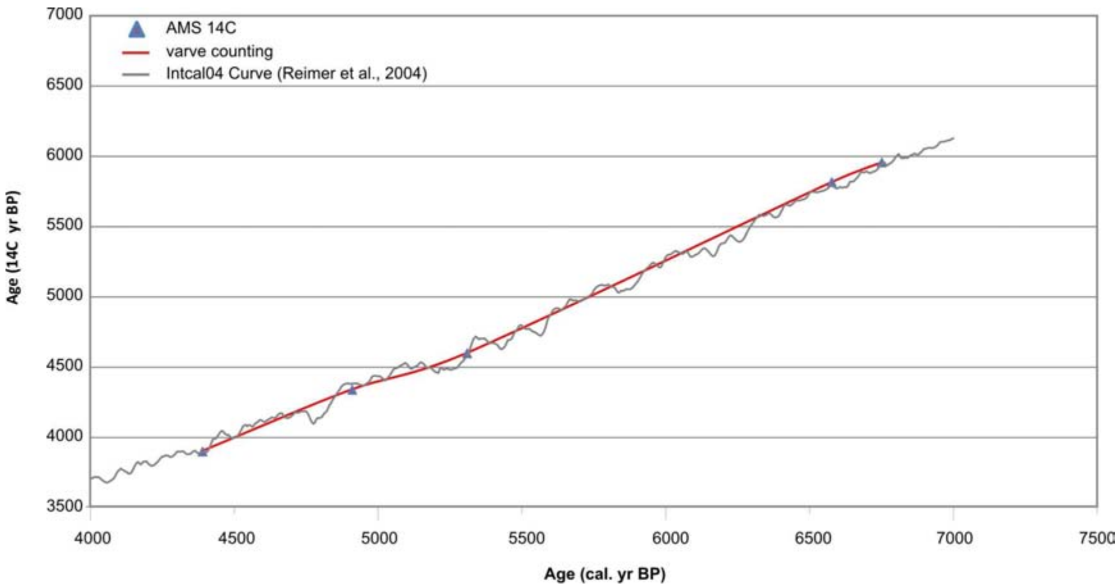

Fig. 1. Correlation between INTCAL04 curve and floating varve chronology. Absolute varve interval from 6829 to 4335 cal yr BP. Varve time interval form 6865 to 4371 varveyr BP. Total varves 2750 which 255 were interpolated.

Varves are made of organic and detrital laminae: i) organic laminae are composed of diatoms, corresponding to summertime. The composition of summer layer is variable happening different diatoms blooms (Stephanodiscus sp., Fragilaria sp. and/or Cyclotella sp) along the studied interval. In some short intervals summer layers are formed by Crysophyceae layers (Mallomomas sp.); detrital laminae are clay to silt sediments deposited during winter and also organic matter. Additionally, vivianite in form of nodules or lamina occur along the whole core, mainly post depositional in organic rich layers. Varve thickness is highly variable and, although summer layers are generally thicker than winter ones, thickness variability is controlled mainly by changes in the winter sedimentation, except for the period 4800-4380 cal yr BP (Fig. 2a). Based on thickness variability and the relationship between winter and summer layers we can identify four different phases (Fig. 2a): i) Phase I (prior 6150 cal yr BP), high thickness variability and good correlation between winter and summer layers; ii) Phase II (6150-5850 cal yr BP), higher variability and bad correlation between the seasonal layers; iii) Phase III (5850-4750 cal yr BP), lower thickness variability and bad correlation; and iv) Phase IV (after 4750cal yr BP), good correlation between the layer but summer layer are thicker than winter layer.

Geochemically, the sediments are enriched in Fe, K, Al, Si and Ti and impoverished in the carbonated component (Ca, Mg and Sr), reflecting the volcanic and siliciclastic nature of country rock. Al, K and Ti show a high correlation (0.8-0.9), but it is not significant with Si and Fe. Si content is both, detrital siliciclastic and diatoms layers. Si/Al ratio has been used as biogenic silica (diatoms) proxy, since it has been proved for lakes with volcanic setting (Robinson, 1994). Fe is well correlated with P (0.66) and could be associated to vivianite presence in the sediments. For a better interpretation of geochemical composition, it was combined with varve micro-facies analyses showing winter layers enriched in allochthonous component of the sediments and summer layers in Si (Fig. 2b and c). Winter varve thickness and K (as proxy for allocthonous component of the sediments) have similar behavior along the interval studied and suggest a high variability of the sediment influx (Fig.2b), likely controlled by climatic factors.

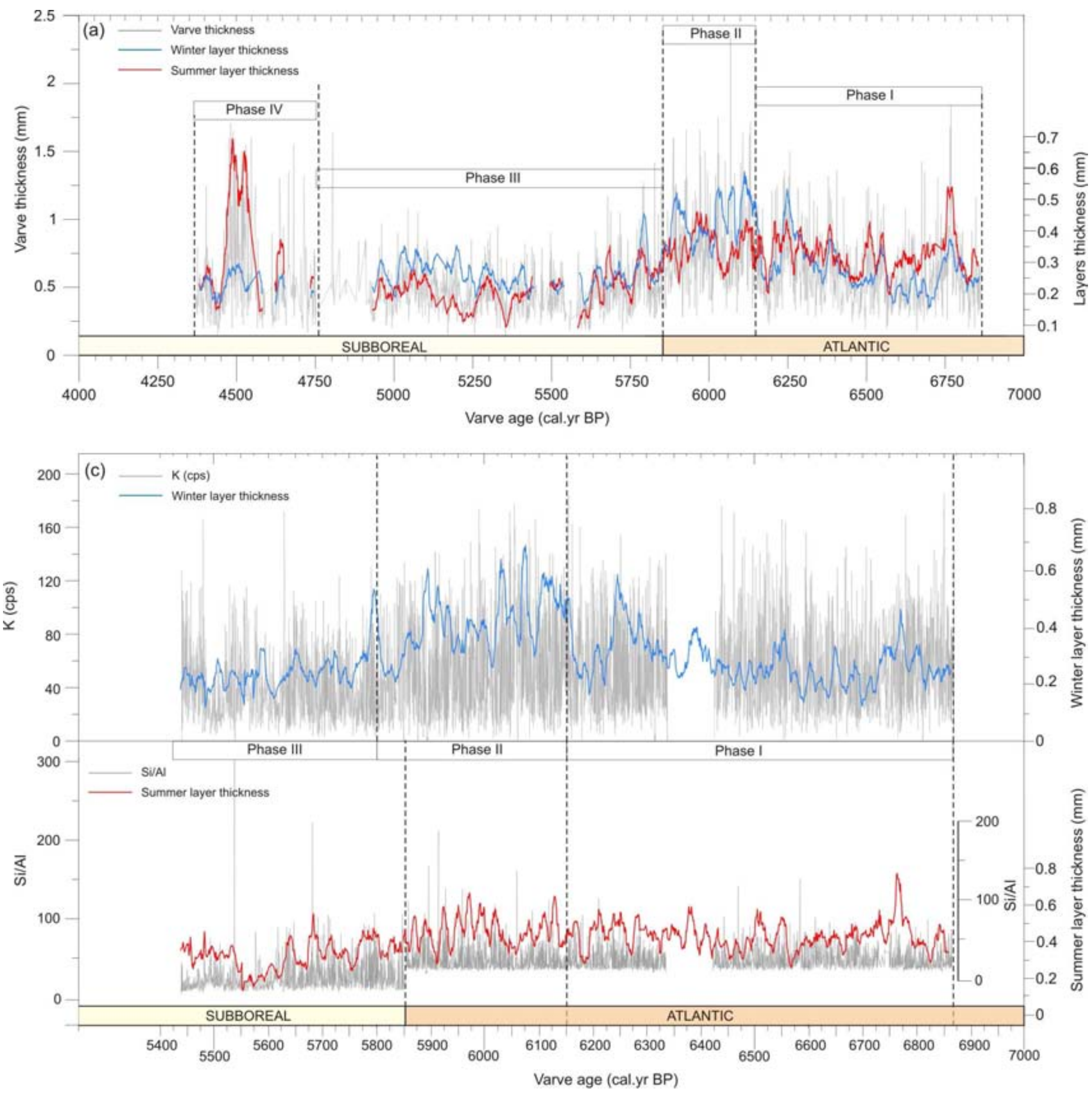

Fig. 2. (a) Varve thickness: gray line is total varve thickness in cm; blue line is 11-yr average winter layer thickness; and red line is 11-yr summer layer thickness. (b) winter layer thickness vs allochthonous input: gray line is K expressed as counts per second (cps); and blue line is 11-yr average winter layer thickness; (c) summer layer thickness vs biological activity: gray line is Si/Al ratio; and red line is 11-yr average summer layer thickness.

Higher variability in winter layer thickness occur during Phase II and at the end of Phase I, from 6400 to 5850 cal yr BP, indicating higher interannual variability at the same time than phases of higher lake level (more humid conditions) in central Europe from 6300 to 5900 cal yr BP (Magny, 2004). Additionally, the boundary between Phase I and II coincides with a period of glacier recession (warmer conditions) in the Alps from 6150 to 5950 cal yr BP (Joerin et al., 2006). Subsequent to this period, lower interannual variability is interpreted from MFM record until 4750 cal yr BP, coinciding with cool climate in North Atlantic region as consequence of the orbital driver mid-Holocene climate change at 6000-5000 cal yr BP (Mayewski et al., 2004). In addition, the boundary defined by the change of the varve thickness at 5850 cal yr BP marks the biostratigraphical Atlantic/sub-Boreal transition (Fig. 2).

Final considerations

As a first approach, we show a study combining stratigraphical (micro-facies analyses) and geochemical (µ-XRF analyses) information in order to characterize the main environmental processes that are controlling the sedimentation in the lake. At centennial scale, MFM shows a clear respond to the main climate changes defined for the Holocene and its record is as good as it was for the Younger Dryas (e.g. Brauer et al., 2008). In order to reach optimal coverage of this record, we claim to relate environmental changes at annual scale with climate forcing such as changes in solar irradiance and atmospheric patterns. However our data are still preliminary and a further investigation is required.

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Consistent centennial scale climate signals, revealed by high resolution sediment chemistry in a fully laminated, expanded S5 Sapropel from the eastern Mediterranean

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Marine Isotopic Stage 5e, the marine analogue to the Eemian Interglacial (126-115kyr), is the last period in Earth's history that features a climate, which is warmer and moister than today. Therefore, this period is an attractive target for climate research, especially holding valuable information on the response of the Earth's system to insolation-driven climate variability without human interference. Its geographic position at the interface of two different climate systems make the Mediterranean Sea very accessible for climatic changes and it is also known to record amplified climate signals, making it a ideal location to investigate climate variability of the last interglacial. Lithological, geochemical and geophysical data from a fully laminated sapropel horizon with a thickness of almost one meter are shown here, representing the peak warmth of MIS 5e. Three sediment cores from the northern Levantine Basin were investigated to document their degree of correlation in the visible pattern of lamination to each other and also to elemental abundances and geophysical properties in millimetre and sub-millimetre scale. The extraordinary thickness of the sapropel indicates sedimentation rates at levels of 20-30cm/kyr, potentially providing sub-centennial temporal resolution of climate signals preserved in the sapropel sequence.

Studies of Lake Nautajärvi varved sediment record – chronology and environmental interpretations

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The strength of varved lake sediments is that they reflect the annual (seasonal) cycle of sedimentation allowing construction of an inherent and continuous chronology on the condition that the annual nature of these couplets has been verified (Saarnisto, 1986). In addition, the physical characteristics of varves in aquatic environment have been found to preserve a proxy record of the palaeoenvironment and climate. Physical varve properties recorded for the last ca. 10,000 years from Lake Nautajärvi, central southern Finland provide a potential proxy record of winter precipitation and temperature via catchment runoff and erosion (Ojala, 2001).

Lake Nautajärvi is located in central southern Finland (61° 48' N, 24° 41' E) in the River Kokemäenjoki drainage basin and at an altitude of 103.7 m a.s.l. (Ojala & Alenius, 2005) (Fig. 1). Nautajärvi is a small (0.17 km^2) oval-shaped lake that was isolated from the Lake Ancylus (Baltic Sea basin) 7675 BC (Ojala et al., 2005). The maximum and mean water depths are 20 and 10 m, respectively, and sediment varves are confined to water depths >18.5 m. The lake is supplied by three inflows from the north and there is one southern outflow. Lake Nautajärvi has an inverse water stratification and anoxia (<1 mg l^{-1}) near the bottom during winter and summer, suggesting a dimictic nature. Total N and P in the water column are highest near the bottom and vary between 400–800 and 15–80 µg l^{-1}, respectively, indicating mesotrophy.

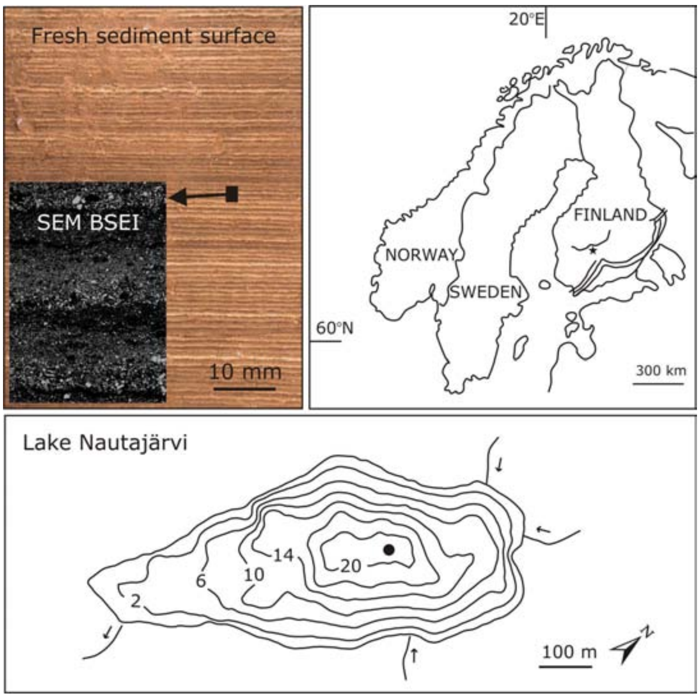

Fig. 1. Clastic-biogenic varves from Lake Nautajärvi and a location and bathymetry of the lake.

During the past decades, we have aimed to improve our understanding of the long-term evolution and seasonal patterns of the Holocene climate and environmental changes by combining the palaeoclimatological and palaeoecological (pollen, diatoms) interpretation of seasonal-scale varve record of Lake Nautajärvi (e.g. Ojala & Alenius, 2005; Ojala et al., 2008a, Ojala et al., 2008b; Giesecke et al., 2008). Altogether, more than 40 sediment cores have been taken from the Lake Nautajärvi basin between 1997 and 2010, of which 10 from the deepest part where varves are lying. Physical and chemical analyses over the years have included measurements of water content, LOI, a wide range of different palaeo- and mineral magnetic analyses (e.g. NRM, susceptibility, IRM, SIRM, ARM, S-parameter), LECO CHN-600 carbon analyses, ICP-MS analyses, X-ray radiography and densitometry, SEM BSEI analyses, digital image analyses, quantitative pollen and diatom analyses.

Chronology

Establishing a sediment chronology is often difficult and time-consuming task, even for sequences that have a varved sediment structure. Lake Nautajärvi sedimentation reflects an annual cycle of two seasonal components. A lighter minerogenic layer that is from the catchment and influxed during spring floods, and a darker layer of organic material (e.g. plants, algae) that accumulates in summer to autumn. There is a sharp boundary between winter organic lamina and a layer of mineral grains. Occasionally, a small quantity of minerogenic material is transported into the lake during autumn storms and forming an additional light layer below the darkest winter lamina. The entire post-isolation sediment sequences in Lake Nautajärvi is 6.6 metres in thickness in the deepest part of the lake.

Varve chronology as well as physical varve and seasonal layer measurements from the Nautajärvi succession are based on X-ray densitometry and digital image analysis (Ojala & Alenius, 2005). Varve counts were repeated 1 to 2 times from each of the 4 different cores and counts were compared between visually discernible marker horizons. The most likely number of varves was determined and combined to represent the final varve chronology (Ojala & Alenius, 2005). Deviations between counts, were registered to represent the margin of chronological error associated within the varve counts. The cumulative calculation errors for the entire Nautajärvi sediment profile covering 9,898 varves down to the sediment depth of 6.6 m was estimated to be +83 (0.84%) and -97 (0.98%) varve years. The fidelity of the Lake Nautajärvi sediment chronology is discussed in detail by Ojala and Tiljander (2003), and it is believed to be reliable within the estimated ±1% margin of error (Fig. 2).

The varve chronology was cross-checked by comparing palaeomagnetic measurements with other independently varve-dated palaeomagnetic records from Finland (Ojala & Tiljander, 2003) and Sweden (Snowball & Sandgren, 2002; Zillén, 2003). This work resulted in a varve dated Holocene palaeomagnetic secular variation and relative palaeointensity stacks for Fennoscandia called FENNOSTACK and FENNORPIS (Snowball et al., 2007).

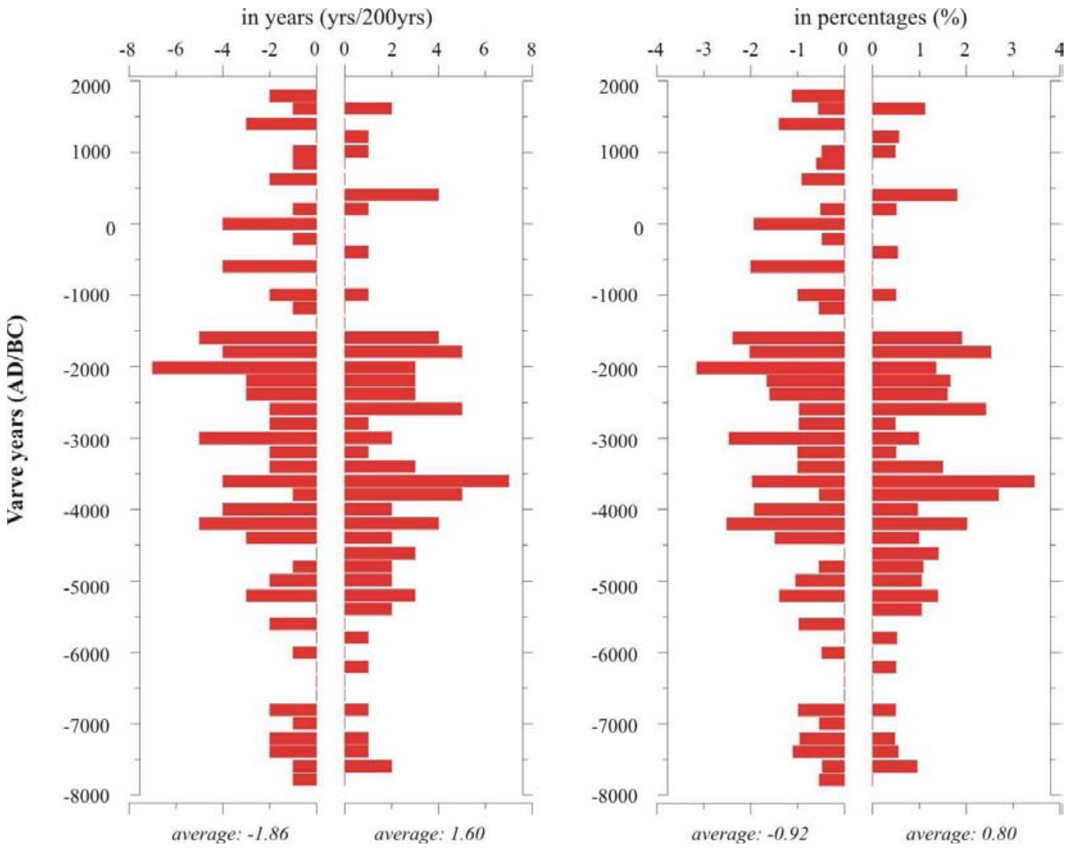

Fig. 2. Error estimates of the Lake Nautajärvi varve chronology in years (left) and percentages (right) at 200 years intervals (Ojala & Tiljander, 2003).

Climate and environmental interpretations

While the varve record reflects predominantly the sedimentological dynamics within the lake basin and its catchment, the pollen record is derived from larger area representing vegetation and pollen-production dynamics over a considerably larger region. Comparing seasonally resolved varve records with pollen-based climate reconstructions (growing degree-days=GDD) from Lake Nautajärvi, we examined seasonal climate and environmental variability in the Lake Nautajärvi region during the Holocene (Ojala et al., 2008a) (Fig. 3). The summer component (organic layer) of varve record and the GDD reconstruction show roughly comparable trends supporting that they predominantly reflect production season temperatures. There appears a low but rising trend during early-Holocene (7500 to 6500 BC). The Holocene Thermal Maximum (HTM) in the GDD record appears to date to ca. 5500 to 2500 BC, whereas the organic varve record along with reconstructed changes in vegetation composition, i.e. a peak of Tilia pollen percentages, suggests that during the HTM there was a trend towards a more continental climate with maximum mid-summer temperatures reached at 4500 to 2500 BC. However, both records indicate the start of the post-HTM cooling at around 2500 BC, contemporaneously with an increase of catchment erosion and mineral matter transportation into the lake. This suggests gradually colder and/or longer winters with high net accumulation of snow. The organic varve record and the GDD record start to diverge at 2000 cal. yr BP, possibly owing to the human influence on catchment processes. Overall, minerogenic varve data shows periods of increased catchment erosion at 7590–7530 BC, 7450–7400 BC, 7220–7110 BC, 7000–6000 BC, 5400–5200

BC, 4400–4000 BC, 2700–2400 BC, c. 1500 BC–AD 500, and 1400 AD onwards, strikingly different from the organic varve component and GDD patterns (Ojala et al., 2008a).

Understanding the full range of natural climate variability is a fundamental basis for palaeoclimate reconstruction, and therefore it is important to investigate the magnitude of the variability of the identified or known climate cooling/warming episodes in regional and global scales. Many of these several decades or centuries long climate episodes, such as the Medieval Climate Anomaly and the 8.2 ka climate cooling event, have been reported from numerous proxy records in the Northern Hemisphere. We looked for evidence of a climate-induced environmental change in central southern Finland around 6000 BC (i.e. around 8000 cal. yr BP) (Ojala et al., 2008b) and around AD 1000 from an annually laminated lake sediment record from Lake Nautajärvi (Ojala, 2001; Ojala & Alenius, 2005). The main sources of palaeoinformation in these papers were variations in varve physical properties (annual mineral and organic material accumulation) and fine-scale investigation of diatom and pollen assemblage percentages and accumulation rates.

A varved dataset from Lake Nautajärvi indicates two or three colder episodes around 8000 cal. yr BP (i.e. around 6000 BC) rather than a single event cited as the 8.2 ka climate cooling event. Diatom evidence suggests that during one of these oscillations (8160–8010 cal. yr BP) climate conditions shifted towards cooler winter temperatures that caused prolonged duration of the ice cover, development of thermal stratification in spring coupled with possibly reduced water circulation and shorter growing seasons (Ojala et al., 2008b; Heinsalu, 2010). During this 150 yr long period, diatom composition changed from planktonic species dominance to more littoral species dominance at around 8160 cal. yr BP. The change was followed by a fairly rapid recovery. This period was also characterized by increased catchment erosion and higher than normal spring discharge as well as lower than average annual accumulation of organic matter. However, we found no conclusive change in the Lake Nautajärvi pollen stratigraphy that would indicate vegetation change or adaptation to climate fluctuation around 8000 cal. yr BP. Put together, the evidence points out that this was not a major change but enough to be recognized with sedimentological and aquatic palaeoproxies. Based on the evidence, we also suggest that this period had the most prominent impact on winter climatic conditions in central southern Finland, but also led to curtailed summers as reflected by a low annual accumulation rate of organic matter and changes in diatom composition.

One of the characteristic features in the Lake Nautajärvi sediment record as well as in other Finnish clastic-biogenic varved records is a very low sediment mineral matter influx occurring between ca. AD 1000 and AD 1400 (Ojala, 2001; Tiljander et al., 2003; Ojala & Alenius, 2005). It has been interpreted as indicating attenuated spring floods caused by milder and wetter winters. In particular, the period between AD 1000 and AD 1200 is characterized by decreased rate of erosion and increased rate of organic matter accumulation, and these dates are corresponding well with the last historically recorded warm interval in Europe, known as the Medieval Climate Anomaly (MCA).

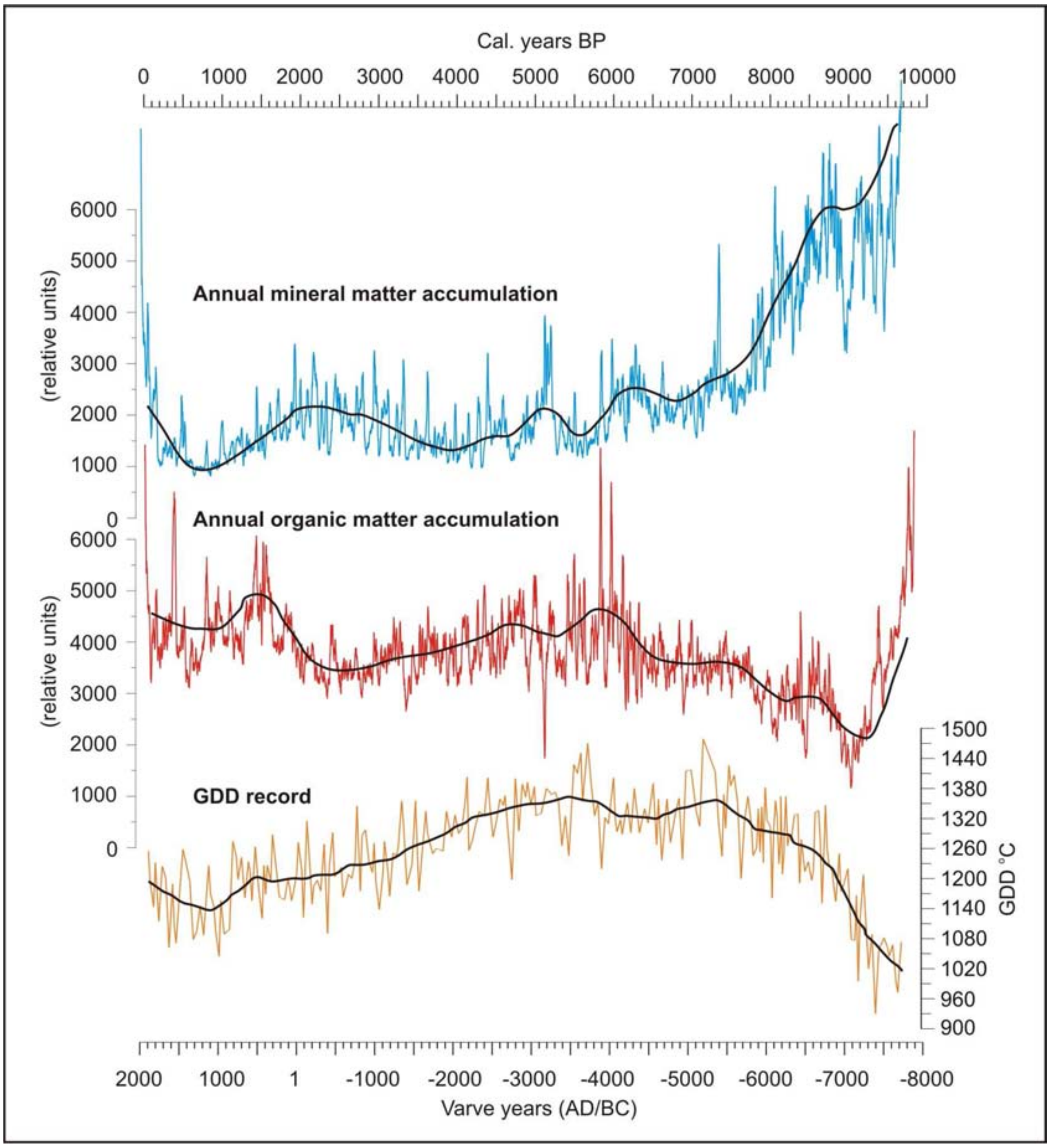

Fig. 3. Sum of growing degree days (GDD) above 5ºC reconstruction from Lake Nautajärvi pollen stratigraphy (thick line: with a LOESS-smoother with a span of 0.1) with, and annual accumulation organic and mineral lamina of varves (the varve data also smoothed with a LOESS-smoother with a span of 0.1) (Ojala et al., 2008a).

Future perspectives – work "in-progress"

Recently (winter 2008/2009) we installed near-bottom sediment traps to the deepest point of Lake Nautajärvi and started to monitor the seasonal deposition (Fig. 4). The aim of this work is to quantity the amount and property of seasonally sinking particulate material in order to better understand how varves are formed and how well and sensitively they really reflect changes in the catchment erosion and autochtonous organic productivity driven by environmental and climate fluctuations.

In terms of chronology, a preliminary assessment of the viability of tephrochronology as a tool for dating sites in Finland has been undertaken in the Lake Nautajärvi site (MacLeod & Palmer, 2007 unpublished, Sabourin, 2008, MacLeod, pers.comm.). This is actually the first times in Finland when someone has described tephra particles from Finnish lake sediments, and so far these studies have concentrated only to the early Holocene period. The studies show that there is a substantial potential for development of a tephrastratigraphic framework for Lake Nautajärvi sequence, but the results are still preliminary. Several attempts have also been made to date the Lake Nautajärvi core with C-14 dating methods using both, conventional and AMS dating. The results show that C-14 dates are systematically too old throughout the entire sequence when calibrated. For example, there is an offset of 800 years for AMS C-14 dates around the 8.2 ka climate cooling episode. The reason for this is currently under investigation (Muscheler, pers.comm.).

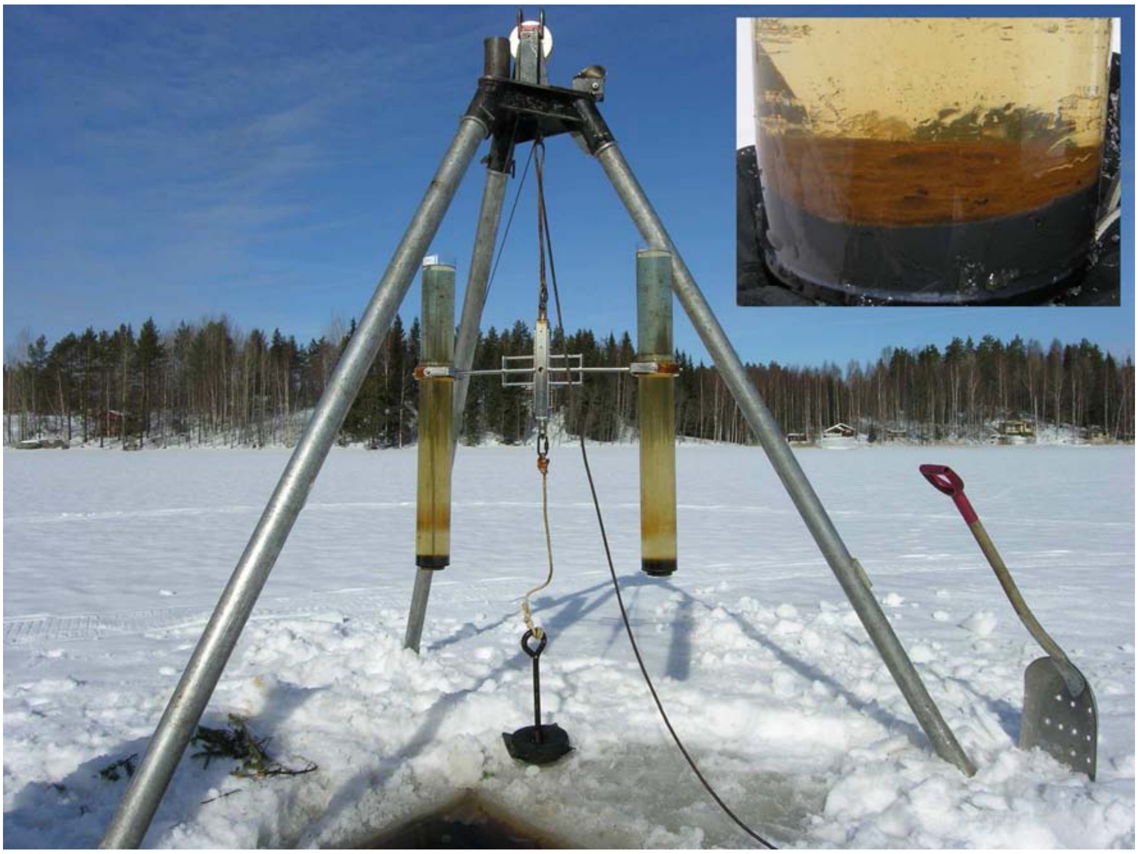

Fig. 4. Sediment trapping in Lake Nautajärvi (Photo: Ojala, AEK, 2010)

The CLIM-ECO ("*Climate variability in NW Europe during the last 4000 years and its ecological consequences*" 2008-2011) project, funded by the Academy of Finland, aims to improve our understanding of Late-Holocene climatic changes (natural and human-induced) and their impacts on the structure and functioning of boreal ecosystems and ultimately to human societies through palaeoecological studies and synthesis activities. Within this project, physical measurements with scanning electron microscope backscattered –mode (SEM BSEI) have be applied to the Lake Nautajärvi varved lake sediment sequences to deliver seasonal scale mineral matter grain-size variability during the last 4000 years. As shown by Ojala & Francus (2002) earlier, the amount of particles recorded in the BSEI analysis correlates well with the thickness of seasonal laminae in these clastic-biogenic varved sequences. However, SEM BSEI studies will provide information about mineral matter grain-size variability, which is another important proxy indicator in this environment. The influx and grain-size variability is related to intensity of spring (occasionally autumn) runoff and erosion, and therefore a proxy for winter precipitation and severity (e.g. Ojala & Alenius, 2005). SEM studies will also be used to characterize different varve components and varve formation processes through time. The data acquisition is ongoing.

High-resolution XRF investigation of the Lake Nautajärvi sequence is another component of the CLIM-ECO project. Results from these studies have been published in this abstracts volume by Kosonen et al. (2010). In addition, we have started analyzing fluctuation of silicon isotope composition of biogenic silica (diatoms) as a proxy for environmental change in the Lake Nautajärvi sequence. This proxy is rather new in palaeosedimentology, but the isotopic composition of silicon in diatoms ($\delta^{30}Si_{diatom}$) has been suggested to correlate with the relative uptake of silicic acid by the organisms in surface water (e.g. Leng et al., 2009). As a consequence, $\delta^{30}Si_{diatom}$ should directly and/or indirectly indicate things such as nutrient utilisation, ecosystem productivity, and palaeoenvironmental and -climate change. The equipment we are using at GTK is laser ablation-MC-ICP-MS.

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Microfacies analysis of clastic laminated sediments and the discrimination of clastic varves using thin section micromorphology: examples from Lochaber, Scotland

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Thin section micromorphology has become an important tool for palaeoenvironmental science for refining reconstructions of sedimentological and soil sequences. It is an ideal technique for the analysis of varve sediments, which are commonly composed of very fine sediment structures that require understanding of their composition and precise measurement. Microfacies analysis has been adopted to differentiate sediment types at the microscopic level and identify seasonally deposited components of biochemical, organo-clastic and clastic varves from both modern (actively developing) and ancient varve sequences. Modern varve sequences benefit from the analysis of seasonal allocthonous and autocthonous inputs to the basin and independent radiometric dating of the most recent sediments. However to improve our understanding of the palaeorecord, comparison of varve sediment structure to modern structures is necessary. The first stage to achieving this is to develop a consistent descriptive scheme that will allow this comparison. This paper uses examples from a glaciolacustrine sequence in Lochaber, Scotland to illustrate the descriptive scheme, consider a process-based interpretation of the sediment structures and examine the potential of this approach to improving palaeoenvironmental reconstructions.

In each of the Lochaber sequences examined, the microfacies of each lamination type was made based on the textural properties, sorting, structure, nature of the contacts between the laminations and irregular structures such as load structures, scour channels, bioturbation and the presence of organic material. Several packages of distinct lamination types could be classified into laminations sets, which are composed of alternations between texturally coarse and fine-grained components. This process of splitting lamination types and reconstructing into lamination sets can be applied to any laminated sequence and is aimed at generating a descriptive basis for interpretation of the process.

Sixteen lamination sets have been identified in the Lochaber sequences, which are composed of persistent alternations between two components: one dominated by coarser-grained sediment (normally silt or very fine-grained sand) and the second dominated by finer-grained sediment (very fine-grained silt and clay). The coarser-grained component can be composed of either a single, massive, normally graded or inversely graded lamination type, and where it is massive the sediment can be well, moderately or poorly sorted. The coarser-grained component can also be comprised of multiple lamination types with either two distinct lamination types or with repetitions of fine, well-sorted, coarse-grained silt laminations alternating with fine, medium-grained silt laminations. There are normally sharp contacts between the fine laminations. The finer-grained component is normally comprised of a single lamination type which grades from very fine-grained silt to clay, with a sharp contact to the underlying coarse-grained component and to the succeeding lamination. There is normally a strong masepic fabric in the fine lamination type. The mean thickness of the lamination sets is between 2-4 mm at the sites within Lochaber.

The interpretation of the lamination sets are consistent with glaciolacustrine varve sediments described by Ashley (1975), Smith (1978) ad Ringberg and Erlstrom (1999). The key microscopic elements that allow this are: i) the sharp contacts between the coarse and fine components; ii) no grading within the coarse components and; iii) grading within the fine components. The microfacies approach also highlights the differences in the structure of the summer layer in particular the degree of sorting within the single massive laminations, allied to a limited amount of very fine silt in the lower part of the fine component. These are hypothesised to reflect deposition from sediment entering the lake as overflows, whereas more poorly sorted sediments in the coarser component, allied to evidence for multiple pulsed and graded laminations in the summer layer are attributed to underflow processes. From this form of analysis, it is possible to generate time series which reflect variations in sediment supply to the lake basin, which could be the product of climatic controls.

In addition, the microfacies approach has allowed the counting of the summer layer laminations which are ranked according to the number of sediment pulses delivered to the lake basin during the summer period: those assigned to Group one have a single lamination in the summer layer, Group two has two and Group three have three or more. When plotted as a depth function using moving averages, periods can be identified when one of the groups tends to dominate. It is also important to note that there appears to be no clear relationship to varve thickness and as such the summer layer information may provide additional or alternative palaeoenvironmental information. Comparison of this sediment pulse data have been made to the Greenland isotopic records, which suggest that there is a positive relationship between enriched isotope values in Greenland during the latter part of the Younger Dryas. The fluctuations in both records occur at a similar frequency and magnitude hinting at synchroneity of climate changes across the North Atlantic at this time, although independent testing of this relationship is necessary and is a priority for current and future research.

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Late Quaternary marine varves from the Antarctic Margin: diatom silica oxygen isotope records

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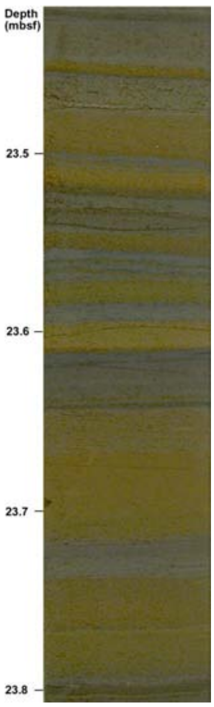
Antarctica and its ice sheets have played, and continue to play, a major role in the global ocean-atmosphere system, hence, it is crucial that we have a sound understanding of the past behaviour of Antarctica and its ice sheets with a view to understanding their variability under a warming climate. Ice cores and ocean sediments provide intriguing insights into the timing and nature of the rapid climate transition that occurred at the last deglaciation (~13-11 kyr BP) and the Southern Ocean is key to mechanisms proposed for the bipolar seesaw of global thermohaline circulation that drives such glacial-interglacial cycles and rapid climate transitions. In order to further investigate these processes that originate in Antarctica and lead to changes in global climatic conditions it is necessary to understand the transfer mechanisms of ocean-climate signals from the Antarctic ice sheets, across the continental margin, into the Southern Ocean. The environment of the Antarctic continental margin is dominated by the seasonal advance and retreat of the sea ice. As such, the seasonal variability in sea ice coverage around Antarctica is one of the most significant factors regulating the energy balance of the Southern Hemisphere atmosphere and oceans.



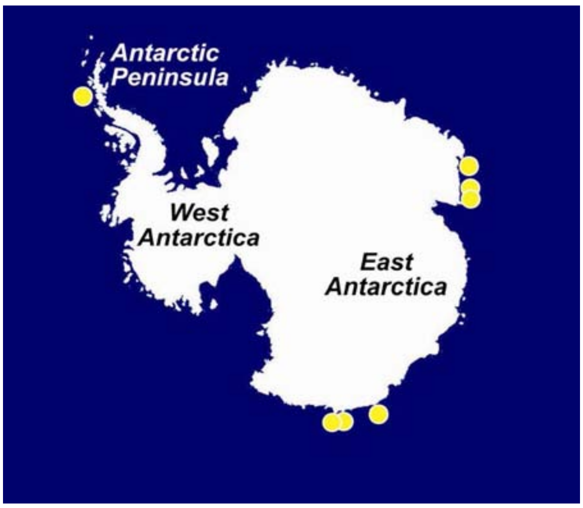


Fig. 1. Left: Deglacial varves from core NBP0101-JPC43B, Iceberg Alley, East Antarctic margin. Orange laminae are dominated by Hyalochaete Chaetoceros resting spores. Right: Sites of accumulation of varved deglacial Antarctic sediments.

Exceptional, high resolution Antarctic margin sediment cores recovered during the last decade contain an excellent archive of these ice-ocean-climate interactions (Figure 1; Leventer et al. 2002; 2006). Indeed, many of these cores from the continental shelf contain remarkably well-preserved laminated sequences through the last deglaciation (e.g. Leventer et al. 2006; Maddison et al. 2005; 2006; Stickley et al. 2005) that were deposited in a calving bay re-entrant environment (Figure 2; Domack et al. 2006; Leventer et al. 2006). These laminations are dominated by exceptionally well-preserved fossil planktonic diatom assemblages; individual species of which are sensitive to sea surface conditions including sea ice concentration, fresh water influx, and open ocean influence upon the margin. The deglacial laminations have been shown to be seasonal in origin and established as marine varves. Spring laminae are dominated by diatoms associated with the spring sea ice melt and the formation of a freshwater cap trapping nutrients in the surface waters (e.g. *Hyalochaete Chaetoceros* spp.); summer laminae being more terrigenous-rich and associated with diatoms that favour slightly more oligotrophic, open-water conditions (e.g. *Corethron criphilum* and *Rhizosolenia antennata*); and autumn laminations being associated with diatoms that form resting spores in response to lowering light levels and sea ice re-advance (e.g. *Thalassiosira antarctica*) (Figure 3; Maddison et al. 2005; 2006; Pike et al. 2009; Stickley et al. 2005).

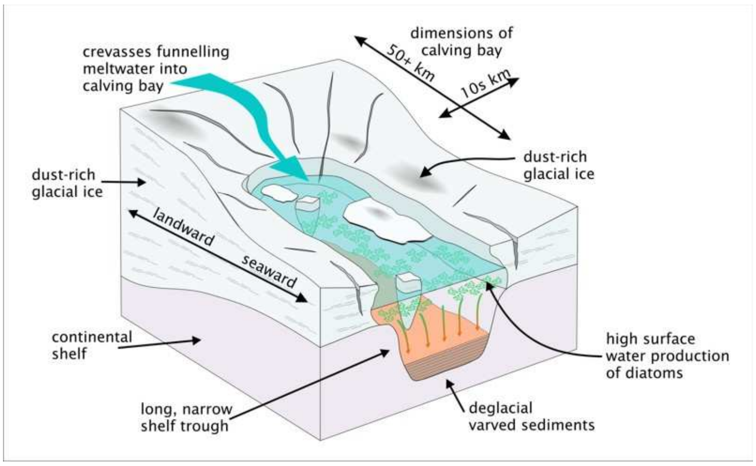


Fig. 2. Formation of deglacial varved unit (after Leventer et al. 2006)

Now that these laminations have been established as marine varves, this provides the opportunity to exploit the exceptionally high, deglacial sediment fluxes for novel analyses. Diatom oxygen isotope measurements provide a means of obtaining stable oxygen isotope records from high-latitude, carbonate-poor marine sediments that are equivalent to those measured in planktonic foraminifera at lower latitudes. The measurement of diatom silica oxygen isotopes has become an established method in lakes however, to date, there have been fewer attempts to apply this proxy in palaeoceanographic reconstructions (Swann and Leng, 2009). Early studies using deep, southern ocean cores demonstrated the sensitivity of diatom silica oxygen isotopes to changes in fresh water flux, salinity, sea surface temperature and currents (e.g. Shemesh et al. 1995; 2002). For the first time, we are applying this proxy

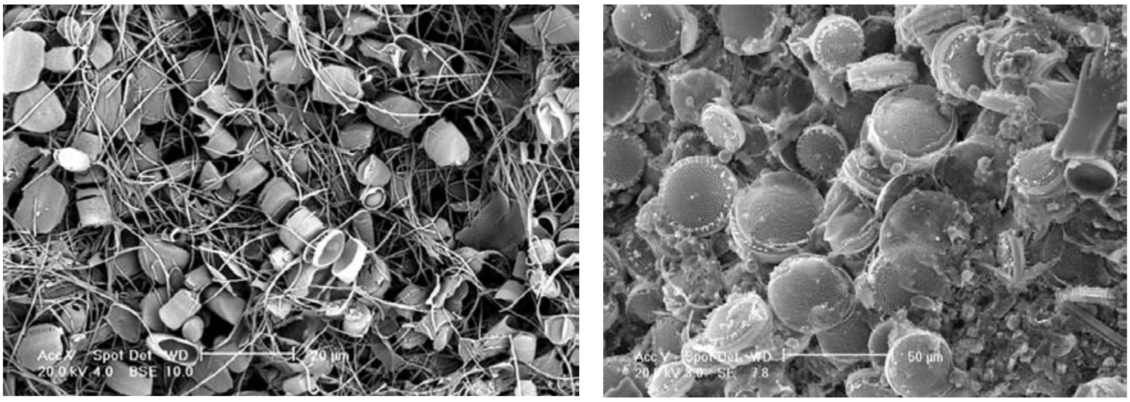


Fig. 3. Left: Scanning electron micrograph of Hyalochaete Chaetoceros resting spore spring lamination. Right: Scanning electron micrograph of Thalassiosira antarctica resting spore autumn lamination

to Antarctic continental shelf sediments and, specifically, we are targeting the deglacial varves in order to construct seasonal isotope records. We intend to analyse single taxa sequences of spring laminations (dominated by *Hyalochaete Chaetoceros* resting spores) and autumnal laminations (dominated by *Thalassiosira antarctica* resting spores) through the deglaciation, and then construct whole Holocene planktonic oxygen isotope records for two sites: Palmer Deep, west Antarctic Peninsula, and Iceberg Alley, East Antarctic margin. The advantages of using the varve sequences are that diatoms are already somewhat separated into mono-taxic layers, the preservation is excellent minimising the impact of silica maturation, and we can investigate vital effects by looking at year-on-year sequences. We will present our preliminary results from analysis of the deglacial sequence from Palmer Deep.

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Review of recent studies and work in progress on varved lake sediments in northern Sweden

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We give a brief summary of work on varved lake sediments accomplished by the Environmental Change Assessment Group at Umeå University, and focus on recent work and work in progress that we consider to be of particular interest to the PAGES Varves Working Group. We would like to stress that a large number of colleagues have been and are involved in the research and these are honoured in the presentation.

Using the historical atmospheric deposition record of lead pollution as a chronological marker in lake sediment and peat deposits in Europe

Large-scale lead pollution of the atmosphere has occurred for at least 3000 years in Europe. Metal production and smelting were the main sources until the 20th century. Rates of atmospheric fall-out have varied over time. Using analyses of lead concentrations and stable lead isotopes ($^{206}Pb/^{207}Pb$ ratios) of varved sediment deposits from lakes in northern Sweden, we have found pronounced peaks in lead pollution fall-out at AD 0-400, AD 1000-1200, AD 1530 as well as in the 1970's (Fig. 1). Pollution fall-out was synchronous over large geographic areas and analyses of pollution lead in sedimentary deposits can be used for indirect dating (Renberg et al. 2001).

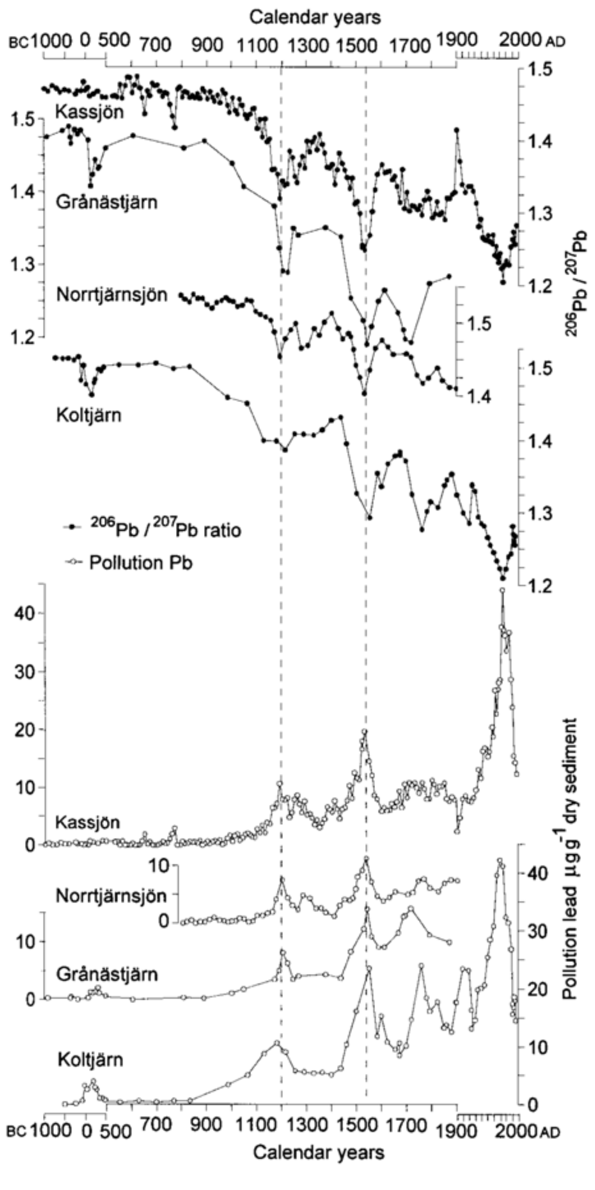

Fig. 1. $^{206}Pb/^{207}Pb$ isotope ratios and pollution lead concentrations in sediment cores from four northern Swedish lakes with varved sediments. Results are plotted on a calendar time-scale obtained by varve counting (Brännvall et al. 1999).

Is the mineral matter content of varves and its distribution a winter climate record?

In her thesis from the 1990's, Gunilla Petterson studied a 6300 years long varve record from Lake Kassjön. She used image analyses to quantify the annual accumulation rate of mineral matter (Petterson 1999, Petterson et al. 2009). She found that there was a considerable inter-annual variability in the mineral matter influx (Fig. 2), and hypothesized that the main reason was variations in the water discharge in spring causing changes in channel bank erosion and transport of mineral grains to the lake. Given that the spring runoff intensity is related to the amount of accumulated snow in the catchment during the winter, she argued that the mineral matter accumulation record in Kassjön contains information about past winter climate. Work is now in progress to analyze the image analyses data that Gunilla Petterson produced. A first step is to describe the annual patterns of the grey-scales in mathematical terms in order to be able to infer past changes in hydrological regimes.

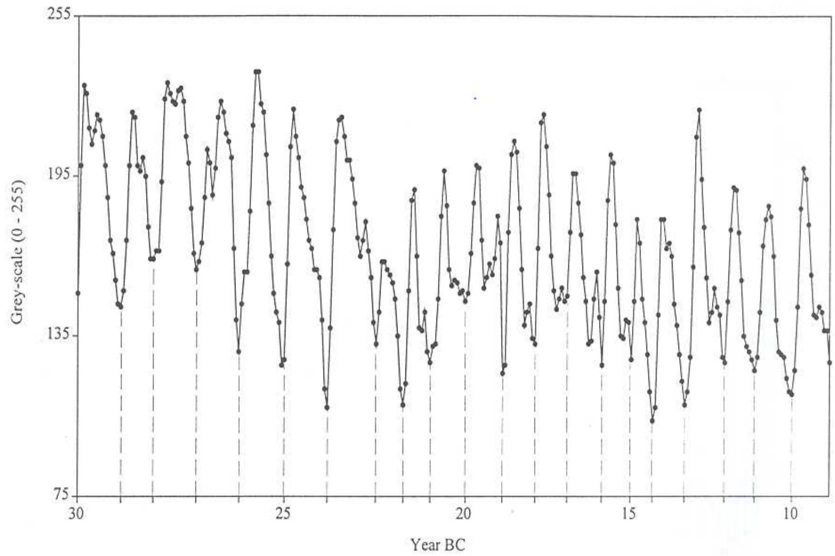

Fig. 2. The within-varve variations of the grey-scales during a twenty-year period. High grey-scale values (light-coloured sediment) represent minerogenic matter and low values organic matter (troughs are winter layers) (from Petterson 1999).

The Lake Nylandssjön project

The overall objective of this project is to improve the ability to infer past environmental and climate information from varved lake sediments. In order to reach that goal we need a better knowledge about varve formation, varve properties, and how present-day environmental variables are imprinted in the varve properties. Nylandssjön has very thick and distinct recent varves (Fig. 3).

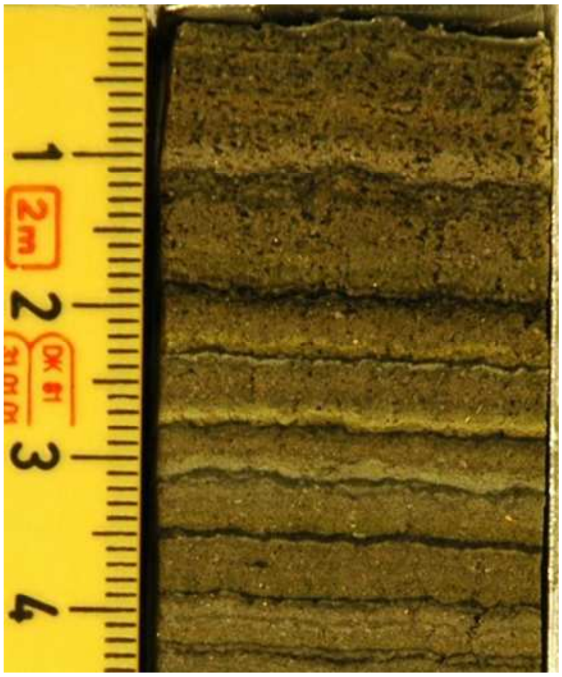

Fig. 3. Photo of eight near-surface varves (years 2001-2008) from a freeze core collected in April 2009 from Nylandssjön.

Between 1979 and 2009 a series of freeze cores have been collected in the lake (cores from about 20 different years). Since 2001/2002 we are running a limnological program in the lake (water chemistry, and plankton samples and oxygen profiles from 160 occasions). Since 2002 an automatic sediment trap is employed (about 160 samples).

Diagenetic changes

A key issue for understanding links between environmental variables and sediments is: What happens when sediment is ageing, how are sediment properties changing? We have used our unique collection of stored freeze cores to address this issue. We have studied how concentrations of Ti, Rb, Al, Zr, Hg, Fe, S, C and N change in individual varves with time over a period of nearly 30 years (cores from 1979-2009). We do this by tracking surface varves in cores taken subsequent years, e.g. the 1978 varve in cores taken 1980, 1985, etc to 2009. No significant diagenetic changes were observed for Ti, Rb, Al, Zr, Hg, Fe and S (Boes et al. submitted, Rydberg et al. 2008, Gälman et al. 2008a), while C and N change considerable. There was a 23% loss of C and 35% loss of N after 27 years (Gälman et al. 2008b). Also the isotopic composition changes with time. The $\delta^{13}C$ increased by 0.4-1.5‰, while $\delta^{14}N$ decreased by 0.3-0.7‰ (Gälman et al. 2009). Work in progress addresses changes in Cs and Si.

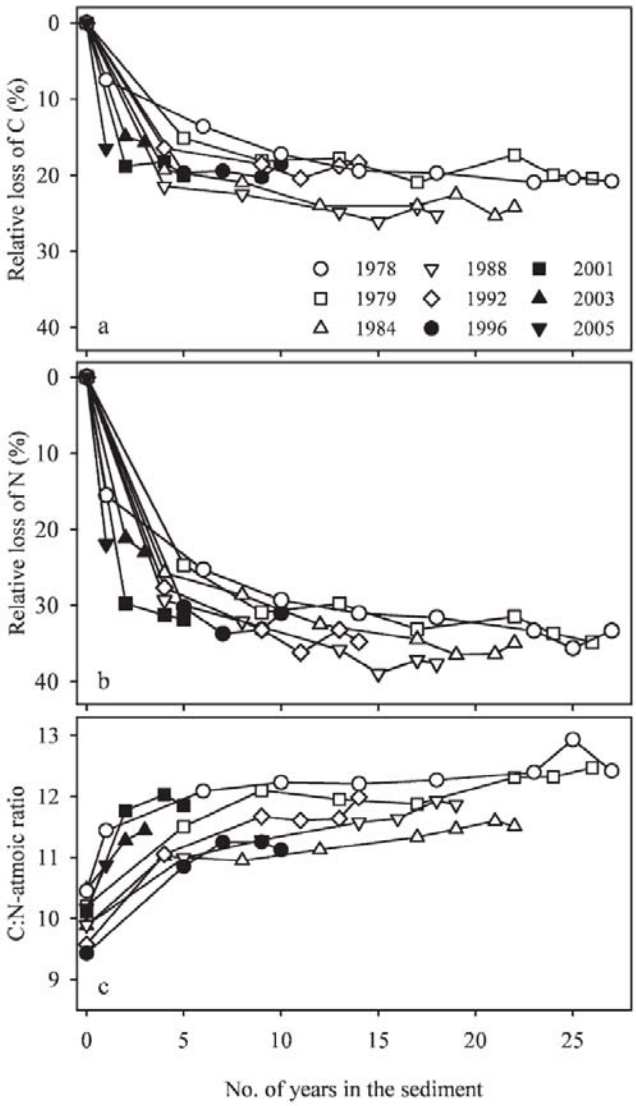

Fig. 4. Curves illustrating the relative loss of (a) C and (b) N, and (c) shows the C:N ratio (from Gälman et al. 2008b).

Comparing the chemistry of sediment trap material with the chemical stratigraphy within individual varves

As a part of a study aiming at better understanding how sedimenting material transforms to sediment, we present an ongoing investigation where we compare the chemistry of about 30 consecutive trap samples from 2007 with the chemistry of the varve accumulated in 2007. We use an ITRAX core scanner for the analyses.

Linking diatoms in plankton, in traps and in varves

With the objective to better understand how the current diatom assemblage in the lake is preserved in the varves, we compare diatoms in plankton, the sediment trap material, and in the internal stratigraphy of the varves. We present some preliminary results at the workshop.

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Optical scanning of water-wet and epoxy-embedded sediment mini-slabs for structural documentation of laminated unconsolidated sediment: Energetic turbidites erode underlying varves in Santa Barbara Basin, California

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An inexpensive and relatively fast method was developed for imaging of structures in soft, waterlogged sediment. We use a slightly curved, scoop-like metal blade to cut ~2-mm thin sediment slices from split sediment cores. During the cutting, the cathodically charged, wet metal blade develops a lubricating coating of hydrogen gas upon contact with electrically conductive sediment. Sediment slices are placed on wet glass slides avoiding entrapment of air. Slides are immediately scanned through the glass at high resolution using an optical color scanner. Subsequently, the sedimentary pore water can be exchanged with acetone and Spurr low-viscosity epoxy resin (Spurr, 1969; www.polysciences.com) for archiving of sediment slices and in preparation for scanning electron microscopic imaging and mapping of the elemental composition. The hardened, epoxy-embedded sediment can be polished to 1 µm and optically re-scanned, but the resin impregnation darkens the sediment and reduces color contrast. The quality of scans is improved when a mixture of water and iso-propanol (3:1 vol/vol) displaces any air between the glass of the scanner and the polished epoxy surface (i.e. fluid immersion). Contrast can be partially restored by using Photoshop image-enhancing techniques.

We present examples from the central Santa Barbara Basin (SBB) off California where occasional turbidites interrupt a largely varved Holocene sedimentary record. We compared sediment cores from various locations in the SBB with differences in local turbidite deposition. Comparison among sites proves that emplacement of turbidites can be associated with strong bottom currents that may erode some of the topmost, water-rich varves (see color scans of water-wet sediments in Fig. 1). 'Missing varves' limit the dating accuracy that can be achieved by counting varves down-core.

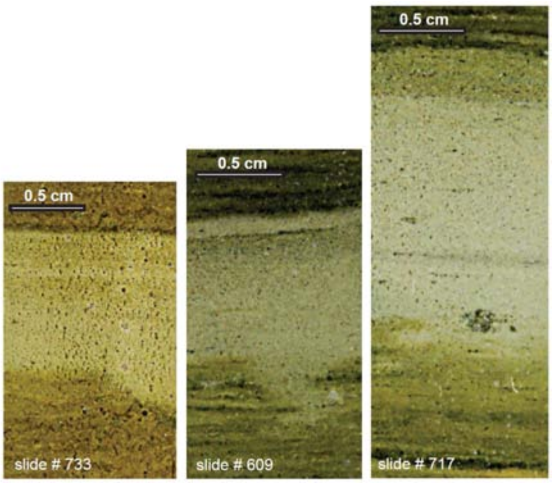

Fig. 1. Three color scans of water-wet sediment across gray turbidites in Santa Barbara Basin. Color and contrast have been enhanced by editing in Photoshop (sediment in slide #733 has been slightly oxidized). Energetic turbidite flows eroded some of the underlying varves, whereas upper depositional boundaries to varved sediment are sharp.

A regular, annually varved sediment record from AD 1931 to 2009 was observed in a 2009 SBB box core from 585.8 m water depth (34° 16.847’ N, 120° 02.268’ W). However, below the 1931 varve, we found a turbidite resting on a ca. 1923 varve, as determined by cross-correlation of the pre-1924 varve pattern with records from other box cores featuring continuous 20th century varves (see color pictures and black/white scans of epoxy-embedded and polished sections in Fig. 2). The turbidite was likely triggered seismically on 5 August 1930 when a strong earthquake shook Santa Barbara (Hamilton et al., 1969). The turbidite bottom current of 1930 eroded about 7 annual varves from 1924 to 1930. Careful sectioning of a cylindrical sub-core from the same box core showed ca. 1-cm large rip-up clasts of varved sediment with various angles of lamination embedded in the lower portion of the 1930 turbidite.

The color contrast among varves in anoxic marine sediments depends in part on the preservation of sulfide mineral pigmentation. Our experience with SBB sediment shows that storage of unopened piston cores in PVC core liners for one year in a cold room can cause significant oxidative loss of sulfides and dramatic color changes in affected sediment (Fig. 3). Early sampling and impregnation of sediment mini-slabs with Spurr epoxy resin effectively stops the oxidation of sulfides and preserves a useful color contrast, although the resin itself darkens the sediment and reduces the contrast.

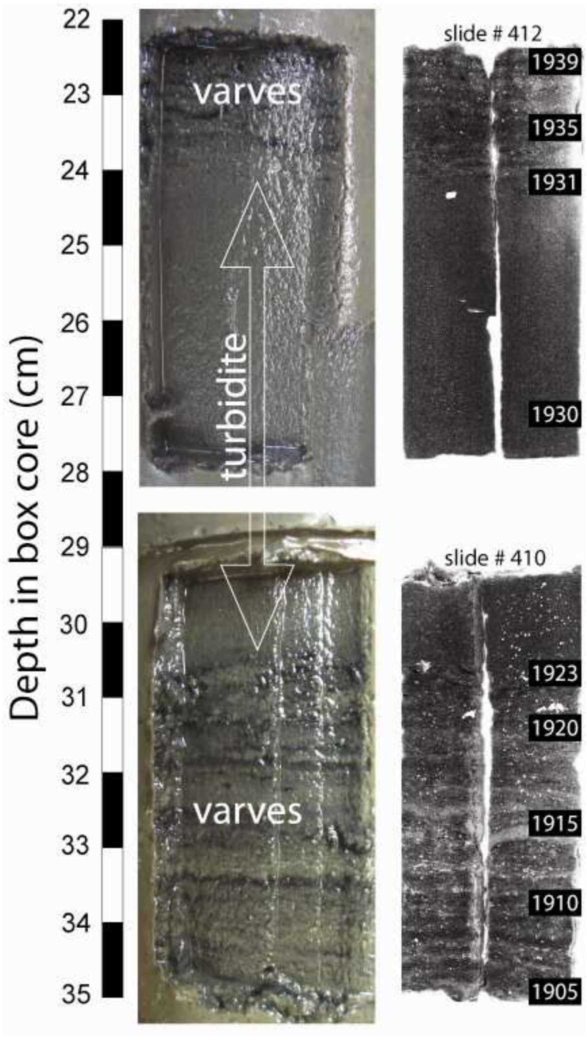

Fig. 2. A 1930 AD turbidite in a box core is resting on a ca. 1923 AD varve in Santa Barbara Basin sediment. Varves of ca. 1924 – 1930 have been eroded during emplacement of the turbidite and are missing. The left images are photographs from the exposed sediment core after cutting mini-slabs, whereas the right images are black/white, Photoshop-enhanced scans of the polished surfaces of epoxy-embedded mini-slabs.

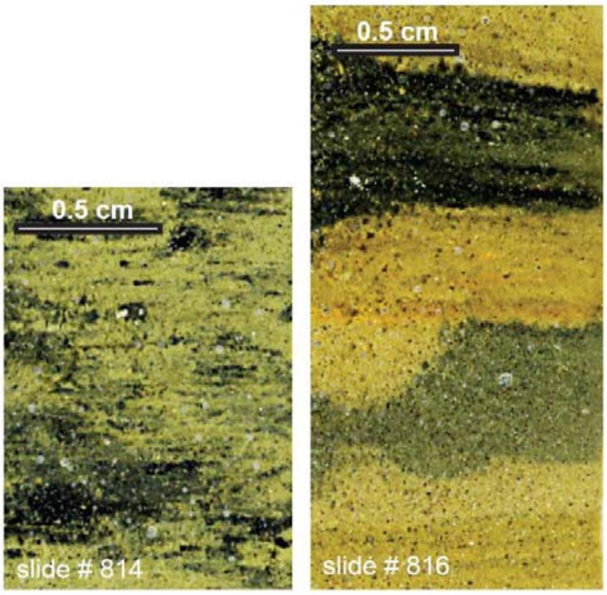

Fig. 3. Color scans of water-wet, partially oxidized sediment from a Santa Barbara Basin piston core that had been left unopened in storage in a cold room for one year. Color and contrast have been enhanced by editing in Photoshop. Oxidation destroys sulfide pigmentation, brightens sediment, and reduces contrast between varves. Oxidation preferentially follows cracks in sediment cores and progresses faster in more permeable sediment with lower abundances of sulfide and organic matter.

Acknowledgements

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Suigestu Varves 2006: An automated algorithm for varve interpolation

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The 1993 sediment core from Lake Suigetsu is one of the most comprehensive terrestrial radiocarbon records. It is extremely rich in leaf fossils, providing a unique, truly atmospheric record of radiocarbon for the last 10-50 kyr BP (Kitagawa & van der Plicht, 2000). Since the Lake Suigetsu sediment is varved for much of its depth it is suitable for extending the terrestrial radiocarbon calibration model up to 50 kyr BP. However, the data presented by Kitagawa & van der Plicht (2000) significantly diverged from alternative, marine-based calibration datasets, due to gaps in the sediment profile and varve counting uncertainties (Staff et al., 2009).

In 2006 four parallel cores were recovered from Lake Suigetsu and combined to construct a complete and continuous master profile (SG06). Along with a new program of AMS radiocarbon measurement, varve counting is being carried out using two different techniques: i) thin section microscopy and ii) high-resolution X-ray fluorescence and X-radiography (Marshall *et al.*, this workshop).

Due to poor varve preservation in some sediment intervals, the counts of these sections have to be interpolated. The new approach presented here is based on an automated analysis of frequency distributions of annual sub-layers from the compromised section itself, allowing an estimate of sedimentation rate that is unbiased by neighbouring sections or subjective interpretation.

The interpolation is tested on artificial data in order to determine the ideal settings for the interpolation. The settings may depend on variables such as sedimentation rate or percentage of interpolated years. Moreover, the artificial data can be used to define the method-error.

Sedimentation rates are calculated from the independent varve counts (microscopic and µXRF) and are then combined. The application of these sedimentation rates (combined and independent) to the raw counts yields a varve count synthesis, as well as an error estimate for the age model.

Comparison of the varve count synthesis for the Late Glacial with the radiocarbon dates calibrated using Intcal04 (Reimer *et al.* 2004) and Fairbanks *et al.* (2005) shows good agreement between the chronologies.

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Spectral imaging of sedimentary pigments in varved sediments – method and applications

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As a novel technique of rapid high-resolution paleolimnological analysis, we studied the applicability of spectral reflectance analysis for determination of sediment optical properties, and particularly chlorophyll quantification. We used spectral cameras analyzing both the visible (380-780 nm) and infrared (900-1750 nm) ranges. The work was focussed of the characteristic chlorophyll reflectance properties.

Analysis of different types of lake sediments showed that the reflectance spectra typically contain a depression around the 675 nm wavelength, due to the sedimentary chlorophyll derivatives. In a test set of ten samples representing different types of sediments, a good linear correlation ($r^2 = 0.76$, $p < 0.001$, $n=10$) was obtained for a first-derivative index of the depression and ethanol-extracted chlorophyll concentrations. The spectral analysis was then carried out on four sequences of annually laminated sediments, representing the past development (50 to 400 years) of limnologically different types of lakes. The analysis was done with 0.2 mm vertical resolution, and integrated annual chlorophyll deposition histograms (in arbitrary units) were computed as cumulative and averaged quantities. Examples of the results will be given.

Direct chlorophyll determination from natural reflectance spectra is well established in remote sensing studies of e.g. terrestrial vegetation and algal blooms. Our preliminary results show that the spectral analysis approach is applicable also in micro-scale for paleoproductivity assessment of sediments. The method may serve at least as an exploratory tool in tracking the trophic history of lake sediment sequences. Annually laminated of varved sediment sequences are of particular interest in these studies, while they represent the most accurate high-resolution environmental archives available in the nature. As a rapid non-destructive analysis, spectral imaging provides an approach to gather maximum amount of the available annual or even seasonal pigment and paleoproductivity information at reasonable expenses and work input.

The spectral imaging approach proved promising, but unfortunately we only received funding for a one-year pilot project. The work could be pursued further along several development paths, essentially enabled by the advanced analysis techniques and equipment developed at the InFotonics Center of the Universitiy of Eastern Finland:
- As a basic calibration work, comparisons and standardization of the reflectance properties of differently prepared sediment samples (fresh, freeze-dried, dried and compressed, embedded in different liquid or solid media);
- Further analyzing of other reflectance spectral properties besides the chlorophyll depression around 675 nm, including analyses of the IR reflectance spectra;
- Investigation of the fluorescence properties of sediments with a new high-sensitive detector system (250-800 nm range at 2 nm resolution), which would be highly suitable for the specification of sedimentary photosynthetic pigments.

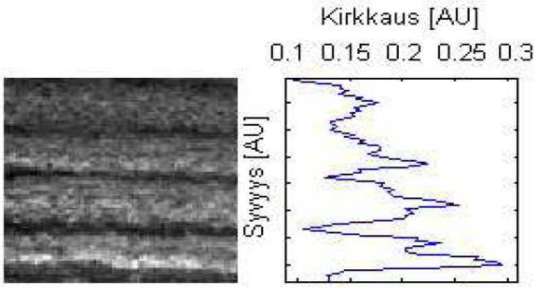

Fig. 1. Grey-scale image of four varves of Lake Laukunlampi, and their brightness in arbitrary units.

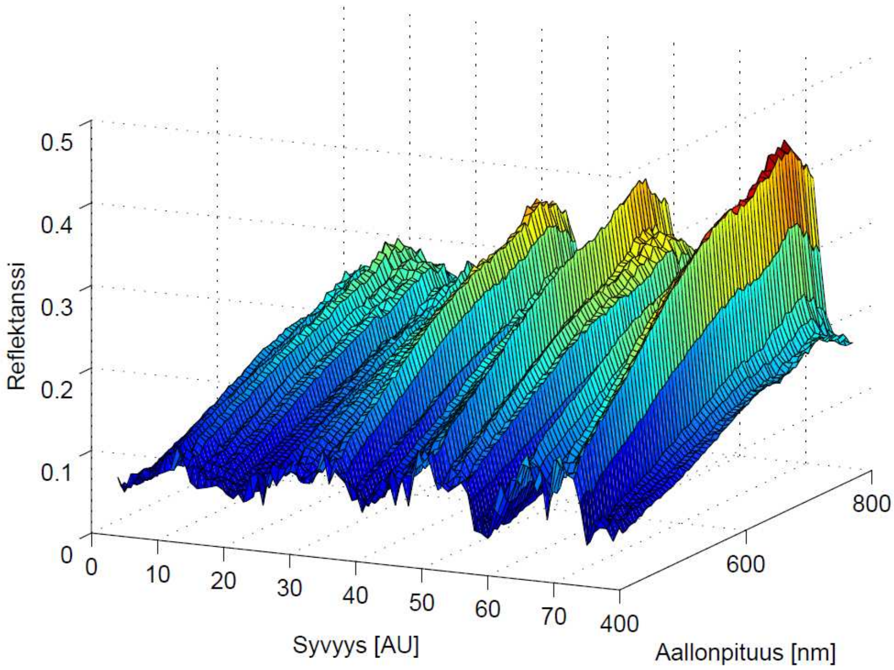

Fig. 2. Scan of the reflectance spectra (400-780 nm) across the four-varve sequence shown in Fig.1 (Fält 2006). Reflectance and depth (=Syvyys) scales in arbitrary units.

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Insights into the annual particle and sedimentation cycles of Lake Van (Turkey) by combining remote sensing data and sequential sediment trap analysis

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Lake Van is by volume the world's fourth largest hydrological closed lake (607 km^3) and by area the world's largest soda lake (3570 km^2). It is situated on a high plateau in Eastern Anatolia, Turkey, at an altitude of 1648 m above sea level. Lake Van holds a partially varved sedimentary record that spans potentially several glacial-interglacial cycles. Thus, Lake Van became a key site within the International Continental Scientific Drilling Program (ICDP) for the investigation of Quaternary climate evolution in the Near East and targeted to be drilled as part of the PALEOVAN Project.

The modern sedimentation processes of Lake Van have never been investigated in detail, so that paleo-varve formation and its paleoenvironmental interpretation have not been calibrated to the modern lacustrine system. Indeed, such a calibration is necessary to determine the dependency of sedimentary processes from environmental conditions. Within this study, this link is obtained by combining well-established limnological methods (e.g. water column measurements and sequential sediment traps) with state-of-the-art remote sensing data. Remote sensing observations provide data of high spatial and temporal resolution, which offers a novel perspective to achieve a comprehensive knowledge of particle processes within the epilimnion.

The sediment-trap based particle fluxes between July 2006 and August 2009 show high fluxes during spring and autumn, and low fluxes during winter (Fig. 1). This pattern agrees with the satellite-based total suspended matter (TSM) estimates illustrating high particle-concentrations from spring to autumn (Fig. 2). ~400 mg m^{-2} d^{-1} particles were recorded annually, which are composed of aggregated carbonates, diatoms, chrysophycean cysts, amorphous organic material and detrital minerals (Fig. 3). The autochthonous carbonates are the main component of the particle flux. From space, carbonate precipitation occurring in whitings is visible as surface plumes at the river inlets and as strong-reflecting km-wide areas within the deep Tatvan Basin indicating surface currents, i.e. eddies. Satellite data, showing high particle-concentration in the summer months, allow filling the gaps of sediment-trap data missing from that period. An exceptionally high carbonate-productivity peak during winter 2007, recorded with the sediment traps, could also be confirmed with satellite images. These refine the knowledge of the annual particle cycle due to their higher temporal and spatial resolution.

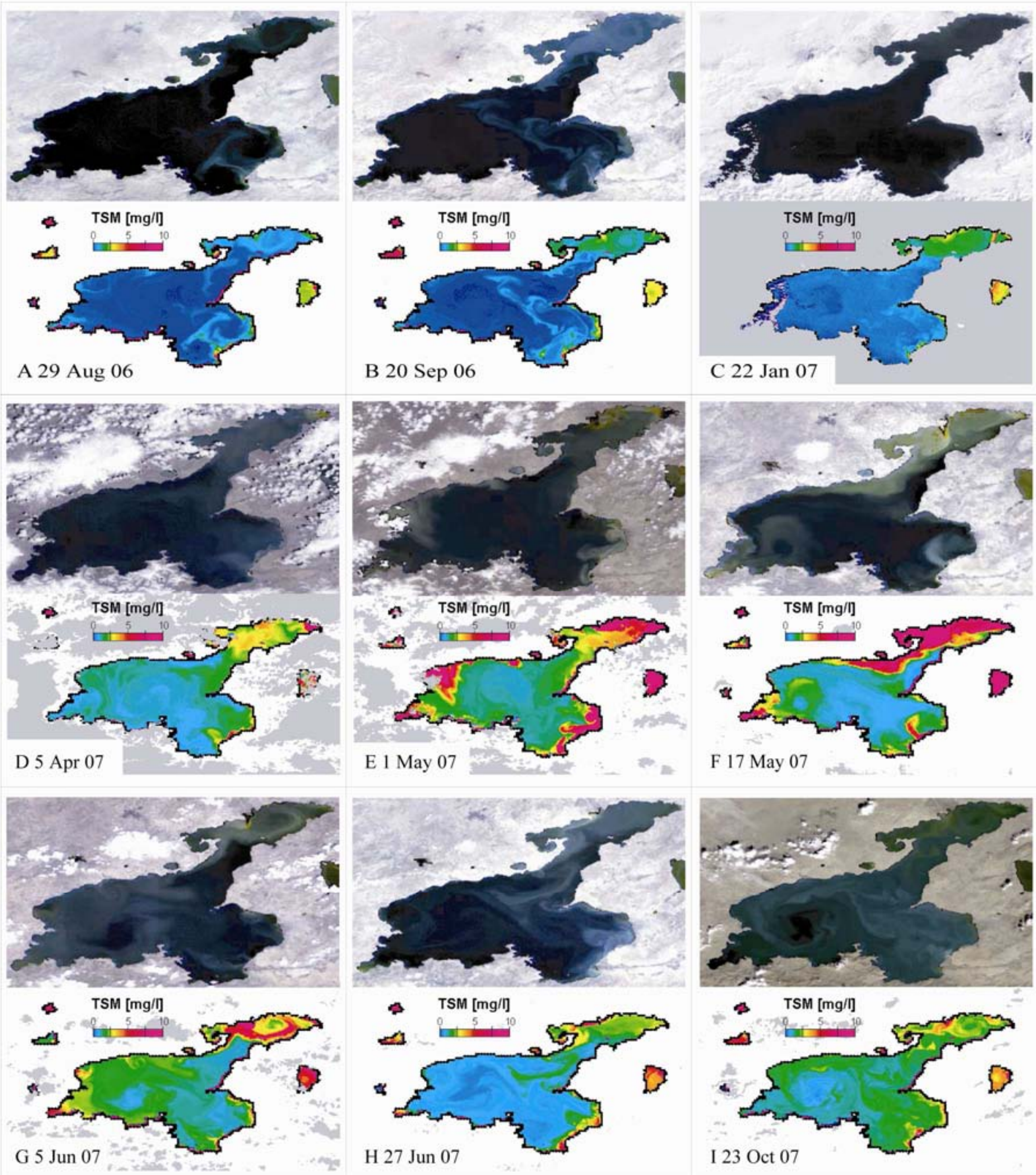

Fig. 1. Time series of MERIS image couples (A to I) each with the true color composites on top and TSM concentration map below. The grey areas are pixels, where the algorithm set the “bright” flag indicating clouds or snow (specific threshold at 442.5 nm).

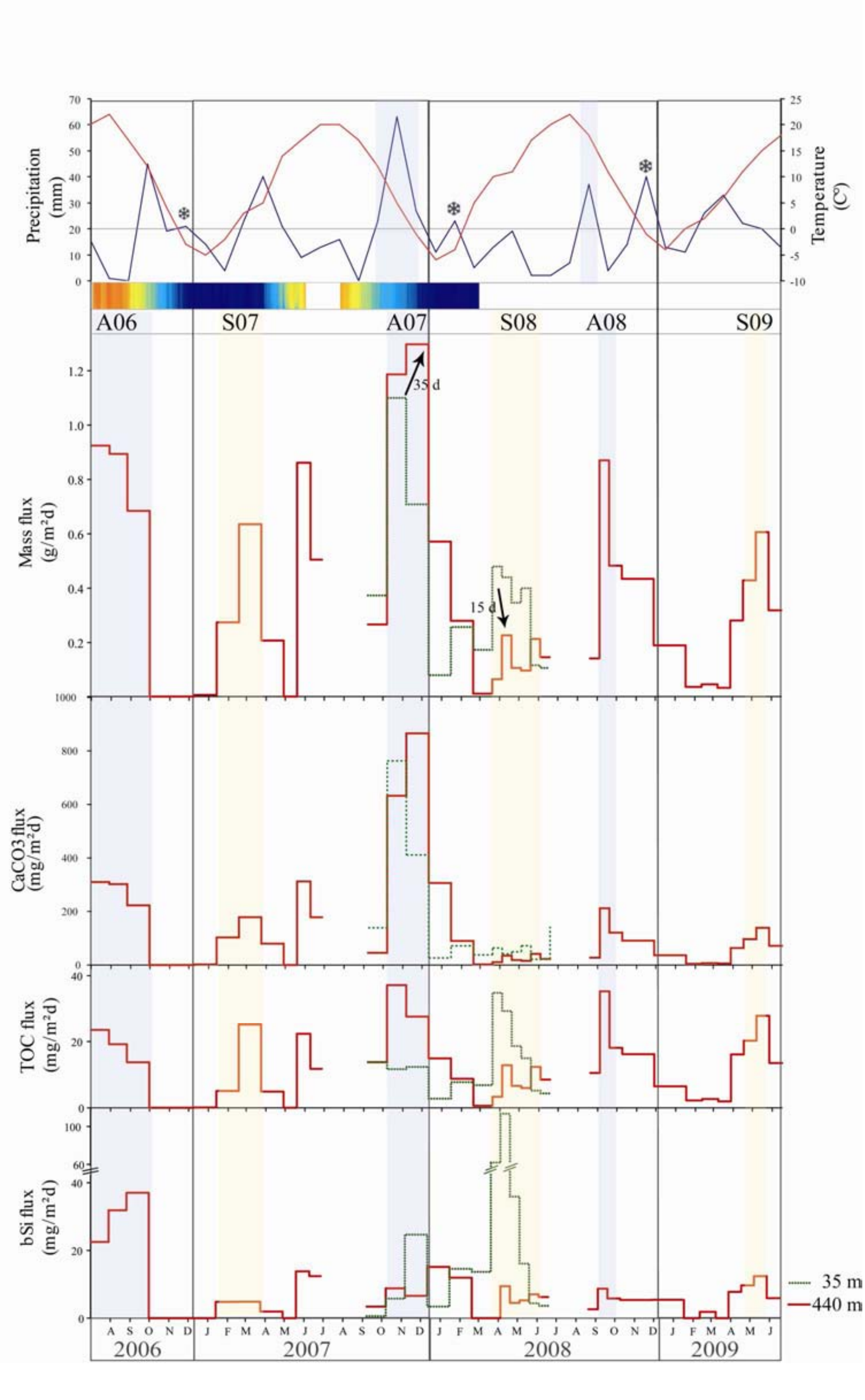

Fig. 2. Time-series of sediment trap data. Top: Monthly mean air temperatures and precipitation displayed together with the water temperatures (color code given in Fig. 8). The snow flakes represent snow precipitation. Below: Mass flux, CaCO3 flux, TOC flux and bSi flux over 3 years at epilimnion trap at 35 m depth (green line) and hypolimnion trap in 440 m depth (red line). A06, SO07, A07, S08, A08 and S09 refer to the high particle-flux periods (S= spring, A=autumn). Black arrows indicate the delays between the arrival of the particle flux peak at 35 m depth and 440 m depth, which consist of 35 days (a), respective 15 days (b).

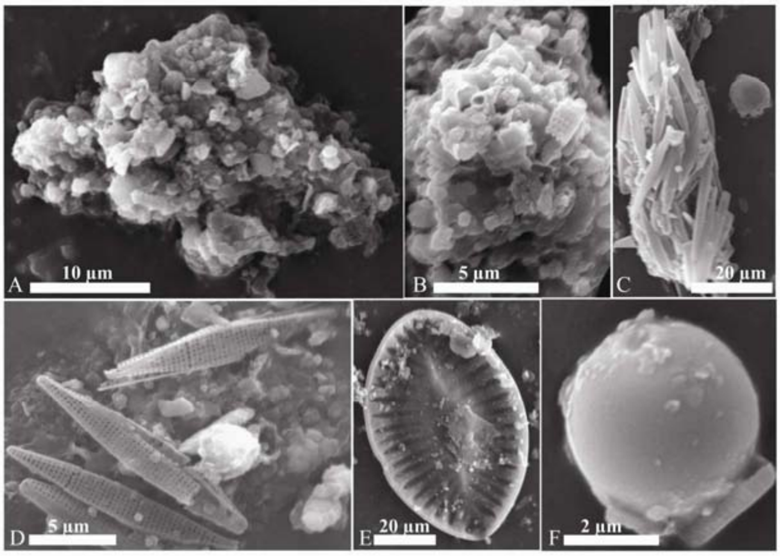

Fig. 3. SEM pictures of sediment trap samples all from 440 m water depth with scale as width of the image; A. Autochthonous carbonates (S-trap sample 08.03.-12.04.07); B. Autochthonous carbonates (S-trap sample 08.03.-12.04.07); C. Fecal pellet build of pennate diatoms (S-Trap sample 08.03.-12.04.07); D. Diatoms and autochthonous carbonates (Z-trap sample 14.07.06-22.07.07); E. Pennate diatom (S-trap sample 08.03.-12.04.07); F. Chrysophycean cyst (S-trap sample 14.09.-19.10.06).

The annual particle cycle of Lake Van and its inter-annual variability are a product of changes in runoff, temperature and water mixing, all of which are controlled by climate. The seasonal nature of these changes, i.e. high and low particle-production periods, result in seasonal particle pulses that, due to bottom water anoxia, become preserved as laminated varves. High-resolution XRF measurements of sediment cores show a clear correlation of Calcium peaks to light laminae (Fig. 4), which reflect the particles of the whitings during spring and autumn. High-resolution SEM/EDX analysis of thin sections will be used in the future to get insights into the mineralogical composition of the varves at seasonal resolution.

The combination of the satellite-based information with the well-established limnological methods provides a powerful approach to determine the linkages between physical water processes and geochemical particle processes. Calibrating the ongoing water column and particle processes with instrumental climate data will furthermore allow for better paleoenvironmental interpretations of the annually-laminated sediment record from Lake Van.

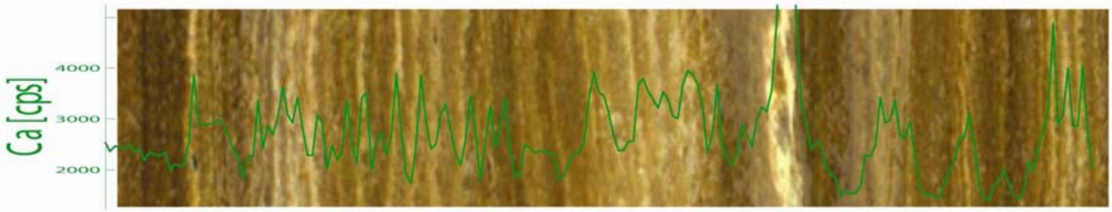

Fig. 4. 4 cm long section of a sediment core (Van07-05) from the Tatvan Basin at the mooring position matched with high resolution Calcium intensities. The sub-mm lamination is composed of an alternation of light-colored lamina mostly composed of carbonate and a dark lamina mostly composed of organic matter and allochthonous constituents. Each couple is interpreted to represents one annual particle cycle, i.e. a year.

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High-temporal resolution reconstruction of East Antarctic climate changes based on a varve analysis

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The goal of my research project is to reconstruct paleoclimate and ecological changes in Enderby Land (East Antarctica) by means of a multi-proxy biological analysis (diatoms, fossil pigments and ancient DNA) from radiocarbon-dated lake sediment cores. More specifically is my aim to answer following research questions: (i) How did ice sheet thickness change over the period from the Last Glacial Maximum until now?, (ii) How did the temperature dependent precipitation-evaporation history in this region vary over shorter to longer timescales? and (iii) How did ecosystem characteristics (primary production) and taxonomic composition change in function of climate anomalies?

From one of the lakes, we retrieved a finely laminated sediment core, which can potentially provide an absolute time scale (by varve counting) and a high-resolution paleoclimate reconstruction (Boës and Fagel, 2005). A sedimentation rate of 15 years per centimeter has been estimated based on a preliminary calculation, indicating that the record probably covers the last 900 years. This should allow us to examine whether the Medieval Warm Period (MWP) (1100-700 yr BP), the Little Ice Age (LIA) (300-100 yr BP) and the recent discovered temperature increase from West Antarctic ice cores (Schneider and Steig, 2008), have an East Antarctic analog. Thin sections were produced following the revised method by Boës and Fagel (2005). Digitalized thin sections will be analyzed using the ImageJ software and the most recent varves will be calibrated based on direct weather data available since 1957 for this region (surface temperature, sea level pressure and wind speed) (Sato and Hirasawa, 2007). We hypothesize that during relatively warm springs and summers, primary production will increase due to a lesser ice extent and/or a higher water temperature, which will be reflected in the thickness of the biogenic zone of the varves. However, the laminated structure seems to be lost in the thin sections produced so far, most likely due to the very high water content of the core. Consequently, I hope to learn alternative methods for varve analysis and find an answer to the following questions: (1) Is it possible to count and measure the individual laminations on a high-resolution picture or would this lead to an underestimation of the correct number of varves, as stated in Lotter and Lemcke (1999)? and (2) Is there another impregnation method available, particularly suited for sediment cores with a high water content?

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Glacial and interglacial climate variability in Guaymas basin (Gulf of California) from a varved record

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The latest Quaternary in sediment core MD02-2515 (65 m, 7-50 kyr BP, Gulf of California) is predominantly varved with few bioturbated intervals and is therefore ideally suited to test for interaction on all scales of climate variability from orbital (glacial/interglacial) via millennial (D/O cycles) to interannual oscillations (ENSO). Guaymas Basin allows reconstruction not only of regional upwelling and precipitation but also of intermediate and subsurface ocean circulation in the North and Equatorial Pacific. A varve age model, supported by radio- carbon dates, correlation of δ15Norg data with the GISP2- record and backscatter electron imagery (BSEI), has allowed the estimation of biogenic and lithogenic fluxes at annual to near-annual resolution. The distribution pattern of opal does not correlate with typical North Atlantic patterns (e.g. D/O cycles). Annual resolution records of opal content and δ15N in laminated intervals from the last glacial, Bølling/Alleröd and Holocene show ENSO-like variability, but there is no consistent change in strength or frequency. Rates of opal, TOC and lithogenic material during the last glacial were 2-3 times higher than Holocene rates, indicating that carbon export production is controlled by total mass fluxes. Strong correlation between opal and benthic foraminifer δ13C indicates the main control on basin dysoxia is regional productivity (as opposed to intermediate water circulation). The linking of ultra-high resolution opal data with BSEI demonstrates the site's exceptional potential.

Assessing the potential of varved sediments of Lake Silvaplana (South-Eastern Switzerland) for high-resolution quantitative climate reconstruction

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High-resolution quantitative temperature records are needed for placing the recent warming into the context of long-term natural climate variability. In this study we test the potential of sediments of varved Lake Silvaplana (south-eastern Swiss Alps) to yield quantitative high-resolution climate reconstructions. Lake Silvaplana is a small (2.7 km^2), deep (78 m), distal (10 km from glacier terminus), proglacial, high altitude (1791 m a.s.l.) lake. In 1998, 5% of the catchment area was covered by three small glaciers. The sediments of Lake Silvaplana formed varves during the last 3500 years. In the first part of this study, we present a high-resolution quantitative summer (JJA) temperature reconstruction based on a combination of the decadal-frequency component (9-100 yrs) of annually resolved biogenic silica (bSi flux) data and the centennial-frequency component of decadal chironomid-inferred temperatures back to AD 1177.

For the calibration (period AD 1864 – 1949) we assess systematically the effects of six different regression methods (Type I regressions: Inverse Regression IR, Inverse Prediction IP, Generalised Least Squares GLS; Type II regressions: Major Axis MA, Ranged Major Axis RMA and Standard Major Axis SMA, Figure 1 a,b,c) with regard to the predicted amplitude and the calibration statistics such as root-mean-square error of prediction (RMSEP), reduction of error (RE) and coefficient of efficiency (CE). We found a trade-off in the regression model choice between a good representation of the amplitude (Type II regressions) and good calibration statistics (Type I regressions). Since the amplitude is the essence of climate variability we recommend using a Type II regression which accounts for an error on the predictor and the predictand. Here, a combination between MA and SMA (Type II regressions) performed best ($r=0.67$, $p< 0.04$; RMSEP=0.26°C, RE=0.22, $\Delta \mathrm{Amplitude}_{(\mathrm{predicted} - \mathrm{observed})} = 0.03$°C; RMSEP/Amplitude=0.197).

The band-pass filtered bSi flux record is in close agreement both in the structure and the amplitude with two fully independent reconstructions spanning back to AD 1500 and AD 1177, respectively. All known pulses of negative volcanic forcing are represented as cold anomalies in the bSi flux record. Volcanic pulses combined with low solar acitivity (Spörer and Maunder Minimum) are seen as particularly cold episodes around AD 1460 and AD 1690 (Figure 2 a,b,c). The combined chironomid and bSi flux temperature record is in good agreement with the glacier history of the Alps. The warmest (AD 1190) and coldest decades (17th century; 1680-1700) of our reconstruction coincide with the largest anomalies in the Alpine tree ring based reconstruction; both records show in the decadal variability an amplitude of 2.6°C

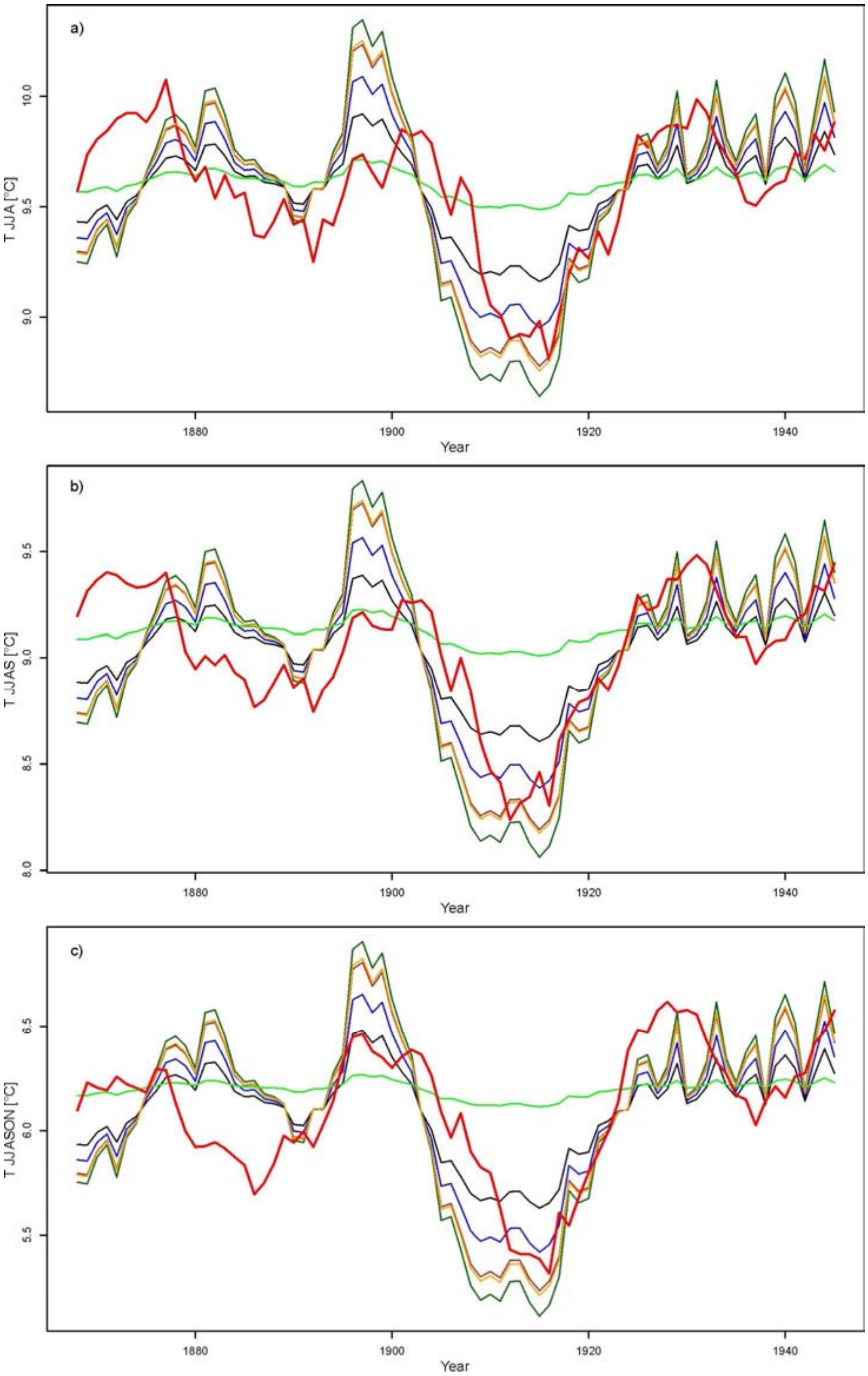

Fig. 1. Comparison of meteorological data (red; Sils Maria) and bSi-inferred temperatures 9-years smoothed (a) top panel JJA; b) middle panel JJAS, c) bottom panel JJASON) calculated with six different regression methods: Inverse Regression (black), Inverse Prediction (green) and Generalised Least Squares (brown), Standard Major Axis (geometric mean) regression (blue), Ranged Major Axis regression (brown) and Major Axis regression (orange) . Inverse Prediction predicts systematically the largest amplitude compared with the instrumental data (red); SMA and RMA regressions are closest to the amplitude of the instrumental record, Inverse Prediction and Generalised Least Squares regression underestimate the amplitude.

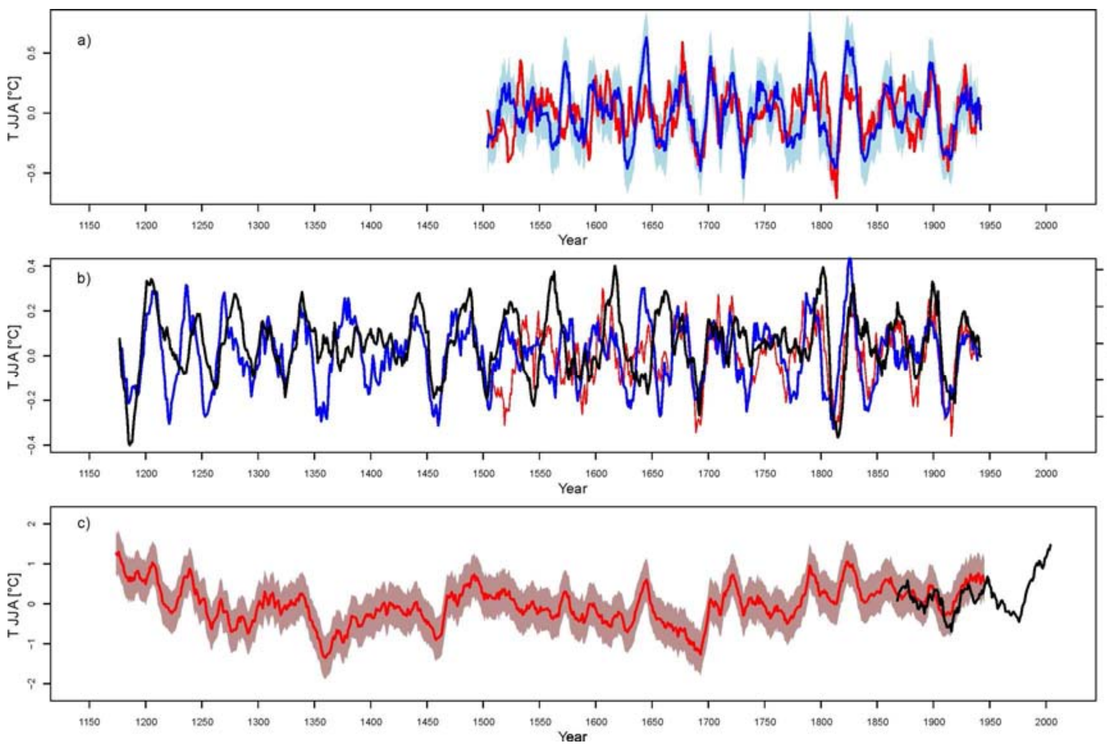

Fig. 2. (a) 100-year high-pass filtered and 9-year smoothed (9-100 years band-pass filtered) bSi flux-based temperature reconstruction AD 1500 – 1949 (blue, light blue indicating the RMSEP) and multi-proxy summer temperature reconstruction (red; Casty et al. 2005, data filtered in the same way). (b) 15-100 years band-pass filtered bSi temperature reconstruction AD 1177 – 1949 (blue), Casty et al. (2005) JJA temperature reconstruction (red) and tree ring based Alpine summer temperature reconstruction (Büntgen et al. 2006) (black). (c) Combined chironomid and bSi flux-based summer temperature reconstruction (9-year running mean, red, light red indicating the uncertainty) and 9-year running mean of summer (JJA) temperature from adjacent station Sils Maria (black). All anomalies are given with respect to the period 1961 – 1990).

between AD 1180 and 1950, which is substantially higher than the amplitude of hemispheric reconstructions. Our record suggests that the current decade is slightly warmer than the warmest decade in the pre-industrial time of the past 800 years.

In the second part of this study, we systematically explore the potential of scanning in-situ reflectance spectroscopy in the visible spectrum (380 – 730 nm) as a novel tool for quantitative, high-resolution (2 mm) climate reconstructions that are well-calibrated against and validated with local meteorological data. Varved Lake Silvaplana (south-eastern Switzerland) is chosen as a case study, because (i) the chronology (varve counting corroborated with documented flood layers back to AD 1177) is very accurate, (ii) the mineralogical and geochemical composition of the sediments are very well understood, (iii) long meteorological data series are available for calibration and verification and, (iv) independent reconstructions are available for comparison. This allows us to assess the performance and skills of the novel method on instrumental and longer time scales.

First, we characterized the individual reflectance spectra with six spectral features (variables). According to principal components and redundancy analysis (PCA, RDA), the six variables reflect the mineralogical composition of the sediments (mainly biotite, illite and chlorite). Individual and combined variables (multiple linear regression) were calibrated against mean instrumental June to September (JJAS) temperature data (AD 1864 – 1950) and tested for their performance (root mean square error of prediction, RMSEP). The best calibration model (Figure 3) was based on three variables (Trough590-730, Min690 and Min 480). It explains 84% of the variance of the meteorological data (1864 – 1950) and has a Leave-One-Out RMSEP of 0.1°C.

The JJAS temperature reconstruction back to AD 1177 is in good agreement with two fully independent temperature reconstructions from documentary (back to AD 1500) and tree-ring width data confirming the high performance of the scanning reflectance-spectroscopy method and reconstruction (Figure 4 (a,b,c,d)). All the major tropical volcanic eruptions (negative forcing) appear as multi-annual negative summer temperature anomalies that were particularly pronounced if combined with solar minima.

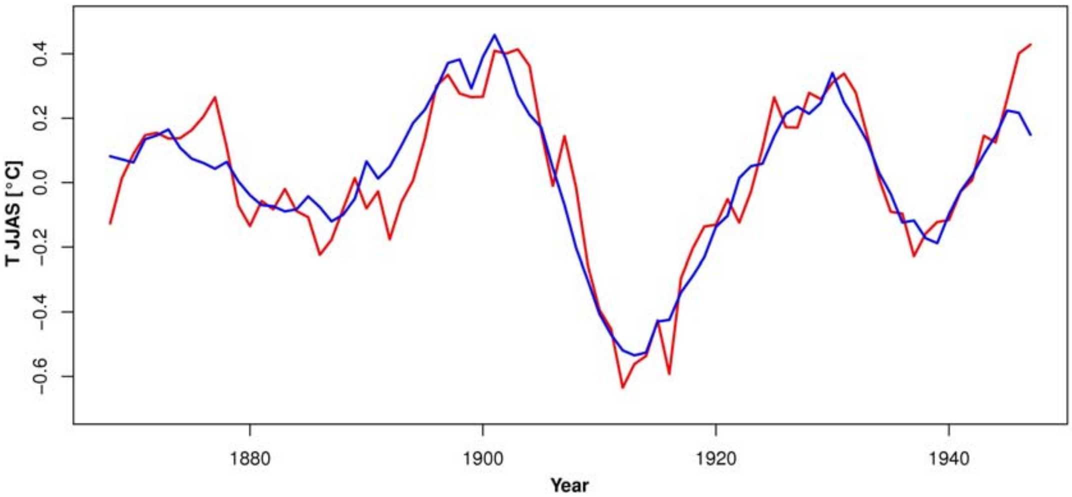

Fig. 3. Multivariate Calibration of detrended 9-year smoothed spectrum-derived variables (blue) with detrended 9-year smoothed TJJAS (red) r^2=0.84. The calibration model is based on multiple linear regression and includes three variables.

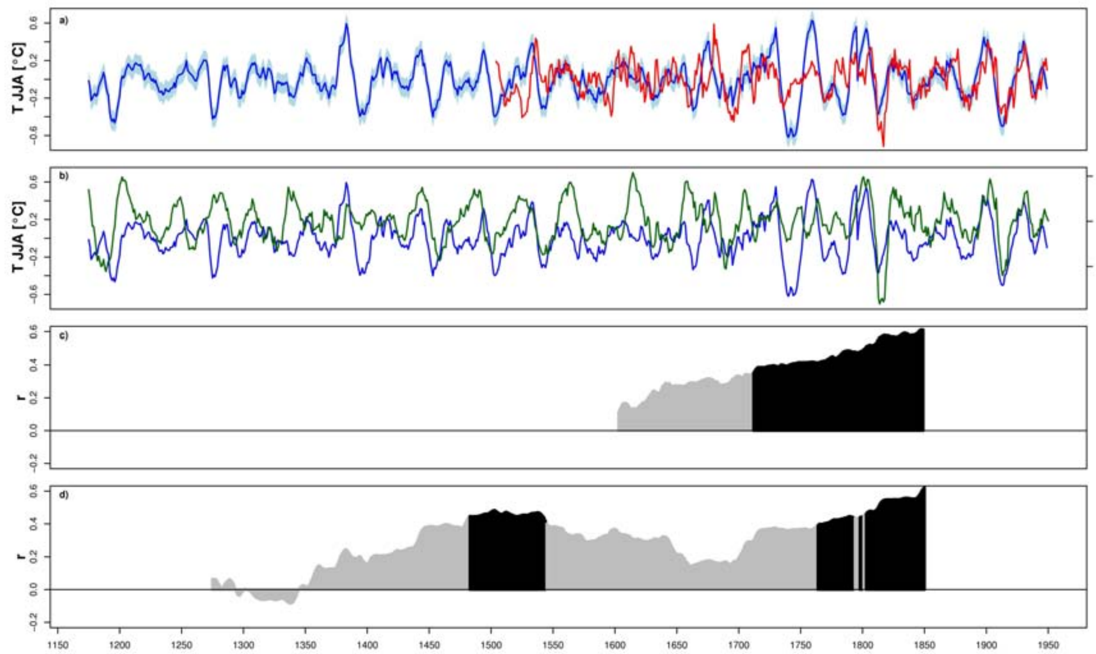

Fig. 4. (a) Comparison of reflectance inferred T JJAS reconstruction using multiple linear regression including 3 variables (blue), with the T JJA reconstruction based on early-instrumental and documentary data (red) (Casty et al. 2005) (b) Comparison of reflectance inferred T JJAS reconstruction with the late-wood density (mxd) based T JJAS reconstruction (green) (Büntgen et al. 2006). 200-year running correlations of the reflectance inferred T JJAS reconstruction with (c) T JJA Casty et al. (2005), (d) tree-ring based (late-wood density) TJJAS reconstruction (Büntgen et al. 2006). Significant (p_c<0.1) correlations are highlighted in black. For running correlation the year indicated is the central year of the 200-year time window.

Impact of landscape changes on the sedimentary record of lakes in South-Central Chile

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Several natural processes can lead to catastrophic landscape changes. The most important ones are earthquakes, volcanic eruptions and floods, which in their turn can cause landslides and mudflows (Keefer and Larsen, 2007). Very strong earthquakes usually have the most profound impact: i.e. by changing river courses, damming rivers by landslides, triggering volcanic eruptions etc. The consequences of these landscape changes are often even more destructive than the earthquake shaking itself.

With a moment magnitude of 9.5 the 1960 Valdivia earthquake was the strongest earthquake ever recorded. In the area that was most strongly affected by the earthquake, superficial as well as deep-seated landslides occurred, and the earthquake even triggered the Cordon Caulle volcano to erupt (Weisher 1963). In 1575 the same rupture zone produced a similar earthquake, and the flooding of Valdivia after the breakthrough of a landslide-dammed lake (Lago Riñihue) caused even more casualties than the earthquake itself. These giant mega-thrust earthquakes alternate with smaller-scale earthquakes, during which only a part of the rupture zone is activated, such as the 1737 and 1837 earthquakes (Cisternas et al., 2005).

The landscape changes induced by these large earthquakes will leave their imprint in lake sediments if they occur in the drainage basin of the lake. Using these lake sediments, the intensity and type of landscape change can thus be reconstructed further back in time than by only studying the geomorphology of the region. The occurrence of several lakes in the onshore area parallel to the 1960 rupture zone (as well as that of the 1575, 1737 and 1837 earthquakes) makes it possible to study the effects of each of these earthquakes in different parts of the affected region.

In 2008 and 2009, several short gravity cores (max 1.2 m long) were taken in 9 different lakes: i.e. Lago Villarrica, Lago Calafquén, Lago Pellaifa, Lago Panguipulli, Lago Neltume, Lago Riñihue, Lago Maihue and Lago Rupanco, from north to south. These cores consist of varved background sediments, interrupted by event deposits.

Several of the cores were impregnated for microfacies analysis. They contain four event deposits, which could be dated and linked to historical earthquakes by varve counting. The 1575 and 1960 earthquakes are present in almost every core, while the 1737 and 1837 earthquakes only left an imprint in some of the sedimentary basins. The varves, which consist of couplets of diatom-rich and clay-rich lamina, are generally thicker just after an event, to then gradually become thinner during the next two to three decades.

One radiocarbon-dated long core of Lago Riñihue with a promising event record and varved background sediments will be impregnated to construct a 2200-year varve chronology.

By analyzing the pre- and post-event varves, we will be able to study the effect of the landscape changes caused by each event (earthquakes, as well as volcanic eruptions). Varve thickness, mineralogical composition and chemical composition (micro-XRF) will be determined. These analyses will enable us to qualify and quantify the landscape changes linked to each of these catastrophic events for several drainage basins, and to better understand how such events finally get encrypted into the sedimentary record.

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Annually laminated lake sediment record from Rõuge Tõugjärv, southern Estonia – implications for paleoclimatic and palaeoenvironmental reconstructions

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Varve chronology based on annually deposited lake sediments yields a continuous high-resolution temporal record and allows absolute dating of the sediment sequence. Furthermore, pollen stratigraphical data allows to derive a quantitative temperature records as well as tracking changes in the vegetation as well as changes of prehistoric human impact on vegetation in the lake's catchment area. Whereas aquatic sub-fossils preserved in varved sediments provide precise data for reconstructing past trophic changes in lakes.

Lake Rõuge Tõugjärv (RTJ) is a small (surface area 4.2 ha and maximum depth 17 m) strongly stratified hard-water mesotrofic lake in a thermokarst depression in the ancient up to 75 m deep Rõuge valley. RTJ is the lowest of a chain of lakes connected by a stream in the ancient valley that cuts the western slope of the Haanja Uplands, the highest area in Estonia, with a characteristic hilly hummocky landscape.

The sediment sequence of 8.3 m mostly varved sediment was recovered from the lake. Chemical examination showed that the upper sequence varves consist of light clastic inorganic spring layer and dark organic winter layer, whereas the lower part of the sequence composes calcareous-organic varves. The chronology for sequence is based on counting of varves of multiple cores with a 1%–2% cumulative error. The age of the base of the varved sequence is at the core-depth of 761 cm is ca 9100 BC. However, as sediment section in between AD 1340 and ca 3250 BC varves is varied with homogeneous gyttja interlayers, therefore the mid and early Holocene part of the varve chronology is floating. It is anchored to the calendar-year time scale by correlation of the well-dated Lake Nautajärvi (Finland) paleomagnetic secular variation curve by Antti Ojala, Geological Survey of Finland. In addition, the chronology is supported by four AMS ^{14}C dates from terrestrial macrofossils. The annual nature of the laminations at the top of the core was independently verified with ^{210}Pb datings and by detecting ^{137}Cs, ^{241}Am, and carbonaceous fly-ash marker layers.

Quantitative annual mean temperature (T_{ann}, °C) reconstructions were compiled using Weighted Averaging-Partial Least Squares (WA-PLS) two component model of Finland-Estonia-Sweden modern pollen-climate calibration dataset and fossil pollen records from RTJ (Fig. 1). The reconstruction suggest a rising T_{ann} pattern during the early to mid-Holocene, with T_{ann} from ca. 1.5 to 7.0 °C at 9500 BC–6500 BC, punctuated by an abrupt decline at 6400 BC. The cooling trend culminated at 6250–6150 BC, when the T_{ann} was ca. 2.0 °C colder than prior to the cooling. The temperature rose to the highest Holocene level i.e. the Holocene thermal maximum at 4500–3500 BC with reconstructed T_{ann} 9.0 °C. The late-Holocene climate is characterised by the gradual decrease of T_{ann} from the Holocene thermal maximum toward modern conditions.

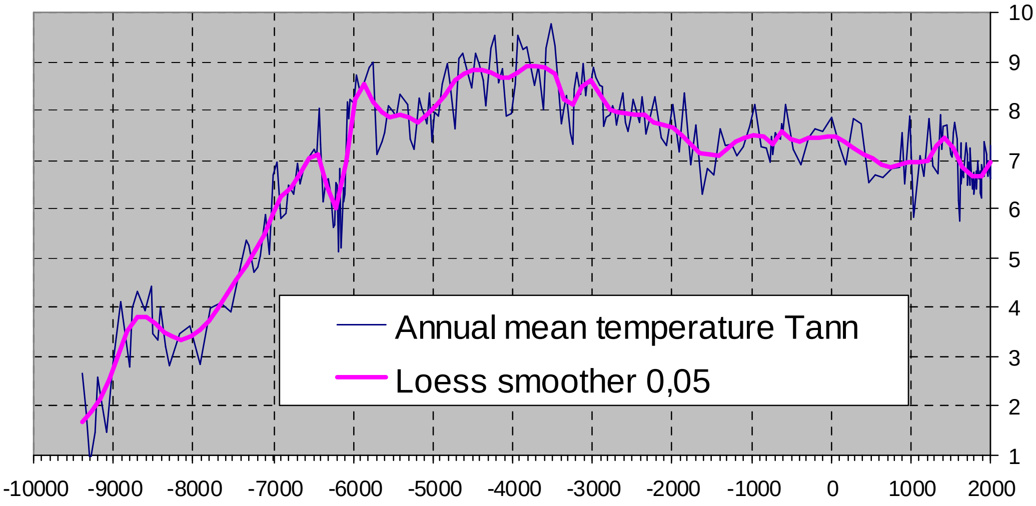

Fig. 1. Pollen-based reconstructed annual mean temperatures from Lake Rõuge Tõugjärv during the past 11400 years.

Quantitative pollen-based temporal-spatial land-cover reconstruction was performed using transformation coefficients derived from a modern pollen land-cover database and a palynological record from an annually laminated sequence in RTJ. The CA_Markov model was used to predict spatial distribution of 4 land-cover classes (woodland, grassland, arable land and settlements) at specific times (Fig. 2). Historical maps from AD 1684, 1870–1899 and 1935 were used for calibration of quantitative estimates and to validate spatial reconstructions. The land-cover reconstruction show development of the area from generally forested landscape (up to 13th century) through gradual opening phase between 13th–17th century to open cultural landscape with maximal deforestation of area reaching 90% during the 19th century. During last century the reforestation of the landscape is recorded.

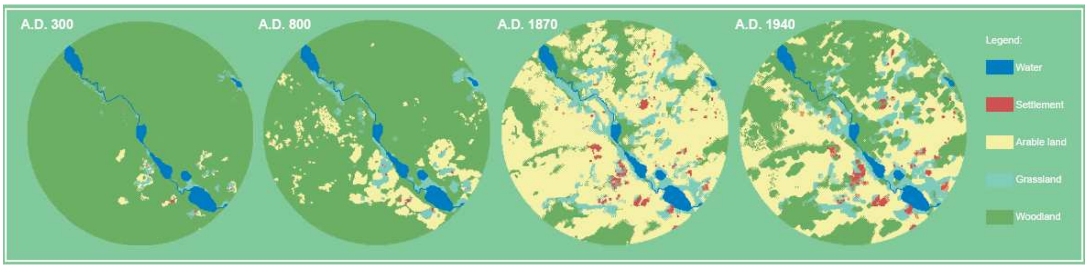

Fig. 2. Temporal-spatial reconstruction of land-cover around Lake Rõuge Tõugjärv based on pollen – land-cover calibration dataset and a CA_Markov land-use change model.

Diatom inferred lake epilimnetic total phosphorus concentrations (DI-TP) were reconstructed online (http://craticula.ncl.ac.uk/Eddi/jsp) using the northwestern European total phosphorus dataset of the European Diatom Database calibration training set and weighted averaging partial least squares regression (Fig. 3). The basal diatom assemblages indicate mesotrophic conditions at 9400 BC followed by a long period of stable nutrient poor conditions until 5500 BC. In between 5500 to 2000 BC lake nutrient conditions slightly rose. Paleolimnological evidence of permanent rural land-use around

RTJ appears from the onset of the Bronze Age, around 1800 BC, marked by the appearance of cereal pollen grains, contemporarily with an increase of other pollen based human indicators, such as ruderal plants. Simultaneously, the diatom composition data and the DI-TP values suggest that the lake was sensitive to this early human induced major catchment disturbance phase, influential change occurred in the lake water quality, in-lake nutrient concentrations increased and the lake switched from mesotrophic to eutrophic state and there was no lag between the external man-made catchment forcing and the lake response. Pollen evidence suggests that the maximum extension of both arable farming activities in the area was reached during the mid-19th century, whereas reconstructed DI-TP values for RTJ were the highest. The pollen data covering the last one hundred years showed a decrease of arable land and reforestation of the area due to the consolidation of farmsteads and more efficient land-use practices, and as a result, the lake responded rapidly to diminishing catchment activities and external loading reductions as seen from diatom composition and the DI-TP data.

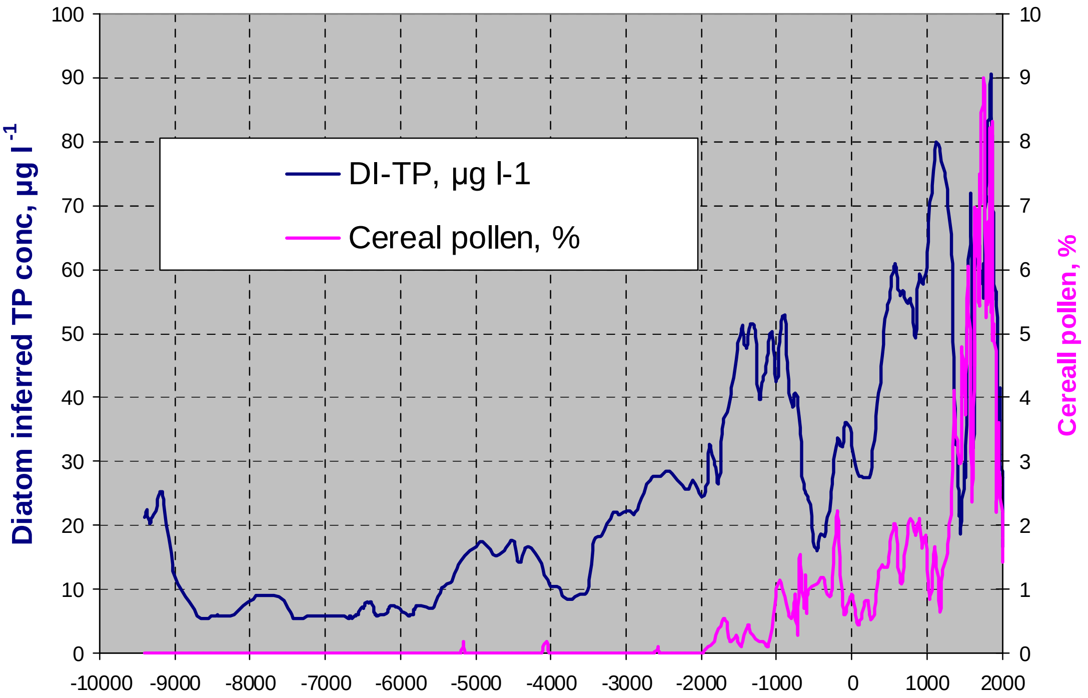

Fig. 3. Diatom-inferred lake surface water total phosphorus concentration (DI-TP; µg l^{-1}) and relative abundance (%) of the cereal pollen plotted against sediment age of Lake Rõuge Tõugjärv.

New tools for the varve community: laminae recognition (BMPix), fully automated counting (PEAK), and evolutionary spectral analysis (ESA-Lab)

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I will present tools for rapid and quantitative detection of sediment lamination, mainly based on the methods that have recently been published by Weber et al. (2010). The algorithms are also available at the Pangaea data library at doi:10.1594/PANGAEA.729700.

The **BMPix tool** is a viusual basic macro that can be executed from within Microsoft Excel. It linearly extracts red, green, blue (R/G/B), and gray values at pixel resolution along a profile line between freely adjustable start and end points (see Figure 1) from any given BMP image file. This means that color and gray values can be generated from surface images (e.g., photos, line-scan images) as well as from transmitted light images (e.g., x-radiographs, thin sections).

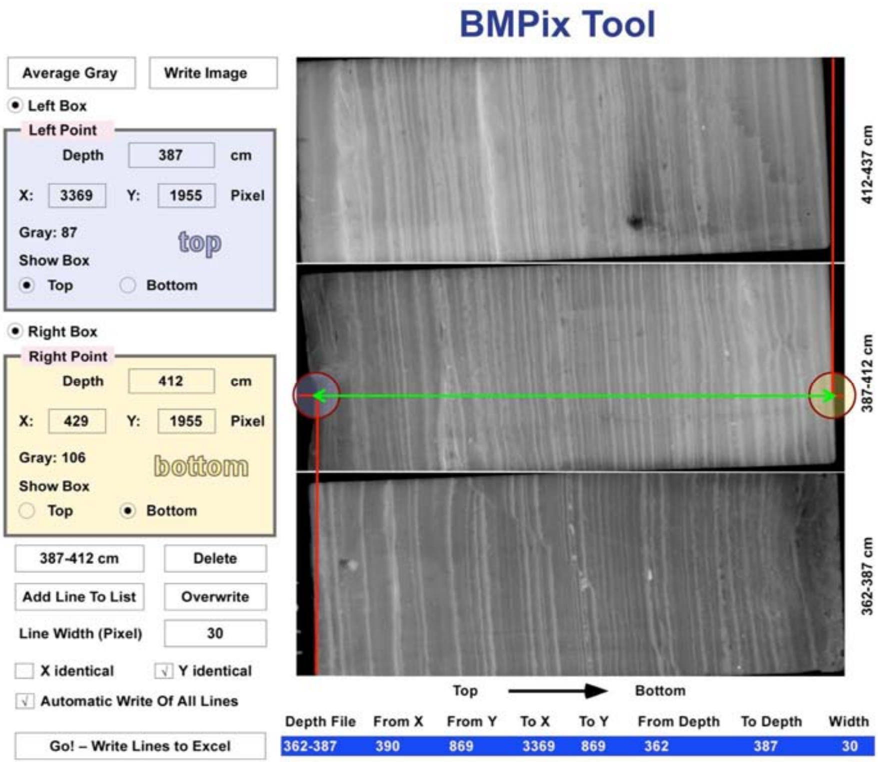

Fig. 1. Input mask of the BMPix tool (Weber et al., 2010). RGB and gray-scale data are generated at pixel resolution along a green profile line between pre-defined start (top, blue) and end (bottom, yellow) points for any given BMP image. Here, 2,940 data points (pixel 429 to 3,369) were measured at Site PS1599 over a 25-cm long x-radiograph image (387 – 412 cm core depth), i.e., resolution is 12 measurements/mm or 85 µm. White numbers on blue background contain reference data from previous profile line in section 362-387 cm. Upon completion, gray-scale data will be extracted from all profile lines added to the list.

The **PEAK tool** is another visual basic macro. It uses the gray-scale curve generated with the BMPix tool and performs, for the first time, fully automated counting of laminae based on three methods. The maximum count algorithm (Figure 2, top) counts every bright peak of a couplet of two laminae (annual resolution) in a smoothed curve. The zero-crossing algorithm (Figure 2, bottom) counts every positive and negative halfway-passage of the curve through a wide moving average, separating the record into bright and dark intervals (seasonal resolution). The same is true for the frequency truncation method, which uses Fourier transformation to decompose the curve into its frequency components before counting positive and negative passages.

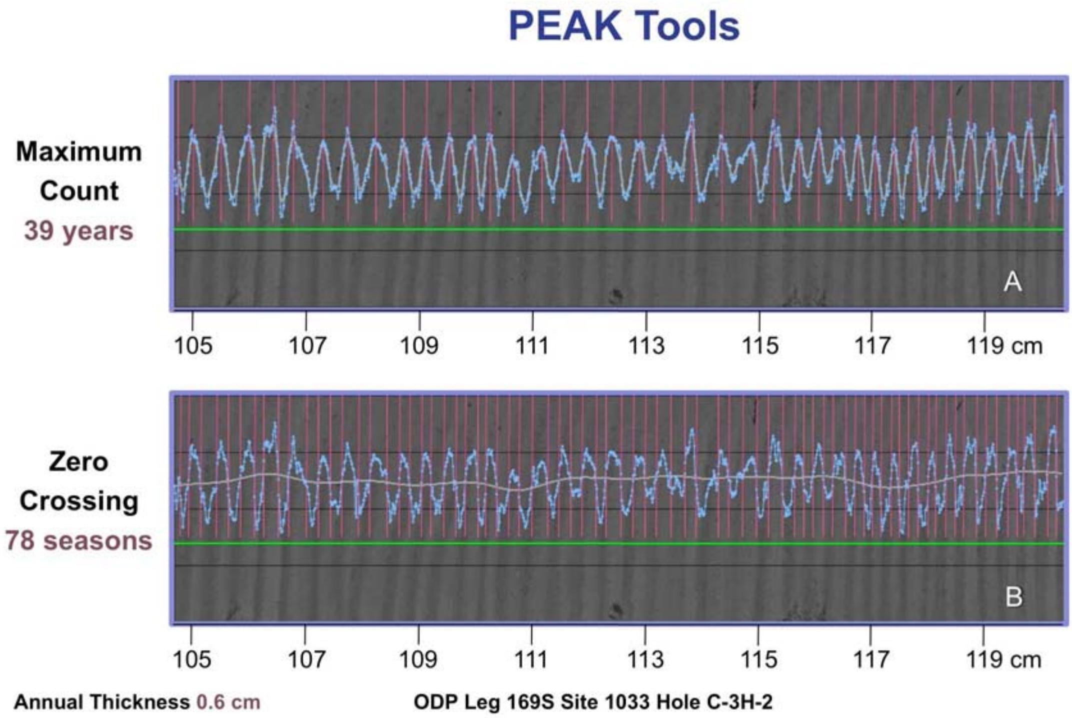

Fig. 2. The two main algorithms of the PEAK tool for automated layer counting (from Weber et al., 2010). Green gives profile line along which gray-scale curves (light blue) and moving averages (gray) are generated. Method is applied to Holocene varved sections from Saanich Inlet (underlying image; ODP Leg 169S Site 1033; Nederbragt and Thurow, 2001). Top shows maximum count algorithm, counting every maximum (purple bars) of a narrow moving average (i. e., every year). Bottom shows zero-crossing algorithm, counting all positive and negative passages (purple bars) of the gray curve through a wide and adjustable moving average (i. e., it counts every season).

So far, the new methods have been successfully been applied to tree rings, to well-dated and already manually counted marine varves from Saanich Inlet (Figure 2), and to marine varves from the Antarctic continental margin (Figures 1 and 3). Additional applications for the future include lacustrince varves, corals, and ice cores.

In order to study the resulting varve time series for frequency pattern and to compare them to modern-day climatic time series, we developed **ESA-Lab** to conduct both bulk spectral and evolutionary spectral analysis. This sofware relies on the Lomb (1976) and Scargle (1989) algorithms. It provides an estimate of the spectrum by fitting harmonic sine and cosine components to the data set. It has two decisive advantages: the input data can be unequally spaced and the resulting spectra are robust and of high resolution (see Figure 3).

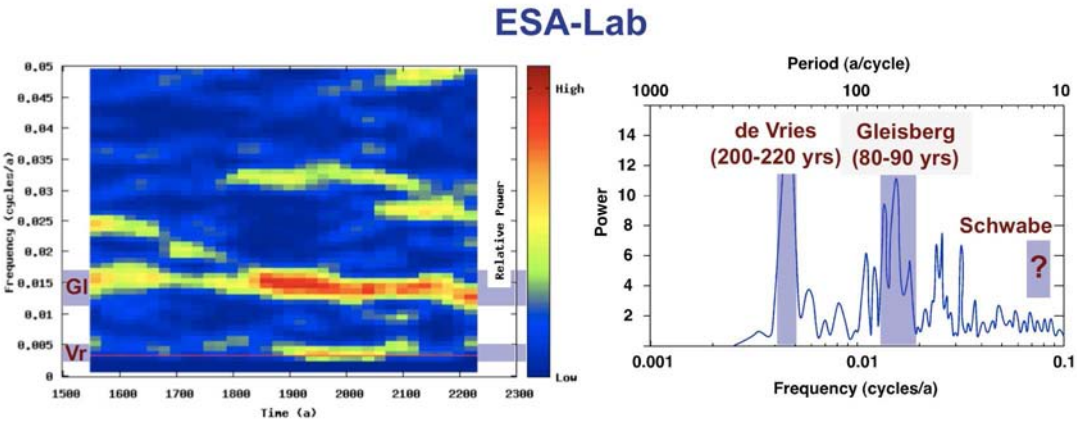

Fig. 3. ESA-Lab analysis on varves from the Antarctic continental margin for Site PS1789 (2411 m water depth). Right gives bulk spectrum over the entire time series (3323 model years during the last glacial maximum). Left shows evolutionary spectral analysis for a 800-yr time window between 1500 and 2300 model years. Note the occurrence of prominent sunspot cycles (pale blue shaded areas; Gl = Gleisberg cycle; Vr = deVries).

The new tools offer several advantages over previous methods:

- First, laminae recognition does not rely on image analysis with all the potential pitfalls involved. Instead, it uses gray-scale curves generated from images.
- Second, the counting procedures are based on a moving average generated from gray-scale curves instead of manual counting. Hence, results are highly objective, rely on reproducible mathematical criteria, and can be gathered rapidely.
- Third, since all information required for the analysis is displayed graphically, interactive optimization of the counting algorithms can be achieved quickly, objectively, and presicely, with a maximum visual control during execution.
- Fourth, the PEAK tool associates every count with a specific depth in a section. Therefore, it also measures the thickness of each year (maximum count method) or season (zero-crossing and Fourier transformation methods) for a varve couplet. Accordingly, PEAK results is predestinated for spectral analysis with ESA-Lab to find out which cycles dominate the response to changing climate conditions over decadal to centennial time scales and how robust these periods are through time.

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East African monsoon and ENSO variability since the last glacial

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Continental climate change during the last glacial is not as well understood within the tropics as it is for the high latitude region. This is particularly true on the African continent. The understanding and interpretation of tropical variations in temperature and humidity, as well as the documentation of short-term climate variability during the late Holocene and the last glacial period, is limited by the availability of well-dated high-resolution archives. Here we present a paleoclimate record from varved lacustrine sediments from Lake Challa (Kenya/Tanzania), which allows the reconstruction of environmental and climatic changes for the last 25,000 years.

Lake Challa (3°19'S, 37°42'E) is located at about 880 m asl on the lower eastern slope of Mt. Kilimanjaro, occupying a volcanic caldera within igneous rocks of the Tertiary Kilimanjaro complex. The monsoon-type climate of Lake Challa is controlled by the interannual latitudinal movements of the Inter-Tropical Convergence Zone (ITCZ). As a consequence of its geographic location in the centre of the ITCZ, Lake Challa experiences two well-defined rainy seasons per year. This precipitation pattern is visible in the sedimentary succession. The laminae at Lake Challa comprise alternating dark and light layers: the dark layers are composed of organic matter and occasional endogenic calcite; the light layers are composed primarily of diatoms and other algae. Comparisons with modern precipitation data and results of a monthly-cleared sediment trap indicate that varve thickness is dependent on the amount of annual precipitation, with thinner varves indicating high annual rainfall and vice versa. Since these sediments show a strong climatically controlled character we can use them as a valuable tool for reconstructing the amount of rainfall in previous times.

Two time-slices of climatic interest were chosen: (1) the last 3,000 years, representing warmer conditions and based on a varve chronology anchored to ^{210}Pb-series data and accelerator mass spectrometry ^{14}C dates, and (2) the glacial period between about 17,500 and 20,500 years BP, representing cooler conditions and based on varve counting controlled by ^{14}C dates. The oscillatory nature of the tropical ENSO process and the interaction between global climate anomalies and interannual ENSO extremes is very complex. Understanding ENSO dynamics and forecasting ENSO extremes are therefore challenging tasks. Our reconstructions from lake sediments have suggested external controls for modelling studies. Varve thickness measurements for the last 3,000 years correlate very well with ENSO indices such as the SOI (Southern Oscillation Index) and the NINO3 SST (Sea Surface Temperature) index. The similarities between the varve thickness record and ENSO records suggest a close coupling between the ENSO driven circulations and the east African climate during this time-slice, and exhibit a perfect correlation between both records. Analyses in the frequency domain indicate the presence of periodicities centered at 2.3, 3.6, and 5.8 yr intervals, suggesting that the East African climate was strongly affected by the ENSO.

Varve thickness measurements and analyses in the frequency domain were also completed for the glacial time-slice. The deglaciation pattern also show cycles between 2-7 years widths, but with the strongest power concentrated at 7 years. It also resembles an ENSO pattern, but is also different from the modern-day ENSO pattern. Our analyses showed less variability in the ENSO during cooler conditions, indicating that ENSO behaviour under different boundary conditions is very difficult to understand and requires further investigation.

Climatic and human control on lacustrine depositional processes: Evidences based on varved sediments from Lake Łazduny, Masurian Lake District (north-eastern Poland)

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For glacial Lake Łazduny in the Masurian Lake District (north-eastern Poland) a varve chronology has been elaborated for the time period since AD 550. Based on a comparison with independent radiometric dating (AMS ^{14}C, ^{210}Pb) the timescale was corrected for an 80 year-long erosional hiatus. Applying this precise chronology in combination with dry bulk density data, component specific sediment accumulation rates were calculated. The entire analysed time period is characterized by relatively low minerogenic input whereas productivity and redox conditions show large variations. Combining these data with stable isotopes of organic and inorganic carbon allows distinguishing between productivity and redox variations mainly controlled by climatic influences prior to AD 1600 from those mainly related to human impact since AD 1600. Of special interest is the Fe/Mn ratio, as it seems to reflect winter temperatures, i.e. the duration of lake ice cover and as such might be regarded as a proxy for the NAO in northern Poland. Prior to AD 1100 redox proxies indicate cold winters with an extended ice cover, meromictic conditions and low lacustrine productivity. The temperature increase related to the onset of the Medieval Warm Period caused a change to more positive values for carbon and oxygen stable isotope signals, corroborated by a slight increase in productivity as reflected by sedimentation rates of organic matter, diatom opal and authigenic calcites. However, there is no additional minerogenic sediment transfer into the lake basin. The latter is surprising as first signs of deforestation have been recognised palynologically for the 12th century. Thus we assume that a warmer climate is the main trigger for the observed fluctuation which also forced a less extended ice cover during winter, intensified mixing of the water column and thus determined the temporary end of meromictic conditions. Between AD 1500 and 1600 less primary productivity returned with an extended meromixis indicative of colder winters. This corresponds to the beginning of the Little Ice Age. However, at about the same time the foundation of villages in the vicinity of the lake could have caused human impact to veil any climatically caused variability: increases in allochthonous minerogenic and organic sediment components caused increases in lacustrine productivity represented by maxima in autochthonous organic matter and related calcite precipitation. Anthropogenic pulses of eutrophication centred around AD 1600, 1780

(after the hiatus represented by a 1 to 2.5 cm thick sand layer), 1870, 1920 and 1990 are characterised by high frequency decadal fluctuations while climatic variability prior to AD 1600 occurs more gradually and on centennial scales.

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