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3rd PAGES Varves Working Group Workshop

varves

Manderscheid (Germany)
March 20-24, 2012

Program and Abstracts

Maar Museum Manderscheid

Deutsche Forschungsgemeinschaft DFG

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PAGES PAST GLOBAL CHANGES

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(überarbeitete on-line Version)

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3rd PAGES Varves Working Group Workshop

Program and Abstracts

Bernd Zolitschka
(Editor)

Manderscheid (Germany)
March 20-24, 2012

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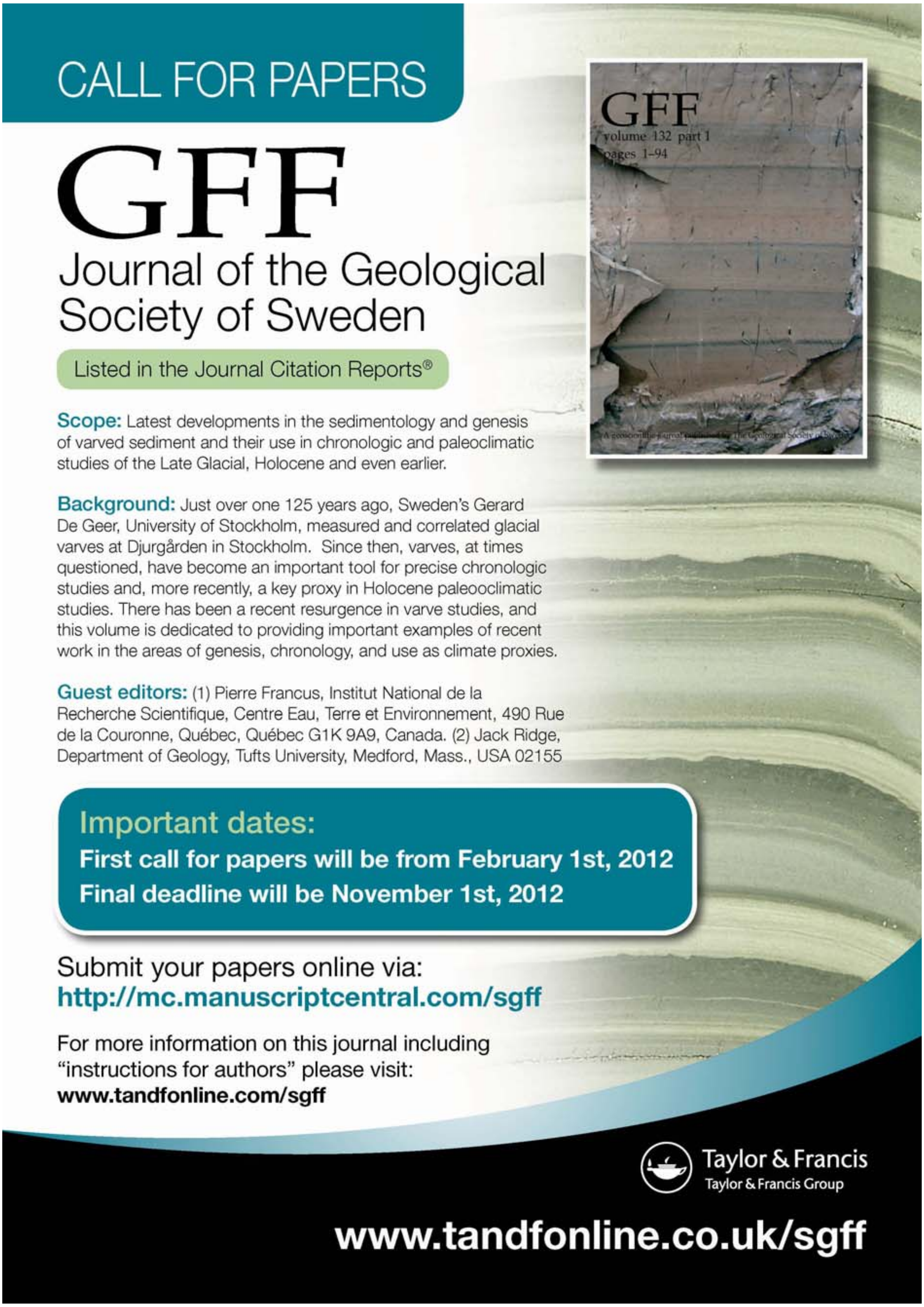
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GFF
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volume 132 part 1
pages 1–94
Scope: Latest developments in the sedimentology and genesis of varved sediment and their use in chronologic and paleoclimatic studies of the Late Glacial, Holocene and even earlier.
Background: Just over one 125 years ago, Sweden's Gerard De Geer, University of Stockholm, measured and correlated glacial varves at Djurgården in Stockholm. Since then, varves, at times questioned, have become an important tool for precise chronologic studies and, more recently, a key proxy in Holocene paleooclimatic studies. There has been a recent resurgence in varve studies, and this volume is dedicated to providing important examples of recent work in the areas of genesis, chronology, and use as climate proxies.
Guest editors: (1) Pierre Francus, Institut National de la Recherche Scientifique, Centre Eau, Terre et Environnement, 490 Rue de la Couronne, Québec, Québec G1K 9A9, Canada. (2) Jack Ridge, Department of Geology, Tufts University, Medford, Mass., USA 02155
Important dates:
First call for papers will be from February 1st, 2012
Final deadline will be November 1st, 2012
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Introduction

During the past years there has been a great amount of new publications on varved sediment records, some of them describing methodological developments and others forming a basis of interpretation of climate and environmental change of mainly postglacial times. In many studies, the varve chronologies of lacustrine and marine sediments form a solid basis of dating, not to mention the environmental and climate signal that is stored in varves and laminae they contain.

Since two years a step forward has been taken and the varve community is gathering during annual Varves Working Group (VWG) workshops to summarize what has been accomplished during the past decade and to exchange new ideas and promote their use in global climate reconstructions. The VWG has formed under the frame of the PAGES cross cutting theme 1 (CCT1) “Chronology” and CCT2 “Proxy development, calibration, validation” to address a number of topics with workshops and products. The main topics of the VWG include:

- Methodological developments
- Marine versus lacustrine varves
- Varve chronologies, including quantification of age uncertainties
- Calibration of archived climatic and environmental signals
- Database management
- Data processing
- Learning from other annually resolved archives

The scientific objectives of the VWG are to organize some or all of the themes outlined below and to bridge the gap between the diverse communities dealing with various aspects of annually resolving records. This includes non-sedimentary archives with annual structures, like tree rings, ice cores, corals and speleothems. After all, varved sediment sequences can be used to improve absolute dating techniques, to improve calibrations (e.g. for radiocarbon dating) and to serve as regional master curves (e.g. for secular variations of the Earth’s magnetic field). Finally, the issue of climatic and environmental signals contained in varved records and their respective interpretations will also be tackled. During and after the workshops we will be guided by giving answers to the following scientific questions:

- How can varve counting and measuring be improved by applying new methodological developments for the analysis of varves (e.g., advanced image analyses, core scanning techniques, techniques towards standardization and repeatability)?
- What can we learn from other communities investigating non-sedimentary annually resolved records (tree rings, ice cores, corals, mollusks, speleothems, and historical

records) about methodology, data processing, environmental signals, and data handling?

- How can robust varve chronologies be developed using additional independent chronological tools like tephrochronology and radiogenic isotopes, e.g. ^{14}C, ^{210}Pb, and ^{137}Cs?
- How can we improve deciphering and calibration of climatic and environmental signals contained in varved sediments by applying process-related complementary studies?
- Can data processing by applying state of the art statistical instruments improve our understanding of varve records?
- How to make the varve records more accessible and usable to a wider community?

Finally, this working group aims at promoting good analytical and methodological practices within our own community in order to make varved records an integral part of syntheses of past climate change to improve our understanding of future climate changes.

The 1st VWG workshop was organised in 2010 in Lääne-Virumaa, Estonia. The focus was directed on reviewing the past decade and discussing new methodological approaches, improvements in proxy data calibration and establishing an inventory (data base) of old and new varved sediment records including an on-line varve image library.

The 2nd VWG workshop was held in 2011 in Corpus Christi, TX, USA entitled "Learning from Other Communities". It was focused on the development of robust varve chronologies based on what can be learned from other paleo communities that use non-sedimentary, annually resolved climate archives. Keynote addresses were delivered by experts from the tree ring, ice core, coral, and speleothem communities to put their tools and methodologies at stake. Best practice techniques from these adjacent fields will be applied and adapted to varved sediments.

3rd VWG workshop in Manderscheid, Germany

This 3rd VWG workshop in Manderscheid, Germany is focussed on how we can improve deciphering climatic and environmental signals contained in varved sediments by applying process-related complementary studies and what can we learn from other communities investigating non-sedimentary annually resolved records in terms of proxy development, calibration and validation. Two additional foci of this workshop are advances in studying varved sediment records and discussing challenging new sites and data.

In addition to workshops four basic products for the varve community are anticipated from the VWG: (1) a review publication about chronological characteristics of varved records, (2) a global meta-database of varved sediment records, (3) an on-line varve image library, and (4) a proceedings volume following this VWG workshop in the Journal of the Geological Society of Sweden (GFF).

In more detail, these are:

1. Review publication: The chronological characteristics of sedimentary varves are reviewed by Ojala, A.E.K., Francus, P., Zolitschka, B., Behl, R., Besonen, M. and Lamoureux, S.F. in a manuscript submitted to Quaternary Science Reviews.

2. Global varve metadatabase: This database gives an overview of annually laminated sediment records worldwide (Ojala et al., this issue). The database holds meta-information on sites and records and information about the availability of associated paleoclimatic data. Some of the paleoclimate datasets are freely accessible, others may be provided on request by the corresponding contributor. This database is already set-up at http://www.pages-igbp.org/workinggroups/varves-wg/metadatabase and needs your input.

3. On-line varve image library: Here we develop a website specifically dedicated to varved sediments that assists researchers to judge the potential of their laminated sediment sequences (Zolitschka & Enters, this issue). It will distribute existing information about varves, their overall macroscopic appearance and their internal structure and composition. This on-line image library is already set-up at http://www.geopolar.uni-bremen.de/varves and needs your input.

4. The GFF special issue will compile the latest developments in the sedimentology and genesis of varved Holocene, Late-Glacial and earlier sediment records and their use in chronologic and paleoclimatic studies. This volume will be guest-edited by Pierre Francus and Jack Ridge. The final deadline for submitting manuscripts is November 1, 2012 (cf. announcement on page 4).

Acknowledgements

Financial support for the Varves Working Group (VWG) activities is provided by the International Geosphere Biosphere Programme – Past Global Changes (IGBP-PAGES) and by the German Science Foundation (DFG). For logistical support in the city of Manderscheid we are grateful to Dr. Martin Koziol (Head of the Maarmuseum Manderscheid).

The Maar-Museum-Manderscheid (Eifel /Germany): "Maars and Scoria cones"

Museum outside

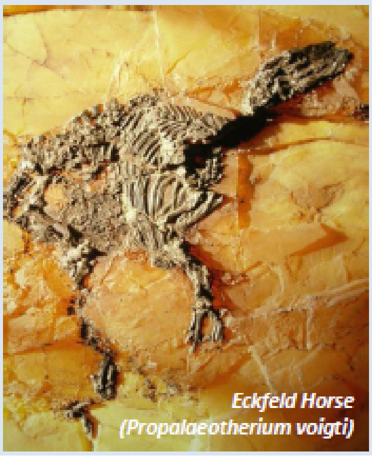
The quaternary volcanic field of the West Eifel includes about 270 volcanic sites of which more than 70 have already been identified as a maar. Those are huge craters which are scattered into the landscape when rising magma makes explosive contact with surface and ground water. The West Eifel is one of the classic maar areas of the world and shows activity from 1 Mio. years back in the past until 10.000 years ago. Besides these young maars there are at least three older maars, among them the oldest maar of the Eifel, the Eckfeld Maar that dates back 45 million years. They all belong to the tertiary „Hocheifel volcanic field" that was active from 45 million years until 35 million years ago.

Museum inside

With the exhibition of the Maar-Museum-Manderscheid opened in 1999 we would like to demonstrate the visitor the huge natural variety and the international meaning of these quartiary and tertiary maars of the Eifel for the region itself and science. The exhibition shows the genesis, history and development of the Eifel maars in past and present. In the Maarmuseum Manderscheid the maars - unique testimonies of ancient times - present themselves in a transparent way. Spectacular simulation shows give information about geological facts from new points of view. A highlight of the exhibition is the big model of a maar with audio-visual performances !

Holzmaar (maar with lake inside!)

Steineberger Maar (dry maar!)



Eckfeld Horse (Propalaeotherium voigti)

Furthermore the museum presents the originals of fossils from the eocene „Eckfeld Maar", such as the „Eckfeld Horse", a pre-horse skeleton bearing a foetus. With the help of the 30.000 fossils the once tropical landscape of the Eifel was reconstructed. The Museum also organizes the "GeoRoute: Volcanic Eifel around Manderscheid". The GeoRoute is divided into three parts: the „Volcanic route", the „Sandstone route" well as the „Devon route" in order to get informations about the nature and geology of this famous region.

For more informations:
Dr. Martin Koziol
maarmuseum@t-online.de
www.maarmuseum.de
www.eckfelder-maar.de / www.vulkanerlebnis-mosenberg.de

MAAR MUSEUM MANDERSCHEID

Location and map

Hotel

Address: Hotel – Café – Restaurant Heidsmühle
Mosenbergstr. 22, 54531 Manderscheid
Phone: +49-(0)6572-747; Fax: +49-(0)6572-530
E-Mail: post@heidsmuehle.de
www: http://www.heidsmuehle.de

WiFi is available and free of charge.

Hotel Heidsmühle is a family business now run in the 5th generation of the Stadtfeld family. It is a popular tourist attraction, not only because of the attractive location but also because of the fresh Eifel cuisine and homemade cakes. The Heidsmühle is located 1 km outside of the castletown of Manderscheid in the valley of the river “Kleine kyll” and at the foot of the late Quaternary volcano “Mosenberg”. The volcanic Eifel around Manderscheid has numerous landmarks, like the two castles of Manderscheid as well as the volcanic nature with its many volcanic features, amongst them the world famous maar lakes.

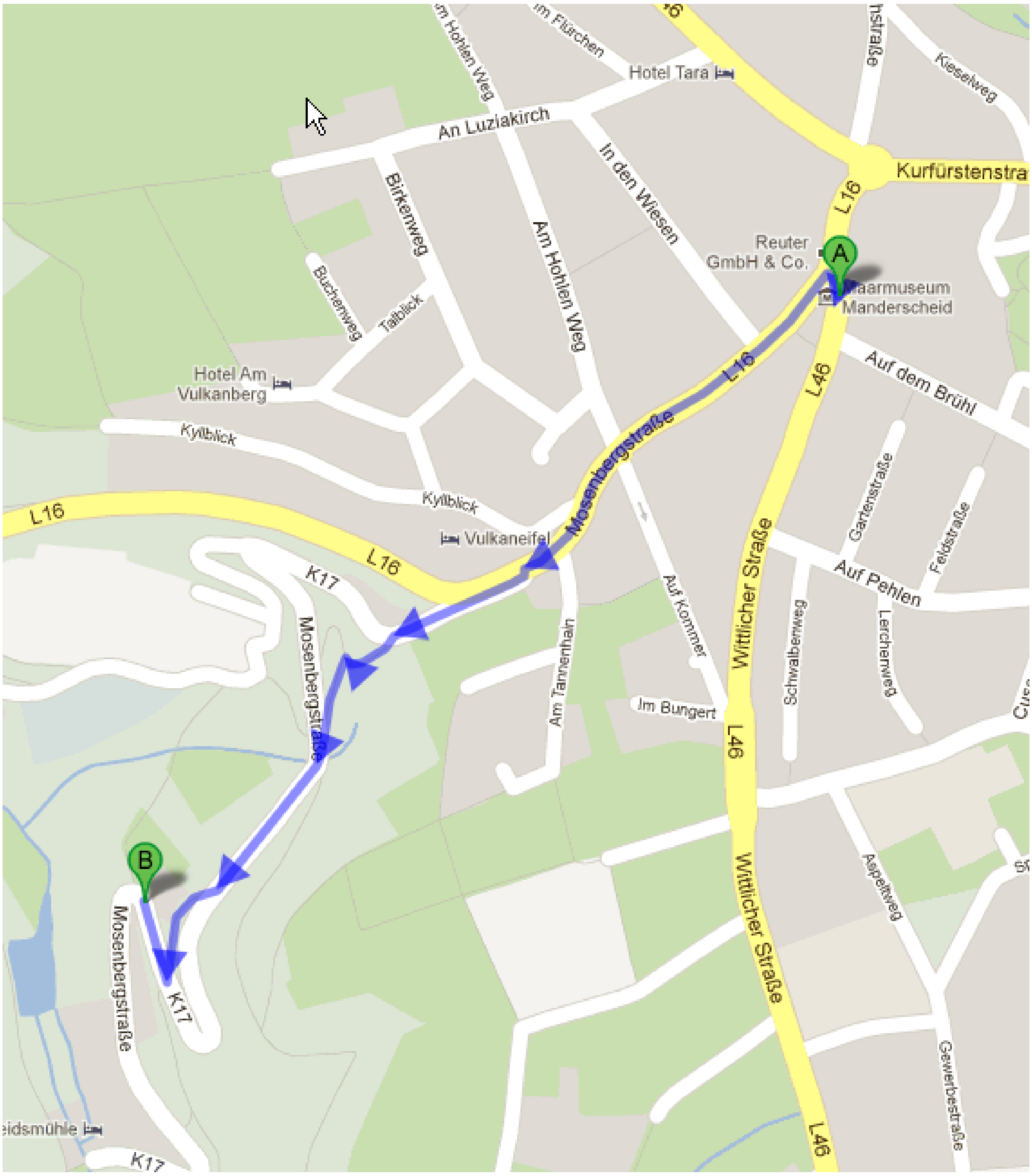
Venue of the workshop

Address: Maarmuseum Manderscheid, Wittlicher Straße 11, 54531 Manderscheid
Phone: +49-(0)6572-920310; Fax: +49-(0)6572-920315
E-Mail: maarmuseum@t-online.de
www: http://www.maarmuseum.de

Exhibitions of the Maarmuseum Manderscheid document the natural beauty of the Westeifel Volcanic Field as well as the international significance of Eifel maars for science and education but also for the region as a tourist attractor. The main subject of the Maarmuseum is the volcanic formation, history and development of maars in the past and in the future. In addition, their importance for local, regional and international Earth history is communicated to tourists as well as school and student classes. This is based on the scientific knowledge of many national and international scientists who support this museum since its foundation.

Getting from the hotel to the Maarmuseum

Hotel Heidsmühle and the Maarmuseum Manderscheid are located in walking distance of 1.0 km (ca. 10 minutes downhill to the hotel and ca. 15 minutes uphill to the museum (see also map on the next page). There is no public transportation available.



Location of Hotel Heidsmühle (B) and Maarmuseum Manderscheid (A), venues of the 3rd PAGES Varves Working Group Workshop in 2012. Walking distance between A and B is 1.0 km or 15 minutes (map source: http://maps.google.de).

Scientific Program

Tuesday, 20th March 2012

	Arrival of participants at Frankfurt/Main International Airport (FRA)
16:30h	Departure of the shuttle bus from FRA
19:30h	Arrival of participants in Manderscheid
20:00h	Ice breaker party

Wednesday, 21st March 2012

09:00h Welcome, introduction, proceedings volume and other administrative issues

Session I: Reconstructing hydro-climatic events from varved sediment records

09:30h Lamoureux, S.: Lake and catchment process studies in the Canadian Arctic to improve our understanding of the formation and environmental signal of clastic varves (keynote 1)

10:30h Coffee break and time to set up the posters

11:00h Francus, P.: Using textural properties of clastic varves to improve calibration with climate data in the Canadian Arctic

11:30h Amann, B.: Quantitative summer MJJA precipitation and rainstorms from varved Lake Oeschinen, Swiss Alps: calibration and validation AD 1920-1986

12:00h Wirth, S.: Reconstructing the seasonality of late Holocene flood events using varved lake sediments of Lake Ledro (Southern Alps, Italy)

12:30h Elbert, J.: Precipitation reconstruction (AD 1530–2002) from varved sediments of Lago Plomo 47°S, Patagonian Andes

13:00h Lunch break

Session II-a: Learning from other communities in terms of calibration and validation

14:00h Guiot, J.: Past climates reconstruction: from transfer functions to data assimilation in process models (keynote 2)

Session III: Advances in the study of varves

15:00h Hajdas, I.: Varve sediments as a tool for the development of 14C dating methods on ultra-small samples

15:30h Schimmelmann, A.: Missing varves in Santa Barbara Basin due to intermittent oxygenation and drought prior to the 18th century

16:00h Coffee break

16:30h Weber, M.: Fully-automated varve recognition and counting (interactive software presentation)

Poster to session I (with oral summary)

17:15h Boreux, M.: Subannual sedimentary structures and regional hydrometeorological record in Chevalier "Lake", Melville Island, Northwest Territories

Posters to session III (with oral summaries)

17:25h Grosjean, M.: High-resolution hyperspectral imaging (380-1000 nm) of varved lake sediments

Renberg, I.: The Lake Nylandssjön project (N Sweden): Understanding relationships between environmental variables and properties of recent varves

Stanton, T.: Using corroborative proxies to validate varve chronologies

18:00h Wrap-up session

18:30h End of day 1

19:30h Dinner

Thursday, 22nd March 2012

Session II-b: Learning from other communities in terms of calibration and validation

09:30h Fleitmann, D.: Climate records in speleothems (keynote 3)

10:30h Coffee break

Session IV-a: Challenging new sites and data – perspectives for environmental and climatic reconstruction: Africa and Asia

11:00h Chu, G.: Seasonal temperature variability during the past 1600 years recorded in historical documents and varved lake sediment profiles from northeastern China

11:30h Kröpelin, S.: Sedimentation changes in a complete Holocene lacustrine record in the Sahara: varve thickness, seasonality and event layers - Problems of identification, interpretation and chronology

12:00h Lunch break

Session II-c: Learning from other communities in terms of calibration and validation

13:00h Swetnam, T.W.: Climatic inferences from dendroecological reconstructions and comparison with charcoal in layered sediments (keynote 4)

Session IV-b: Challenging new sites and data – perspectives for environmental and climatic reconstruction: Baltic region

14:00h Tylmann, W.: Varved Lake Zabinskie, northeastern Poland: a promising site for high-resolution multi-proxy paleoclimatic reconstructions for the last millennium

14:30h Kinder, M.: Annually laminated sediments from Lake Szurpily (NE Poland) - varve thickness variability during the last 8000 years

15:00h Hang, T.: Clay varve chronology and the sedimentary environment at the eastern Baltic Sea coast in Estonia

15:30h Coffee break

Posters to session IV: Asia and Europe (with oral summaries)

16:00h Adzic, I.: Varved lacustrine sediments in the South Velebit Channel, Croatia

Allcock, S.L. (presented by N. Roberts): Reconstructing Holocene climate/environmental variability using ITRAX core scanning technology: preliminary results from Nar Crater Lake, Turkey

Barrett, S.: Tracing the impact of decadal to centennial scale global climate change on Alpine climates (59-28ka) - The Inn Valley banded-clay record

Darin, A.: Microanalytical study of annual layers in the recent sediments of Lake Shira (Khakassia)

Johnson, M.: Change in character of marine varved sediment prior to and following Baltic Ice Lake drainage, southwest Sweden

Kalugin, I.: Seasonal and centennial Sr-anomalies in carbonate sediments as an environmental proxy for Shira lake (South Siberia) during the last 2500 years

Kohv, M.: Varve correlation as a tool to understand the inner mechanisms of slope failures

Marjanac, L.: Distribution of Pleistocene glaciolacustrine deposits in southwestern Croatia

Romey, C.: Discovery of a Quaternary paleolake at Cassis (SE France)

Storen, E.: Nonglacial varves recorded in a lake sediment sequence from Southern Norway

18:00h Wrap-up session

18:30h End of day 2

19:30h Dinner

Friday, 23rd March 2012

Session V: Calibration of bioproxies from varved sediment records

08:30h Lotter, A.: Quantitative environmental reconstruction based on biotic proxies in varved sediments (keynote 5)

09:30h Bigler, C.: Calibrating the biological record in Nylandssjön: Diatom assemblages in the water column, sediment traps and varves since 2001

10:00h Tye, G.: Quantifying abrupt climate events in a varved lacustrine record from MIS 11

10:30h Coffee break

Session IV-c: Challenging new sites and data – perspectives for environmental and climatic reconstruction: Turkey

11:00h Stockhecke, M.: Sediments of Lake Van - a high-resolution archive of changing climate, volcanic events and seismic activity in Eastern Anatolia for the last 500,000 yrs

11:30h Landmann, G.: Lake Van, Turkey: Evidence for a lake level drop of 500 m in the period 20-15 ka BP

12:00h Roberts, N.: “A tale of two crater lakes”: comparing varved records for the last 15 ka BP from Cappadocia, Turkey

12:30h Lunch break

Session VI: VWG output and general discussion

13:30h Ojala, A.: Varve data base (VDB)
13:50h Lamoureux, S.: Protocol for varve analysis
14:10h Zolitschka, B.: Online varve image library – two years later
14:30h Francus, P.: Publication of the proceedings in a special issue of GFF
14:50h Wrap-up session and final discussion
16:00h End of the workshop

16:00h Departure of shuttle bus to Frankfurt International Airport (FRA), arrival at the airport around ca. 18h

16:15h Visit to the Maar Museum (optional) or
Hiking to a “waterfall”, starting at the hotel (optional and if weather permits)

19:30h Dinner

Saturday, 24th March 2012

08:30h Departure of shuttle to Wittlich main station to continue with a train to Frankfurt International Airport (FRA), arrival at the airport 11:59h
08:00h Departure to one-day field trip to the West Eifel Volcanic Field including its famous maar lakes, some of which with well-preserved annually laminated sediments
ca. 18h Return to Manderscheid

19:30h Dinner

Sunday, 25th March 2012

08:00h Departure of shuttle bus to Frankfurt International Airport (FRA), arrival at the airport around ca. 10:30h

Abstracts

(Abstracts are sorted alphabetically according to the first author)

Poster

Varved lacustrine sediments in the South Velebit Channel, Croatia

Ivana Adzic, Tihomir Marjanac and Ljerka Marjanac

Introduction

Pleistocene lacustrine sediments were found in the South Velebit Channel on both north and south coasts. These sediments are exposed on the north shore of the Velebit Channel near Seline in a 500 m long and 4-5 m high exposure, and on the opposite side of the channel at the Ždrilo locality in a 150 m long and 10 m high coastal exposure. Scattered outcrops of lacustrine sediments can also be found at the coasts of Novigrad and Karin Inland Seas, near Žegar and Ervenik settlements as well as in several karst poljes in Northern Dalmatia (Fig. 1). Pleistocene lacustrine sediments of the Novigrad and Karin Sea were briefly described by Marjanac et al. (1990) and Marjanac & Marjanac (2004), who interpreted the lake as formed in a proglacial setting due to common dropstones. The lacustrine sediments in Žegar, Ervenik and in Kninsko polje were studied by Malez & Sokač (1969) and Sokač (1975), who described a rich ostracod fauna indicative of cold climate. Glacigenic sediments were extensively studied in the coastal Dinaric Alps area (Marjanac et al. 1990, Marjanac & Marjanac 2004), and dating of secondary calcite from a moraine which overlies these lacustrine sediments yielded the minimal age of >350,000 years BP.

The lacustrine sediments of Seline and Ždrilo sections were studied from 2009-2011, and a well preserved fossil flora and gastropod moulds were collected. The collected flora comprises 10 specimens of fossil leafs at the Seline section, and more than 70 specimens at the Ždrilo section. The studied fossil flora belongs to 15 tree taxa of 9 families. In addition to fossil plants, mollusc moulds of Unionidae and Gastropoda were found at the Seline section, whilst Congeria–like bivalves and ostracods were found in the sediments from the Ždrilo section.

Description of studied sediments

Seline section

The lacustrine sediments of the Seline section are located in front of the Mala and Velika Paklenica Canyons (Fig. 1), where two stratigraphic intervals of lake sediments are divided by a conglomerate layer. Their close position with regard to the glacial valleys of the Paklenica and Velebit mountain range makes this section and the appropriate lake margin a proximal zone under moderate influence of the glacial debris input.

The older sediment package is well stratified, with common dropstones, whereas the younger is massive without evident stratification. The studied sediments in this profile are light brown, ochre to whitish coloured, are made of silt and sand grains, and do not comprise clayey laminae. The fossil plant debris is abundant but fossil leafs are rare. There also occur frequent moulds of fossil gastropods and bivalves, as well as cobble-size dropstones. The dropstones occur both in older and younger packages of lacustrine sediments and document the proglacial character of the lake.

The conglomerate interbed, which divides the two lacustrine intervals, is a distal part of deltaic fan bodies akin to those which underlie the oldest package of lacustrine fine-grained sediments and were interpreted as Gilbert-type deltas.

Ždrilo section

Pleistocene proglacial lake sediments are also exposed on the southeast coast of the Velebit Channel, at the Ždrilo locality. The position of this section on the opposite side of the modern Velebit Channel and consequently on the opposite side of the paleolake, makes it distal in relation to the sediment sources on the Velebit mountain range and the feeding glaciers. The lacustrine sediments are moderately to highly disturbed due to glacial push, and partly submerged under the modern Adriatic Sea, which makes the study of the whole sediment succession difficult. However, the outcrops are good enough for the study of the younger package of lacustrine sediments, which are locally overridden and eroded by thick lodgement till.

The Ždrilo section lacustrine sediments are perfectly laminated, with well defined varves. The sediments comprise light to dark brown and rusty brown siltstone laminae in alteration with white to light grey clayey laminae. The boundaries between silt and clay laminae are sharp, sometimes with developed small-scale flame structures, sometimes marked by erosional surfaces and sometimes marked by bioturbation. The mid-part of the section was studied in detail, and the silt laminae vary from 1 to 111 mm in thickness. The thickest one is massive and undifferentiated. The clay laminae are considerably thinner with thicknesses between 1 and 30 mm. Traces of bioturbation were observed at the contact of silt and clay laminae, with burrows in underlying silt laminae infilled with clay from above. Silt and clay laminae are in most cases further differentiated which might imply the variation of sediment inflow during their deposition. In one part of the laminated lake sediment in Ždrilo, folding and reverse faults can be observed. This unique case of faulting and folding may indicate a synsedimentary deformation.

The moraine sediments were found on a lateral section in a distance of 300 m. Due to the glacier advance, overridden varved sediments were tilted, eroded and deformed, and a 13 m long slab of lacustrine sediment is incorporated into the moraine.

Fossil flora and fauna from proglacial lake sediments

Lacustrine sediments of the Ždrilo section are rich in plant macrofossils. Most abundant are leaves of *Taxodium* sp. More than 30 specimens of *Taxodium* sp. fossil leaves, varying from poorly to excellently preserved were collected and photographed. The *Taxodium* leaves were found on silty laminae and were covered by a thin film of clay, which is common also for all other fossil leafs at the Ždrilo section. They occur throughout the section, and in most cases together with fossil leaves of *Zelkova* sp. and *Quercus* sp.

Aforementioned *Quercus* sp. and *Zelkova* sp. were second best represented by the number of specimens at the Ždrilo section; eight specimens of *Quercus* sp. and five specimens of *Zelkova* sp. were found. Two specimens of *Quercus* sp. were also found in lake sediments at the Seline section. Leaf fossils from Ždrilo are grey and well preserved, whereas those from the Seline section are rusty brown and poorly preserved. The leaf size of *Quercus* sp. varies from 30 to 100 mm. Five specimens of *Zelkova* sp. were found in the Ždrilo section, and one was found in the Seline section. The specimens were well preserved except for the few, with an invisible leaf nervature but the leaf edges were perfectly recognizable. The leaf size varies between 20 and 30 mm.

The plant macrofossils represented by two specimens were *Castanea* sp., *Acer* sp. and *Fagus* sp, found at the Ždrilo section. The leaves of *Fagus* sp. were found in sediment along with the *Zelkova* sp. and numerous *Taxodium* sp. fragments.

Other plant macrofossils found in varved lake sediments at the Ždrilo and Seline sections, are represented by a single specimen; such as *Liquidambar* cf. *europea*, *Buxus* sp., *Pterocarya* sp., *Tilia* sp., and fruit of *Ulmus* sp. One specimen was recognized as a member of Moraceae family. The fossil leaf of *Tilia* sp. was also found in lake sediments of the Seline section.

Few specimens were poorly preserved and were hard to determine because of the lack of important diagnostic features such as leaf nervature, leaf base or leaf apex. Those are arbitrarily assigned to certain taxa: *Zelkova*, *Parrotiopsis*, *Pyrachanta* and *Buxus*-like specimens.

Poorly preserved specimens of fossil fauna were found in lacustrine sediments both in Seline and Ždrilo sections. Since the diagnostic features were missing, the specimens were determined only by their general characteristics. Seven specimens of fossil gastropods and bivalves were collected in lake sediments of the Seline section, whilst a large number of Congeria-like bivalves was found on a bedding plane of the Ždrilo section lacustrine sediment. Ostracods with unornamented shells and of different sizes were found in the Ždrilo section lacustrine sediments.

Short discussion and conclusions

The fossil assemblage and the sediments of Pleistocene proglacial lakes have great importance in reconstruction of the paleoclimate in Northern Dalmatia and of the extent of glaciations in central Europe. In the south of Europe were the refugia for most of the plant species during the Pleistocene (e.g., Follieri et al. 1986, Magri 1998, Kuntzman et al. 2009). Findings from the localities on the eastern Adriatic coast, Ždrilo and Seline, can contribute to a better understanding of the response of plant communities to glaciations and cold climate.

Plant taphocoenoses found in lake sediments in Ždrilo and Seline correspond to mixed temperate forest vegetation, based on *modern* vegetation distribution pattern. It is generally perceived that the genus *Quercus*, *Fagus*, *Ulmus*, *Acer*, *Liquidambar*, *Castanea*, *Tilia* and *Zelkova* represent typical temperate vegetation, whereas the genus *Taxodium* and *Pterocarya* being representatives of humid climate. Our findings are at odds with this model, the fossil leafs were found in sediments of a lake that was in direct contact with active (advancing) glaciers, as indicated by numerous dropstones and overlying ground moraines. Modern distribution patterns of certain taxa are, we believe, a consequence of several abiotic factors, such as the distribution of glacial ice. The modern plant distribution may neither represent their true distribution nor their climatic affinities in geological history.

The results presented in this paper are at the moment preliminary, and further, more detailed research is planned for the near future, in order to get better understanding of Pleistocene vegetation in the Dinaric Alps.

Acknowledgments

The authors thank Philip Hughes from the University of Manchester who conducted the Uranium-series dating of secondary calcite cement sampled in moraines, and Peter van Calsteren for processing the samples at the NERC-Open University U-series Facility.

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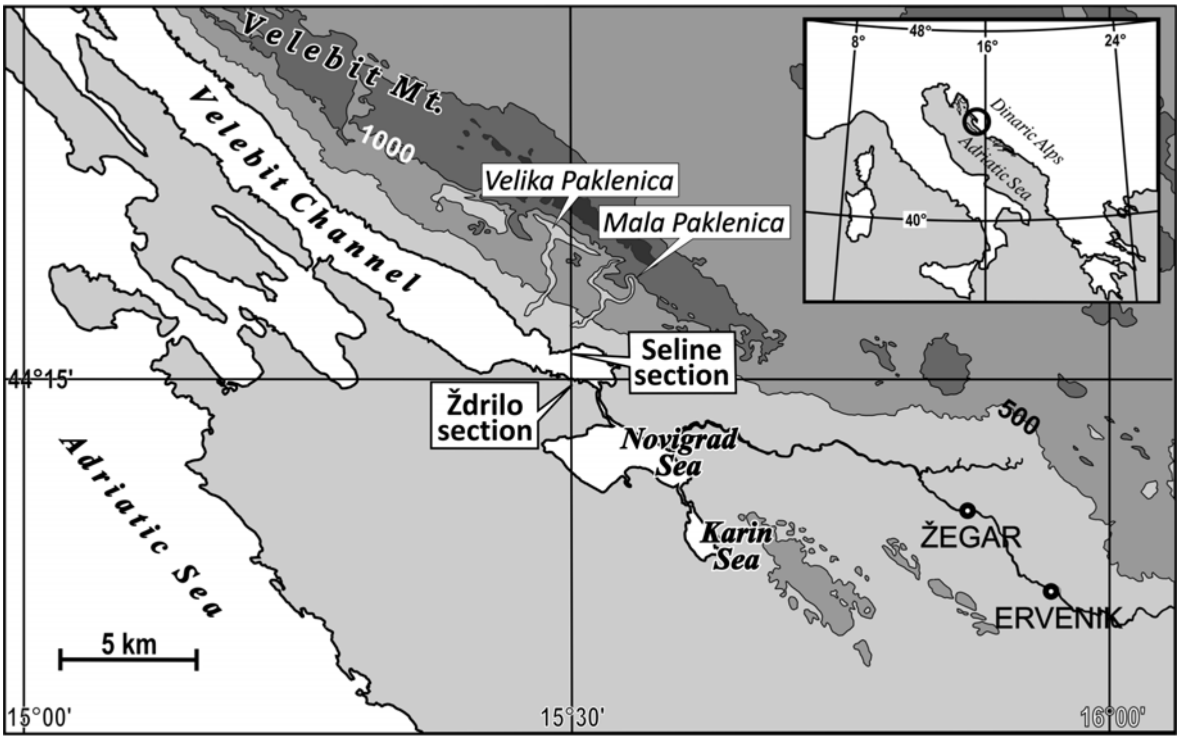

Fig. 1: Location of studied sections on the eastern Adriatic Sea coast.

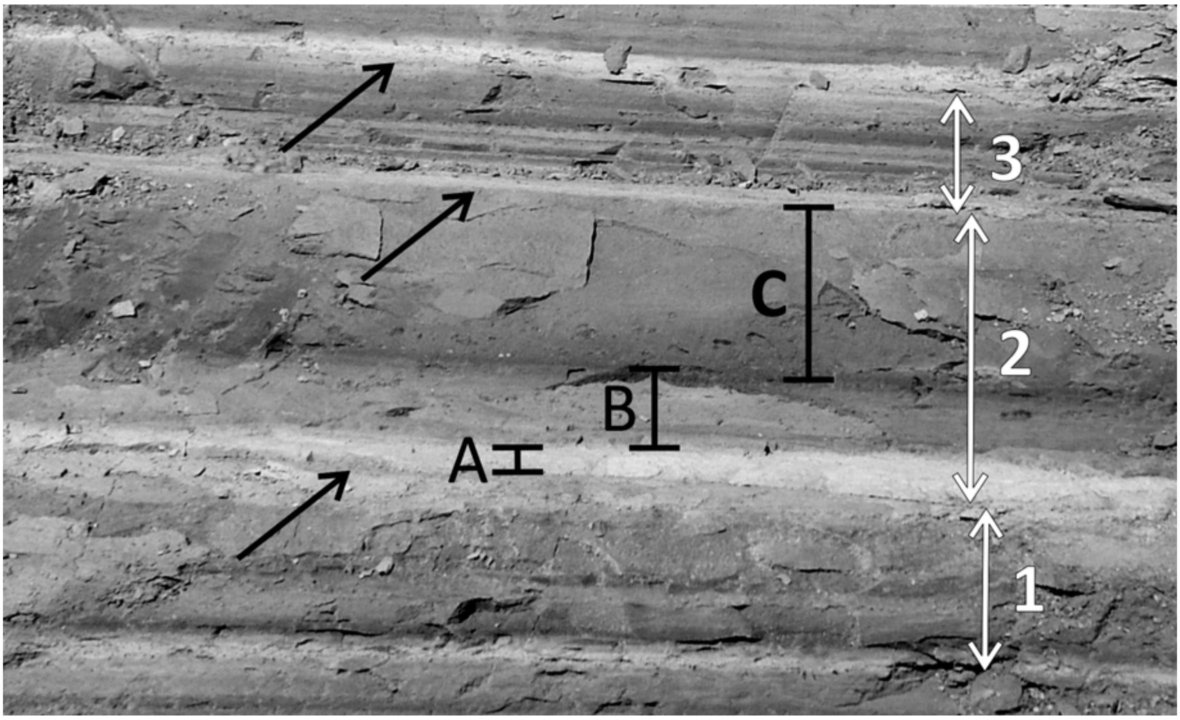

Fig. 2: Varved lacustrine sediment of the Ždrilo section. The section is 15 cm thick. White numbers (1-3) indicate annual layers (varves); a couplet consists of winter layer (white) and spring/summer layer (grey). Packet 3 is a complex varve, probably formed during a year with several freeze and thaw periods. A - winter layer; B - spring layer; C – summer/autumn layer. Arrows point to the autumn/winter boundary comprising fossil leaves.

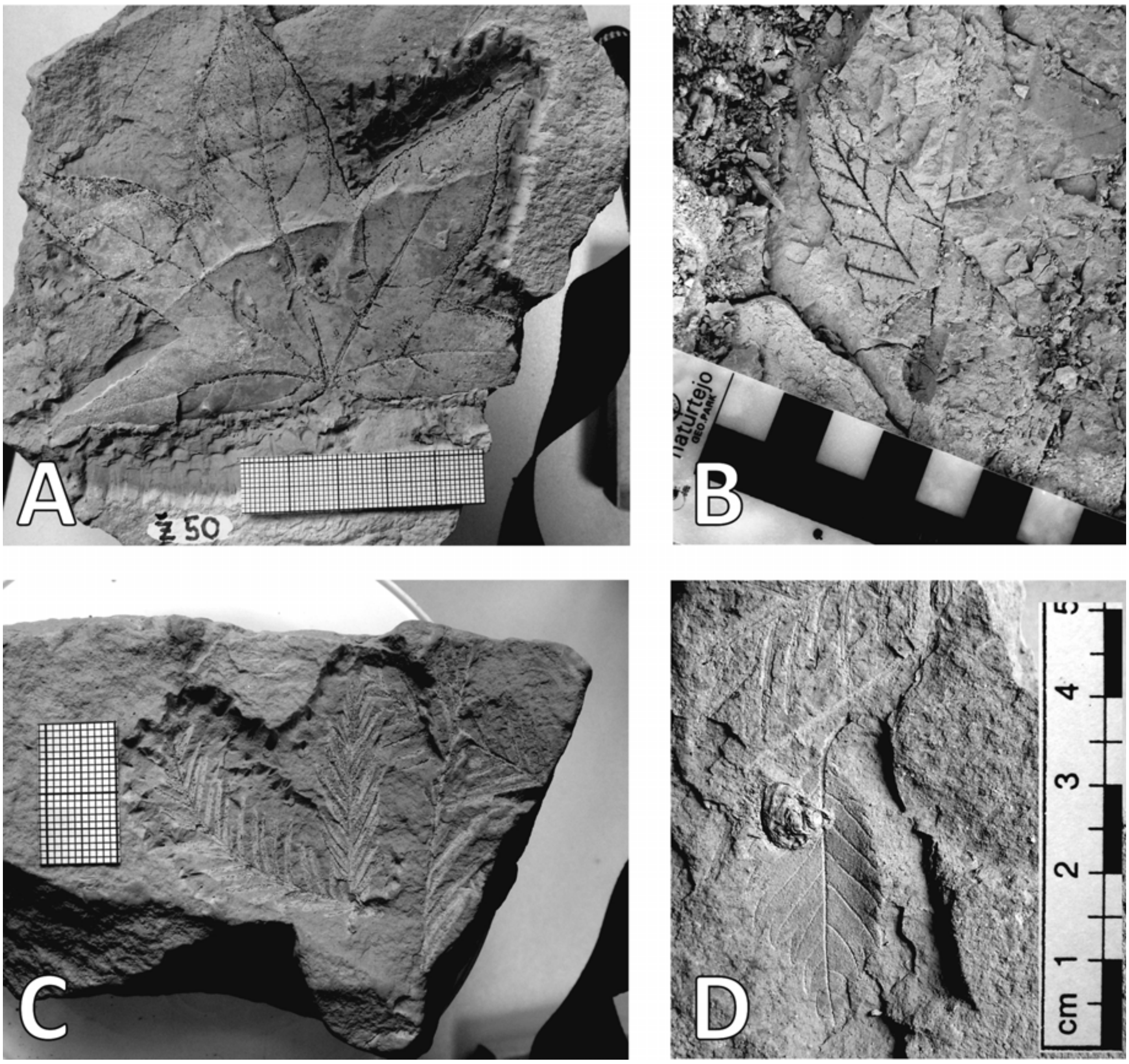

Fig. 3: Fossil flora from Ždrilo section varves. A) *Liquidambar* cf. *europea*, B) *Quercus* cf. *trojana*, C) *Taxodium* sp., D) *Zelkova* sp.

Poster (presented by N. Roberts)

Reconstructing Holocene climate and environmental variability using ITRAX core scanning technology: preliminary results from Nar Crater Lake, Turkey

Samantha Lee Allcock and Neil Roberts

A wide variety of climate information can be extracted from non-biological components of lake sediments. Physical and chemical properties of lake sediments can be related to climate signals either through varve thickness measurements or through geochemical analysis. Traditional methods for extracting these data often rely upon time consuming and destructive techniques. New approaches now utilise ITRAX core scanning to provide rapid high-resolution records. Annually laminated sediment cores from Nar Crater Lake (Turkey) provide an opportunity to investigate the use of ITRAX technology and its applicability to Holocene climate and environment variability studies. The approach combines high-resolution scanning (200 µm steps over 21.6 m), multi-parameter varve counting and laminae observations to detect high and low frequency temporal changes. The project aims to use these data to reconstruct the nature, timing and amplitude of change at the regional scale. Of particular importance are periods of stable and unstable climate, as such episodes are significant in understanding cultural as well as natural change events.

Interpretation is based on geochemical measurements. According to these data, sediment composition is strongly controlled by Ca and Fe, which alternates seasonally. Occasional clastic events are characterized by peaks in Fe, Si, Ti, K, Zr, and Rb, and some periods contain high levels of minor elements Ta, Th, and W. Elemental variation appears to reflect the changing nature of laminae formation from both in-lake and catchment sediment supply. The occurrence of temporal variability in the data is promising for palaeoclimate reconstruction, and can be validated against $\delta^{18}O$ and diatom data for the last 1.7 ka yrs (Jones *et al*, 2006; Woodbridge & Roberts, 2010). Preliminary results are presented, but discussions about their climatic and environmental meaning still remain open. Further analysis on thin sections and catchment samples are currently being conducted to refine interpretations.

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Oral

Quantitative summer MJJA precipitation and rainstorms from varved Lake Oeschinen, Swiss Alps: calibration and validation AD 1920-1986

Benjamin Amann, Fabian Mauchle and Martin Grosjean

Varved lake sediments may provide quantitative insight into millennial- to Holocene-long seasonally resolved climate state variables (temperature, precipitation) and hydrometeorological events, provided (i) the varve-formation processes are understood and (ii) specific varve properties can be calibrated and verified against a time series of meteorological data. This remains a methodological challenge.

Here we present a calibration and verification study from varved lake Oeschinen, Bernese Swiss Alps, for the period AD 1920-1986. We show that varve thickness and mass accumulation rate can be used as quantitative predictors for summer (May to

August: MJJA) precipitation while the internal structure of the summer layer in the varves reflects event layers from individual rainstorms. This provides the foundation for a Holocene-long quantitative precipitation reconstruction and the assessment of rainstorm frequency.

Lake Oeschinen (46°30'N, 7°44'E, 1578 m a.s.l.) is a proglacial and 56 m deep dimictic and oligotrophic high-elevation lake with a surface of 1.2 km^2 located in the north-western Swiss Alps. It has been formed by an Early Holocene rock slide. The catchment configuration (geology, topography and hydrology) is most relevant to the mineralogical composition, the sediment transport and the varve formation processes. 30% of the catchment area is glaciated whereby all glaciers are located in the Jurassic limestone (up to 84% calcite) area to the southeast of the catchment with the high mountains. Tertiary Flysch and sediments with up to 60-80% siliciclastic minerals are found in the north-western part of the catchment. Sediments from this part are transported after snowmelt and warm season rainfall, whereas sediments from the southern glaciated part are mainly transported with glacial meltwater independent from rainfall in the catchment. It is thus hypothesized that the amount of summer rainfall controls the amount, mineralogical and elemental composition of the sediments transported into the lake.

Here we analyze a 50 cm long sediment core that reaches back to AD 1907. The rhythmically mm-laminated lithoclastic sediments consist of two facies, A) varves and B) turbidites. The varves (Fig. 1a) consist of laminae couplets with a coarse (fine-sand and silt) dark summer layer enriched in siliciclastic minerals and a lighter fine-grained (fine-silt and clay) calcite-rich winter layer on top. Three types of varves can be distinguished: Type I with a 1-1.5 mm fining upward sequence, Type II up to 3 mm thick with a distinct fine-sand basal summer layer (attributed to quick and strong snowmelt), and Type III varves with multiple fining-upward sequences (microlaminae) in the summer layer interpreted as individual rainstorm deposits. Diagnostic for the laminae couplet is always the calcite-rich clay-size winter layer deposited when the lake is frozen. Turbidites (facies B, Fig. 1b) are between 1-5 cm thick, normally graded with abundant terrestrial plant debris and coarse grains at the base. Nine turbidites were found between the historic floods AD 1910 and AD 1987 (calibration period). The hydroclimatic interpretation of the sediment sources and the varve formation processes is supported by microXRF (Ca/Si ratios) and XRD data of lake and delta-fan shoreline sediments, and sediment trap deposits.

According to the varve formation hypothesis, we calibrated annual varve thickness with local hydrometeorological data. However, prior to calibrating the sediment proxies with the climate data in the common period with good data (1920-1987), the varve chronology (1910-2006) has been verified with radiometric dates (^{210}Pb and ^{137}Cs), historical floods and SCP profiles. Due to varve counting uncertainties, we applied a 3-years triangular filter on the time series and corrected the correlation coefficients for autocorrelation effects (p_{corr}). The results (Fig. 2) revealed that varve thickness in Lake Oeschinen was primarily controlled by cumulative summer precipitation (MJJA) with $r=0.64$ (at $p<0.05$, means for AD 1920-1986) thus validating the hypothesis.

It remains to be tested whether the calibration model can be improved by using refined proxies such as e.g. the flux of siliciclastic minerals or establishing thresholds for rainfall intensity which lead to the internal structure of the type III varves. This calibration model is now being used for a millennial-long annually resolved quantitative precipitation reconstruction for the NW Swiss Alps.

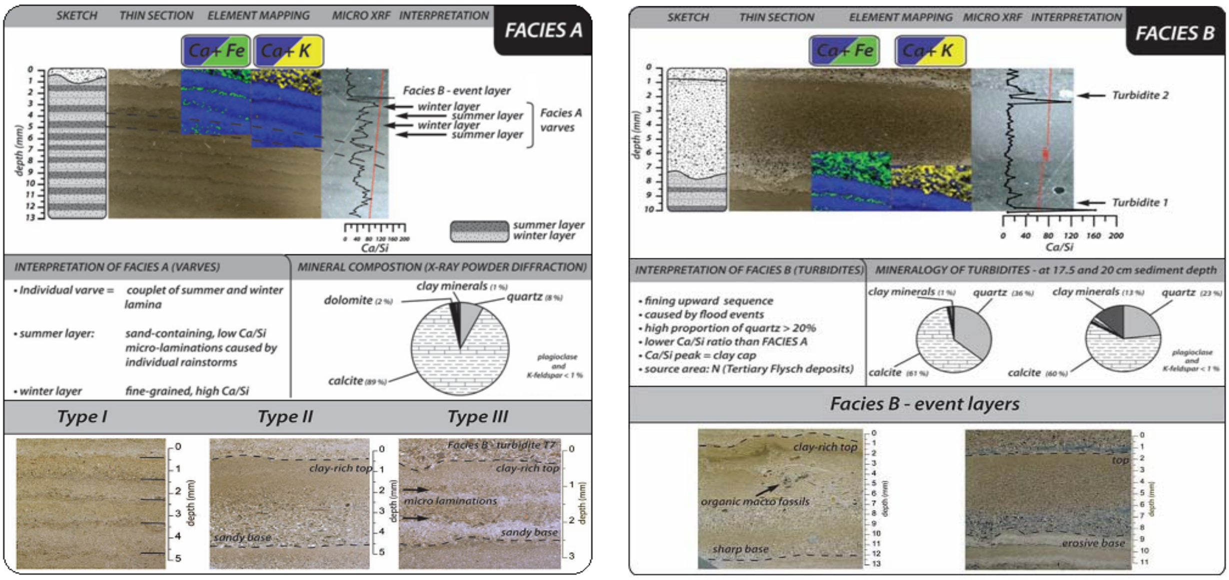

Fig. 1: Geochemical and mineralogical characteristics of a) facies A and b) facies B.

On top of each figure the schematic sketch of typical varved sequences, photographs of the thin section, and X-ray fluorescence elemental maps are represented. The latter are showing qualitative elemental concentrations for the elements Ca (blue), Fe (green) and K (yellow). In the middle part an interpretation of the sedimentary facies and quantitative mineralogical composition of the varved sequences are shown. The lowest part presents photographs of typical a) varve types and b) turbidites found in the sediment record of Lake Oeschinen.

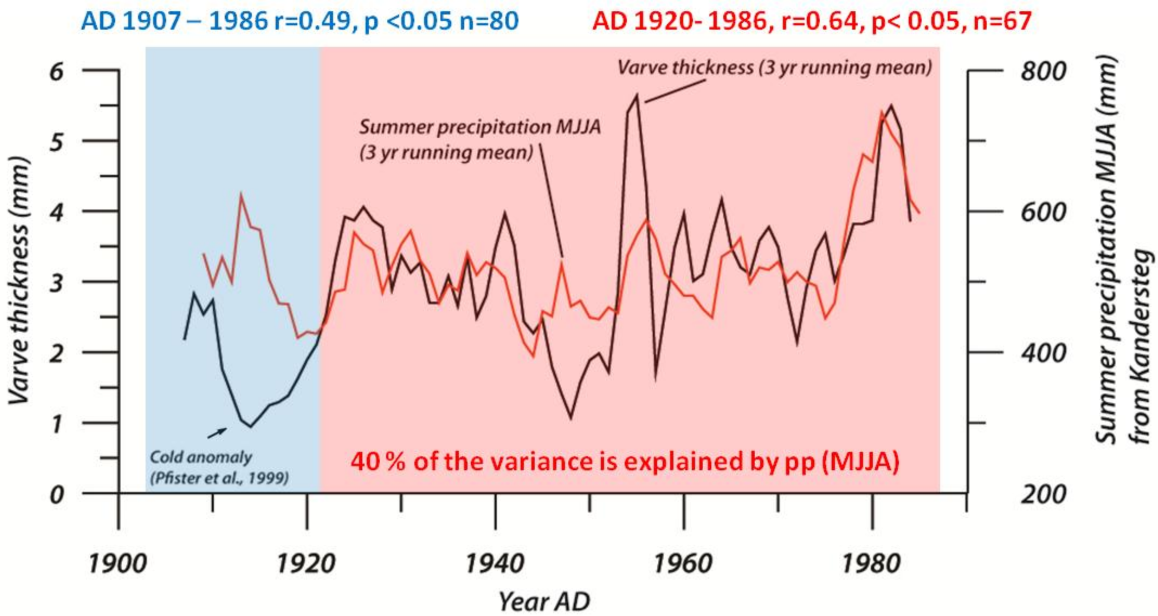

Fig. 2: Comparison of varve thickness (AD 1907-1986) with cumulative precipitation MJJA. Note that a 3-yr running mean was used.

Poster

Tracing the impact of decadal to centennial scale global climate change on Alpine climates (59-28 ka) – The Inn Valley banded-clay record

Samuel Barrett, Michael Sarnthein, Achim Brauer and Christoph Spötl

We are studying the palaeoclimate/environment archive of Banded Clays deposited in a fjord like paleolake of the Austrian Inn Valley. A rare opportunity in the Alps, these deposits document a period of extreme climate instability from 59-28 ka, well known from Greenland ice and Atlantic sediment cores for the abrupt Dansgaard-Oeschger events. Their impact on Alpine palaeoclimate and environment, hitherto largely unknown, forms our central objective. Preliminary high resolution XRF analyses of major elements from a 20 m section of a larger 150 m drill core reveals high amplitude Ca oscillations around 3 mm thick in some sections and 7 mm thick in others. These oscillations appear to be independent of highly irregular, low-amplitude and narrower spaced Si and Ti oscillations. We therefore suspect the thick Ca oscillations represent spring/summer algal blooms implying that the Banded Clay laminations indeed represent varves. Several initial XRD samples do, however, suggest a large proportion of detrital carbonate (Dolomite), so we intend to carry out thin section analyses and further XRD analyses to firmly determine the nature of laminations present. A transition from large amplitude Ca oscillations to very low amplitude oscillations which match Si and Ti oscillations was also observed from the XRF analysis which we tentatively hypothesise as an interstadial-stadial transition. ^{14}C dates from literature provide rough age control but magnetostratigraphic analysis is in progress and OSL and further ^{14}C dating is planned. We also intend to complete the XRF profiling of the entire 150 m core section, and apply a number of palaeoenvironment/climate proxy techniques on targeted sections of the core including pollen analysis, chlorins and biomarker analysis and further analysis of sediment composition and variation. Further drilling to increase the total composite length of the section is planned subject to funding.

Oral

Calibrating the biological record in Nylandssjön: Diatom assemblages in the water column, sediment traps and varves since 2001

Christian Bigler, Veronika Gälman, Dominique Maier and Ingemar Renberg

It is often taken for granted within the paleolimnology research community that a sediment core collected from the deepest part of a small lake (typically with an area of a few ha) is adequately reflecting the prevailing biological indicators of the entire lake. Very few studies exist that explicitly investigate to which extent the biological assemblage in the water body is comparable to assemblage compositions preserved in the sediment. Surprisingly, the role of taphonomic processes is often neglected.

To test this basic paleolimnological assumption for diatoms, we use data from plankton surveys, sediment traps and varves from Nylandssjön, a small lake in northern Sweden (62°57′N, 18°17′E). During the past ten years, we have collected >180 phytoplankton survey samples and >190 sediment trap samples that we aim to relate to the varved sediment record in the near future. Whereas the plankton survey samples have been analyzed by standard limnological methods (inverse microscope, 400x magnification), the diatoms in sediment traps have been analyzed using standard methods established within paleolimnology (regular microscope, 1000x magnification).

As evidenced from the plankton survey data (Fig. 1), the diatom assemblages in Nylandssjön are dominated by *Asterionella formosa, Tabellaria flocculosa* and *Fragilaria* taxa during the past 10 years. Furthermore, the plankton data reveal large shifts from season to season, but also from year to year. For example, *Tabellaria flocculosa* shows a peak during 2001 and relatively high abundances during 2004 and 2005, whereas *Asterionella formosa* is abundant from 2005-2009 (Fig. 1).

The sediment trap diatom record (Fig. 2) indicates comparable overall abundance patterns for some taxa (e.g. *Asterionella formosa*, *Tabellaria flocculosa*). However, peaks and seasonal shifts are less pronounced in the sediment trap compared to plankton data, which is indicating that the trap is partly averaging out blooms occurring in the water body. Interestingly, we find also large quantities of small diatoms (*Cyclotella glomerata*, *Fragilaria pinnata*) in the sediment trap that were too small to be recognized in the inverse plankton microscope with 400x magnification.

This initial analysis of plankton data and sediment trap data is only the first step towards an improved understanding of taphonomic processes in Nylandssjön. The next steps will be (1) to investigate the sediment trap samples at 1000x magnification to be able to remove artifacts arising due to different counting methods, and (2) to analyze the past 10 years of the sediment varve record at high temporal resolution.

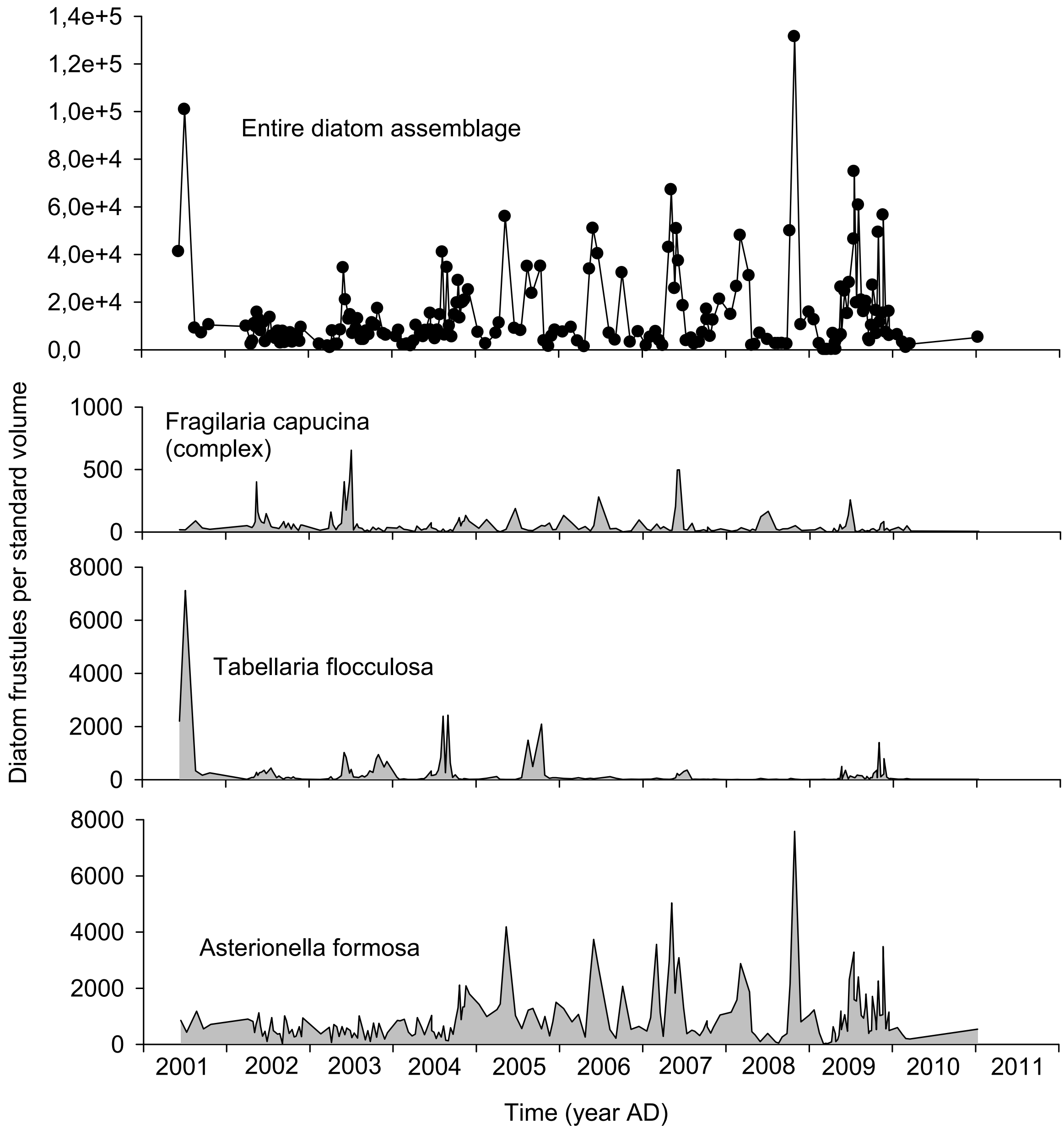

Fig. 1: Plankton survey data: Total diatom concentrations and concentrations of major diatom taxa in Nylandssjön since 2001.

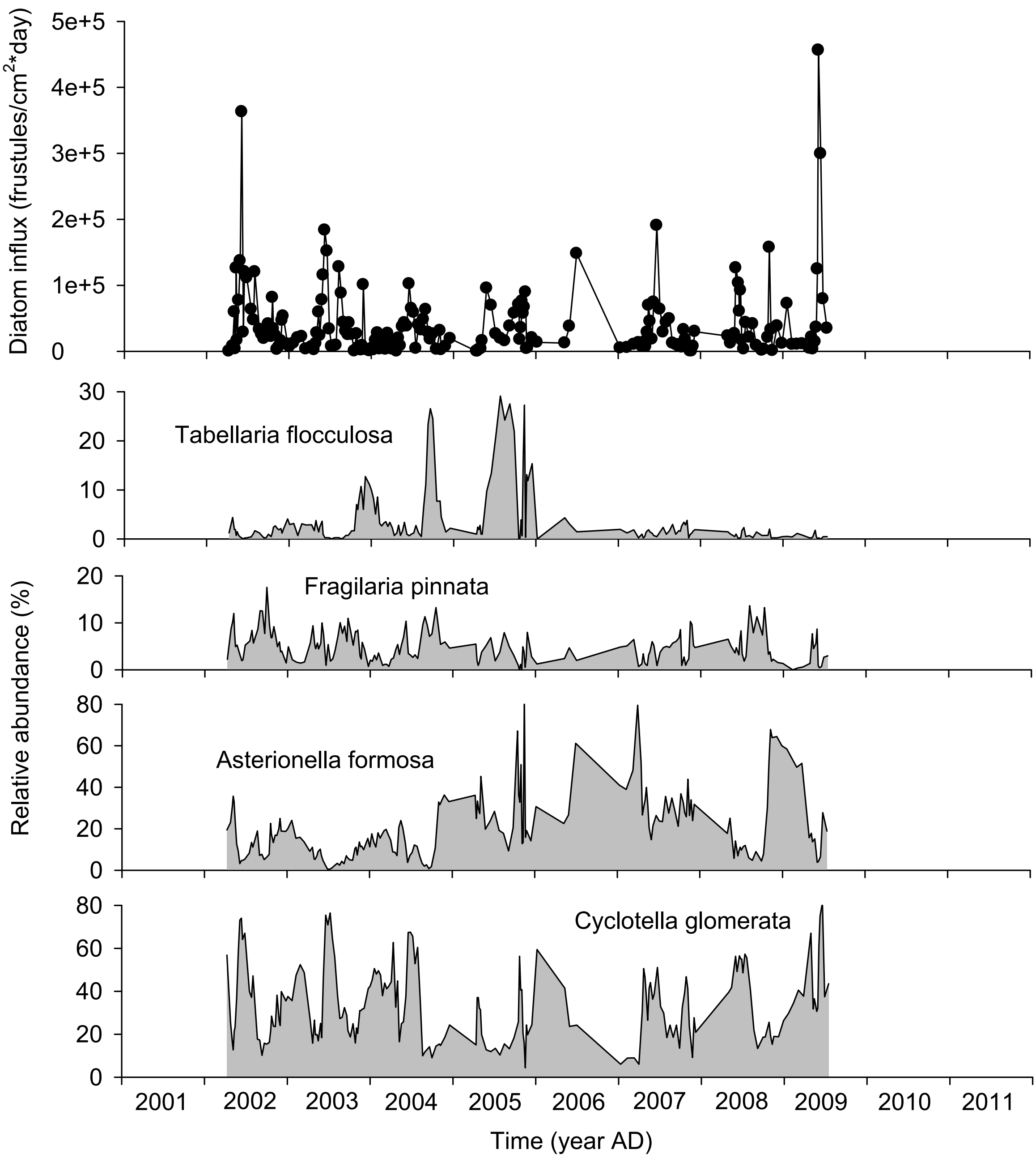

Fig. 2: Sediment trap data: Total diatom influx and relative abundance of major diatom taxa in Nylandssjön since 2001.

Poster

Subannual sedimentary structures and regional hydrometeorological record of Chevalier "Lake", Melville Island, Northwest Territories

Maxime P. Boreux, Scott F. Lamoureux and E. Kjikjerkovska

Laminated sediment records constitute a climate proxy with a high temporal resolution and they are valuable to detect changing landscape, hydrologic and climatic conditions within a catchment. Since 2003, research at the Cape Bounty Arctic Watershed Observatory (CBAWO) on Melville Island (Nunavut) has developed the longest continuous record of hydrological, biochemical and mineral-related fluxes in the High Arctic. Those records show a wide range of runoff and sediment transport conditions, including an unusually warm summer that generated extensive slope disturbance in the form of numerous active layer detachments. Chevalier "Lake" (75°3'10"N, 111°30'38"W), located on the Dundas Peninsula at about 60 km west of CBAWO, is a saline coastal basin that is connected to the sea by an inlet. While the Chevalier catchment is very similar to those at CBAWO, it has a much larger catchment area (c. 350 km^2) that results in high sediment inflows and the deposition of thick laminae. In this context, Chevalier Lake permits the investigation of a high resolution sedimentary record in terms of changing extreme geomorphic and hydroclimatic activity in the watershed. In addition to the long process-study record in a similar setting at CBAWO, this work also benefits from the potential comparison of a long (4200 year) clastic varve record from CBAWO (Cuven et *al*., 2011, QSR, 30: 2651-2665).

A 101.5 cm long core was collected in 2010 and preliminary work has shown that laminae structures in the upper part of the core present relatively high sedimentation rates and variability in grain size. Thin sections reveal distinctive rhythmic laminated sediments that are hypothesized to be varves and also to contain sub-annual structures. In order to construct a chronology of recent sedimentation, a method will be developed to identify subannual components. Each sedimentary structure will be characterized to investigate their potential deposition mechanisms and will be correlated with meteorological records to infer significant hydrometeorological controls over the interannual sediment yield variability. Previous studies on sublamina structures have been successfully carried out elsewhere in the High Arctic at Nicolay Lake (Hambley and Lamoureux, 2006, J Paleolimn, 35: 629–640) and Lake R (Chutko and Lamoureux, 2008, CJES, 45: 1-13). The chronology from Chevalier Lake will then be assessed to investigate the impact of extreme weather events such as prolonged warm weather conditions and major rainfall events on the sediment record and will provide valuable long-term records of interannual climate variability.

Oral

Seasonal temperature variability during the past 1600 years recorded in historical documents and varved lake sediment profiles from northeastern China

Guoqian Chu, Qing Sun, Xiaohua Wang, Meimei Liu, Yuan Lin, Manman Xie, Wenyu Shang, Jiaqi Liu

Seasonality is an important intrinsic nature of climate. Seasonal temperature variability over longer timescales could offer new insights into understanding different forcing factors and response processes in the climate system. We report an alkenone-based temperature reconstruction for growing seasons over the past 1600 years from the varved sediment record of Lake Sihailongwan. The most notable cold spells occurred during the periods AD 480-860, AD 1260-1300, AD 1510-1570 and AD 1800-1900 with a temperature decrease of about 1°C compared to the 20th century. Based on the clear evidence such as “snow or frost in the summertime” and “no ice during the wintertime” in historical documents, we compiled extreme cold summer events and warm winter events over the past 1600 years. The Little Ice Age suffered from more extreme cold summer/warm winter events, the Medieval Warm Period from milder winter. Comparatively, the proxy data show a generally similar pattern with decadal historical documents, except for the time from AD 1620 to AD 1720. The seasonal temperature variations recorded in this study show distinct multi-decadal to centennial cycles. They could be linked with the interaction of natural forcing with atmosphere-ocean circulations, helpful for understanding and predicting the regional climate at multi-decadal to centennial timescales.

Poster

Microanalytical study of annual layers in recent sediments of Lake Shira (Khakassia)

Andrey Darin, Ivan Kalugin, Mikhail Maksimov, Natalya Maksimova, Tatyana Markovitch, Yakov Rakshun, Ivo Zizak, Rolf Simon and Joerg Goettlicher

The bottom sediments of Lake Shira contain annual layers (varves) with thicknesses between 0.5 and 2.0 mm. The fact that these are indeed annual layers is confirmed by isotopic studies – the distribution of ^{137}Cs (Fig. 1).

The aim of our work is the study of the internal structure of the annual layers. Solid samples for the study of the upper 100 mm were prepared from the sediment core Shira_bx_2010 by epoxy-impregnation. The method of X-Ray Fluorescent Synchrotron Radiation (XRF SR) scanning microanalysis was used to study the sediment samples. Measurements were carried out at experimental station accelerators VEPP-3 (Novosibirsk), BESSY-II (Berlin) and ANKA (Karlsruhe). Step-scans varied from 40 to 150 µm, some parts of the samples were studied with a spatial resolution of 20-25 µm. A highly detailed distribution of Si, S, Cl, K, Ca, Ti, V,

Cr, Mn, Fe, Ni, Cu, Zn, Ga, As, Br, Rb, and Sr was studied in 15 annual layers from 1977 to 1992. The intra annual behavior of three types of elements has been shown that characterize the terrigenous, chemogenic and biogenic components of the sediment. Typical elements for each group are: Rb for the terrigenous part (spring), Sr for the chemogenic part (summer) and Br for the organic part (autumn) (Fig. 2).

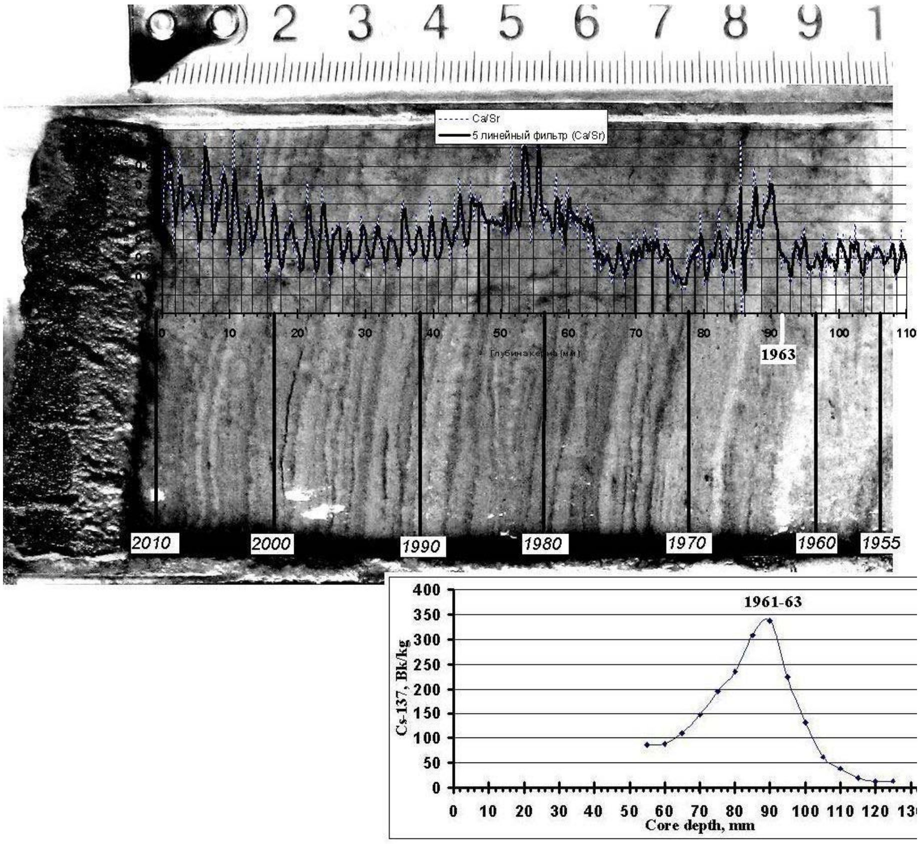

Fig.1: The maximum intensity of the isotope ^{137}Cs marks the years 1961-63 (90 mm sediment depth). Counting of the layers using geochemical markers results in the year 1963 at a depth of 91 mm.

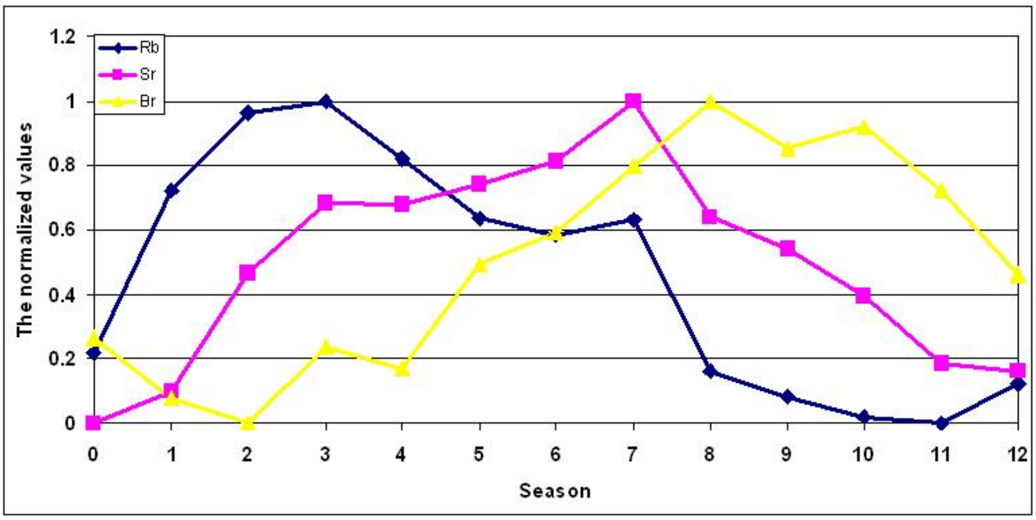

Fig. 2: Intra-annual distribution of terrigenous (Br), chemogenic (Sr) and biogenic (Br) elements.

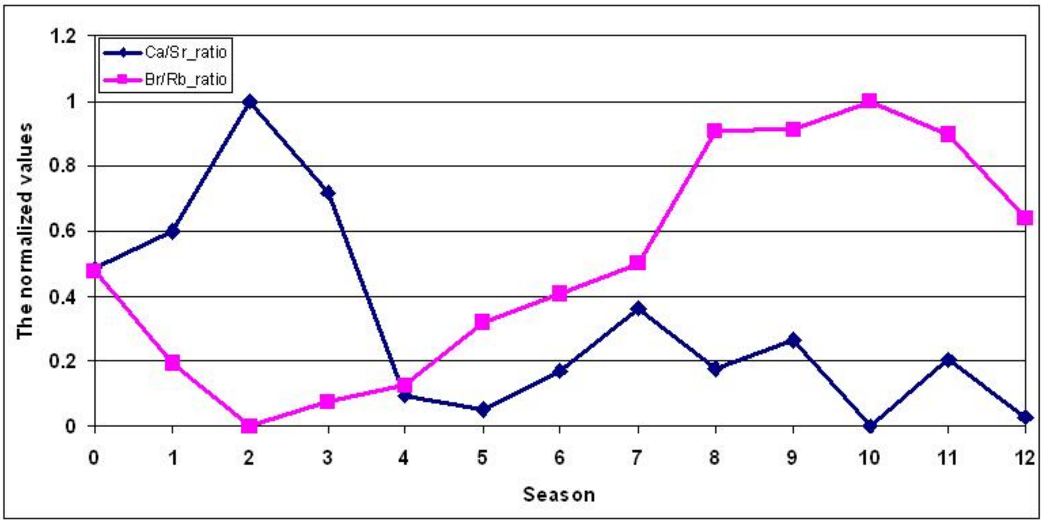

Fig. 3: Maximum of the Ca/Sr ratio marks the beginning of the annual cycle of sedimentation while high a Br/Rb ratio marks the end of the year.

Geochemical indicators were determined marking the beginning and the end of the annual layer, Ca/Sr and Br/Rb ratios, respectively (Fig. 3).

A linear dependence of Sr (correlation coefficient: +0.76) and Ca (correlation coefficient: +0.83) contents with the number of spring floods (precipitation from November until April) was found.

Oral

Precipitation reconstruction (AD 1530–2002) from varved sediments of Lago Plomo 47°S, Patagonian Andes

Julie Elbert, Martin Grosjean, Lucien von Gunten and Richard Wartenburger

High-resolution climate reconstructions from a variety of natural archives across the world are needed to place climate change into a broader perspective. For the Southern Hemisphere meteorological data only reach back until ca. AD 1900 and only few quantitative high-resolution reconstructions (mainly tree ring data) exist for the past millennium. In this context South America plays a crucial role, because it is the largest land mass extending to the south.

Lago Plomo (46°59S, 72°52W, 203 m a.s.l.), a Late-Glacial and Holocene proglacial lake east of the Northern Patagonian Ice field, is one of the exceptional lakes that provides clastic sediments with annually resolved laminations. Three short cores up to 122 cm lengths were collected at 28.9 m water depth about 50 m west of a Late-Glacial moraine that separates the lake from Lago Bertrand. ^{210}Pb and ^{137}Cs activity profiles and a calibrated ^{14}C AMS date of a wood fragment at 41 cm sediment depth (~AD 1850) are consistent with laminae counts confirming the annual nature of the laminae classified as graded clastic varves. The mm-scale sediment laminae were analyzed for varve thickness, mass accumulation rate, X-ray fluorescence spectroscopy and scanning reflectance spectroscopy 380-730 nm (VIS-RS). We compared Mass Accumulation Rate (MAR) to meteorological data of the CRUTS 3 dataset (0.5° x 0.5°) and found a negative correlation for annual temperature (calibration period: 1901-2006) and a positive correlation with winter precipitation (Fig. 1, calibration period: 1930-2006). MAR data were calibrated against austral winter (JJA) precipitation data (CRU TS 3.0) for the period AD 1930–2002 (r = 0.67, p(aut) < 0.05). Using a linear inverse regression model we reconstructed winter precipitation for Lago Plomo back to AD 1530 (Fig. 2). Wetter phases (reference AD 1930–2002) were observed around AD 1600, AD 1630-1690 and AD 1780-1850, and a prolonged drier period AD 1690-1780 with a multidecadal minimum centered on AD 1770. The spatial correlation for South America suggests that the JJA precipitation record from Lago Plomo is representative for large areas in the southwest between *c*. 41°S and 51°S. Coring of longer sediment cores was accomplished during a field campaign in February 2011 to produce a record of approximately 6000 years.

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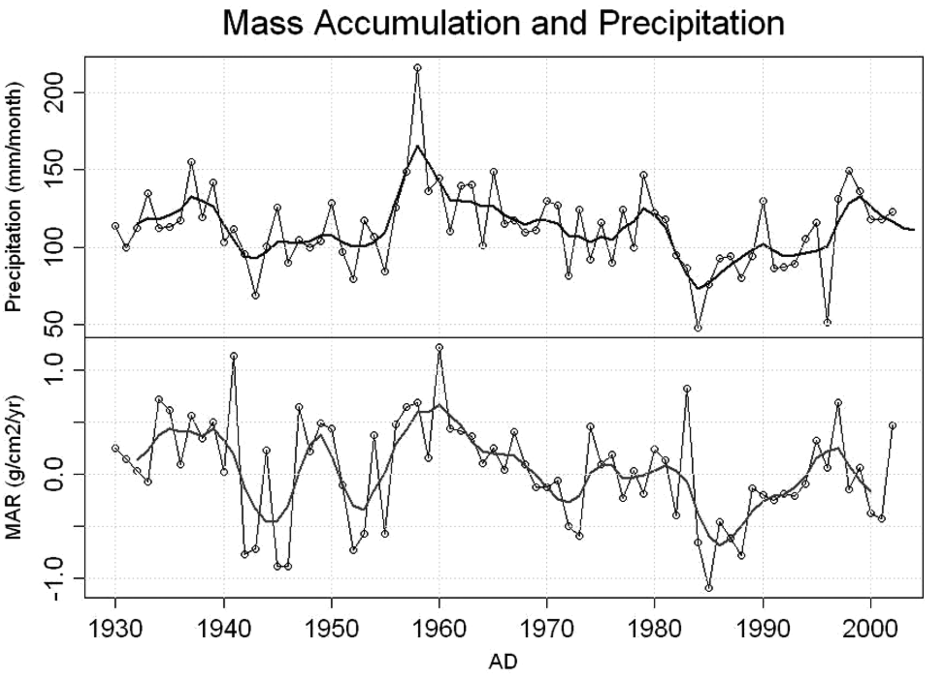

Fig. 1: Annual and 5-year triangular filtered precipitation data (mm/month) from CRU TS3 and annual and 5-year triangular filtered mass accumulation rate MAR (mg/cm^2 per yr; loess detrended with span = 0.85) for the calibration period AD 1930-2002.

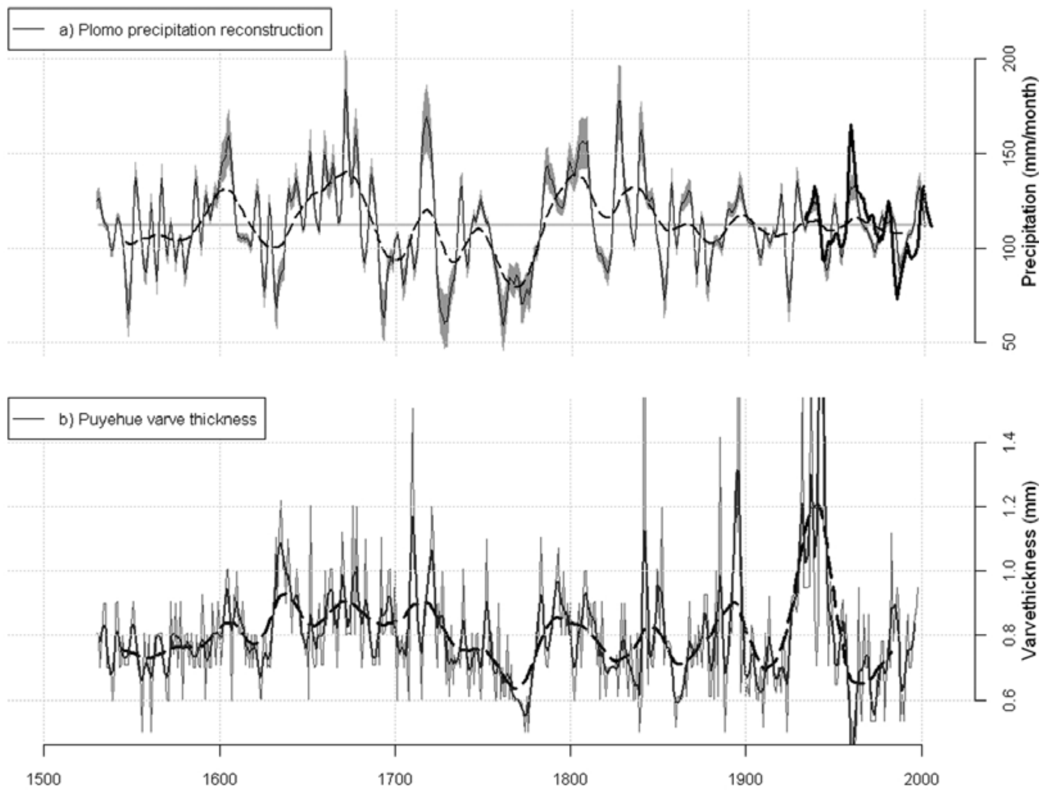

Fig. 2: (a) Austral winter (JJA) precipitation reconstruction based on mass accumulation rate (MAR) back to AD 1530. The thick black line represents 5-year filtered precipitation data (CRU TS 3.0) for the calibration period. The thin black line represents the reconstructed precipitation with the corresponding RMSE (shading). The dashed line shows the 30 year filtered reconstruction. The grey horizontal line represents the average winter precipitation of the calibration period. (b) Varve thickness obtained from short core PUII of Lago Puyehue by Boës and Fagel (2008). The thin grey line represents the annual variations of the varve thickness back to AD 1530. The thick grey line shows the 5-year filtered record and the dashed black line shows the 30-year filtered record.

Keynote

Climate records in speleothems

Dominik Fleitmann

Speleothems, such as stalagmites, stalactites and flowstones, are a rich archive of terrestrial paleoclimate information (e.g., Fairchild et al., 2006). The full potential of these materials has come to realization only during the last decade creating a surge in speleothem-based research. This has led to focused and high-quality research that has utilized many of the more recently available state-of-the-art sampling (e.g. laser ablation mass spectrometry) and dating (e.g. multi-collector ICPMS) techniques. A number of physical (e.g., thickness of annual growth bands, water vapour homogenisation temperatures in fluid inclusions) and chemical parameters (e.g., stable isotopes, trace elements) that can be measured on speleothems. When combined, these parameters can provide information on key-climatic and environmental variables such as precipitation, temperature and ecosystem.

Annual growth bands, their thickness typically varies between 50 and 500 µm, are quite common in stalagmites and the result of strong seasonal changes in the amount of surface precipitation and drip water respectively. Three main types of annual growth bands were described in stalagmites (Tan et al., 2006), these are: (i) luminescent annual growth bands caused by the incorporation of organic matter (Baker et al., 1993; Proctor et al., 2000), (ii) visible couplets of dark compact and white porous calcites (Frisia et al., 2000; Polyak and Asmerom, 2001; Fleitmann et al., 2004) and (iii) couplets of aragonite and calcite layers (Railsback et al., 1994).

Variations in the thickness of annual growth bands are related to the amount of surface rainfall (e.g., Polyak and Asmeron, 2001; Fleitmann *et al.*, 2004, 2007; Cheng *et al.*, 2009) or cave air temperature (e.g., Frisia *et al.*, 2003; Tan et al., 2003). Furthermore, by counting annual bands, radiometric chronologies can be significantly improved (Fleitmann *et al.*, 2004; Cheng *et al.*, 2009). In my talk I will give an overview on annual growth bands in stalagmites, with special emphasis on their origin and paleoclimatic significance.

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Oral

Using textural properties of clastic varves to improve calibration with climate data in the Canadian Arctic

Pierre Francus, François Lapointe and Scott Lamoureux

We used the image analysis method pioneered by Francus (1998) together with a new image acquisition and analysis software developed at INRS, to obtain grain size data within each varve from a 2840 years long sequence from Cape Bounty (East Lake). Several particle size distribution indices show a similar trend through time, especially for the standard deviation and the 98th percentile. These two particle size distributions are strongly associated with high-energy events (turbidites and debris flow), and particle size indices can be used to identify each of the facies found in the sequence. Comparison of the 98th percentile with instrumental data suggests a strong correlation (r^2=0.71) with summer rainfall at Rea Point. Rainfall reconstruction suggests that Cape Bounty recently experienced an unprecedented increase since ~1920 AD. On the other hand, changes in varve thickness are not in phase neither correlated with the particle size distribution. Our study shows that caution should be taken when calibrating instrumental data with varve thickness (VT), since sediment accumulation can result from different hydroclimatic and geomorphic mechanisms, such as snowmelt, rain events and landslides, as well as by changes in lake conditions. Varved sediments have been used to reconstruct past summer temperatures in Arctic regional reconstructions.

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Poster

High-resolution hyperspectral imaging (380-1000 nm) of varved lake sediments

Martin Grosjean, Wojtek Tylmann and Benjamin Amann

In order to calibrate biogeochemical lake sediment proxy data to meteorological time series (calibration-in-time; i.e. 'tree-ring approach') and to, finally, make quantitative high-resolution climate reconstructions an enormous amount of sedimentary proxy data is required. This is particularly the case in varved sediments that offer the unique opportunity to investigate climate variability and phenomena at the interannual, seasonal or even meteorological time scales.

In this context, high-resolution non-destructive scanning and imaging techniques (µXRF, spectrocolorimetry in the visible range VIS-RS, colour indices L*, gray values from X-ray radiography, etc.) are fundamental and the only way to acquire large data sets at sub-varve resolution (typically 100 µm to 1 mm).

Spectrocolorimetric techniques in the visible range VIS-RS (380-730 nm) have the great advantage that they provide direct species-specific information about organic and lithogenic sediment compounds (e.g., illite, chlorite and mica, photopigments, carotenoids, etc.), which makes the interpretation of the sediment formation processes and their relation to climate more reliable. In recent studies, scanning VIS-RS data have shown to be most suitable for calibration, validation and quantitative climate reconstruction from varved and non-varved lake sediments (von Gunten et al., 2009, revised; Trachsel et al., 2010; Elbert et al., 2012, in review). However, the disadvantage of the currently used instruments is the relatively coarse sensor field (> 2 mm) which compromises the potential advantage of varved sediments and in particular the information at sub-varve scales.

Here we present a prototype of a novel hyperspectral sediment core scanner and examples with data from biogenic varves (lakes in Poland) and clastic varves (lakes in the Swiss Alps). The core scanner consists of a hyperspectral camera that takes spectral scans at 3 nm resolution in the range between 380-1000 nm. The pixel size can be as small as 40 x 40 µm providing typically several data points for both laminae couplets in the varves in a 2D view (xy of the split sediment core surface); irregular or tilted (i.e. not perpendicular to the scan direction) bedding of individual varves is not a problem. The scan field has a width of a maximum of 6 cm. The moving tray with the sediment core is synchronized with the hyperspectral scanner and allows scanning of 1.40 m long cores.

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Keynote

Past climates reconstruction: from transfer functions to data assimilation in process models

Joel Guiot

Quantitative palaeoclimate reconstruction is evolving. The statistical transfer functions calibrated on modern data sets and applied to fossil assemblages have provided a number of valuable results. The concept is arrived at its limit. Exogenous variables (e.g. atmospheric CO_2 ratio) can bias the reconstructed signals. Replacing statistical black boxes by inversed mechanistic models of vegetation is a solution that has already proven itself (Guiot et al., 2009). It also provides an elegant solution for a multi-proxy approach (e.g. pollen, lake levels, stable isotopes), which is essential given that the biological assemblages are the result of a combination of climatic factors. At the same time, assimilation of climate reconstructions in the climate models has been very powerful to build physically consistent climate fields (Widmann et al., 2010). Methodological developments are still needed to complete this type of approach. In particular, by coupling climate models to proxy models, proxies can be assimilated directly without going through statistical reconstructions, which are often subject to biases. In conclusion, as no approach is perfect, we recommend to use all of these approaches in parallel (including the transfer functions) to better understand the uncertainties associated with reconstructions. This keynote will present the evolution of the climate reconstructions from simple statistical techniques to complex model inversion and will conclude with some perspectives.

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Oral

Varved sediments as a tool for the development of ^{14}C dating methods on ultra-small samples

Irka Hajdas, Axel Birkholz, Carol Biechele, Georges Bonani, Merle Gierga, Adam Michczynski, Mantana Maurer and Lukas Wacker

Chronologies of natural archives are typically based on radiocarbon dating of organic material. Lake sediments are commonly studied records of environmental changes (climate, vegetation). Because of the so-called 'hard water' effect known to affect the ages of bulk organic matter in sediments, the selection of terrestrial material is optimal when radiocarbon chronology is constructed. Twenty years ago the advance of AMS techniques allowed for dating of very small samples such as terrestrial macrofossils, i.e. fragments of leaves, seeds and other macroscopic plant remains. Such an approach delivers satisfactory results however limits the method to the sites that are rich in such plant remains because only a small fraction of studied lakes contains terrestrial macrofossils in sufficient amount that can be used for radiocarbon dating. Other records are mostly rather barred of macro remains. Therefore, radiocarbon dating becomes a challenge.

Nowadays the development in AMS dating allows for measurements of samples that contain only tens of micrograms of C, therefore minute amounts of terrestrial macrofossils can be analyzed. The cores of laminated lake Soppensee recovered in 1989 gave a basis for the Soppensee varve and ^{14}C chronology (Hajdas et al. 1993). The material selected at the time not always contained the required 1 or 2 mg of C. The clean and dried terrestrial macrofossils were archived and can now be analyzed using the modern AMS equipment (Wacker et al. 2010).

Comparison with the present age-depth model of Soppensee (Hajdas and Michczynski, 2010) allows for validation of the new ^{14}C ages.

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Oral

Clay varve chronology and the sedimentary environment at the eastern Baltic Sea coast in Estonia

Tiit Hang and Marko Kohv

Despite the frequent occurrence of varved clays along the eastern coast of the Baltic Sea, there have been few attempts to extend the Swedish Time Scale to the other side of the Baltic. The Finnish geologist Sauramo (1925) initiated the varve chronological investigations in Estonia summing up with the statement that the Estonian varved clays are hardly useful for geochronological purposes. This statement has influenced varve chronological research in the area for a long period. And only several decades later the chronological usefulness of the Estonian varved clays was demonstrated by Rähni (1963), Karukäpp (Karukäpp et al., 1992) and Hang (2003). These local chronologies were compiled for the Lake Peipsi depression in eastern Estonia (Fig. 1) and were tentatively correlated to the Finnish varve chronology via the Luga and Neva chronologies in northwestern Russia. Average ice retreat values were used to fill the gap between the Finnish and the Russian chronologies while the accuracy of these results depends on the validity of the assumptions. In sum, it is stated that although several varve clay sections have been measured in Estonia, there is no existing regional varve chronology to add new varve graphs.

Here a local varve chronology and varve thickness changes are analysed across the Pandivere-Neva (13.5-13.3 ka yrs BP) belt of ice-recessional formations in western Estonia (Fig. 1). The study area includes the shallow water Pärnu Bay in the eastern Gulf of Riga area and the adjoining coastal lowland. The surface of Devonian sandstones is at an altitude of -10 to -15 m. The entire area is covered by grey loamy till of Late Weichselian age, in turn followed by glaciolacustrine varved clay or silt with average thickness of ca 10 m (maximum reported thickness is 30 m). The upper surface of clay dips towards the south. The Holocene marine sand covering the glaciolacustrine deposits is normally 2–3 m thick (10 m as a maximum) but it can be absent locally. The Pandivere-Neva belt of ice-recessional formations is crossing the study area and is represented by push end-moraines and glaciofluvial deltas. Most often this zone is correlated with the Neva zone in northwestern Russia (Fig. 1). Due to Holocene wave erosion these forms have been levelled and the height of the features range only from a few metres up to 20 m.

Varved clays in the study area have been deposited in the Baltic Ice Lake and are characterised by very distinct laminations and easily distinguishable seasonal layers. Varves are usually thick and clayey with silty microlayers in some intervals. In a limited area at the distal slope of the Pandivere-Neva formations, a massive silty clay unit (0.40-10 m in thickness) with dispersed sand grains and a few dropstones has been described within the varved clay complex.

A new varve chronology comprising 570 consecutive varve years was constructed from the 33 cores obtained from irregularly spaced coring sites located at a maximum distance of 30 km from each other (Fig. 1). Varve correlation was made directly on the sediments considering not only layer thickness, which can vary in different sequences, but also other parameters, such as bedding characteristics, colour and interseasonal layers. Clear varve-to-varve correlation is possible in the older part of the chronology up to the local year 150. Correlation from this level onwards is more complicated because of large variations in the thickness of individual varves and increasing dominance of clayey winter layers lacking specific textural or structural characteristics useful for varve correlation between sequences. The length of the chronology (570 years) certainly underestimates the duration of proglacial conditions in the area due to difficulties in counting of distal varves and because of many varve series have erosional discontinuity at the upper contact with the overlying sands, pointing to post-sedimentary erosion.

Some of the examined varved sequences at the distal slope of the Pandivere-Neva formations are interrupted by an interval of massive clay with dispersed sand and gravel grains and few dropstones. According to varve correlation, the massive clay unit appears in different cores at the same stratigraphical level between the varves 70 and 90 in the local chronology (Fig. 2). An interval of 20 silty varves with dispersed sand and gravel grains in both seasonal layers within a single varve corresponding to this unit is reported from the sequences of a more distal part of the clay basin. Total varve thickness in this series of 20 varves is decreased compared to the neighbouring varves. All investigated clay sequences display a rapid colour change from greyish-brown (10YR 4/2) to reddish-brown (10YR 5/3). The colour change appears on top of the interval of silty varves or above the massive clay unit being synchronous across the studied sequences (Fig. 2).

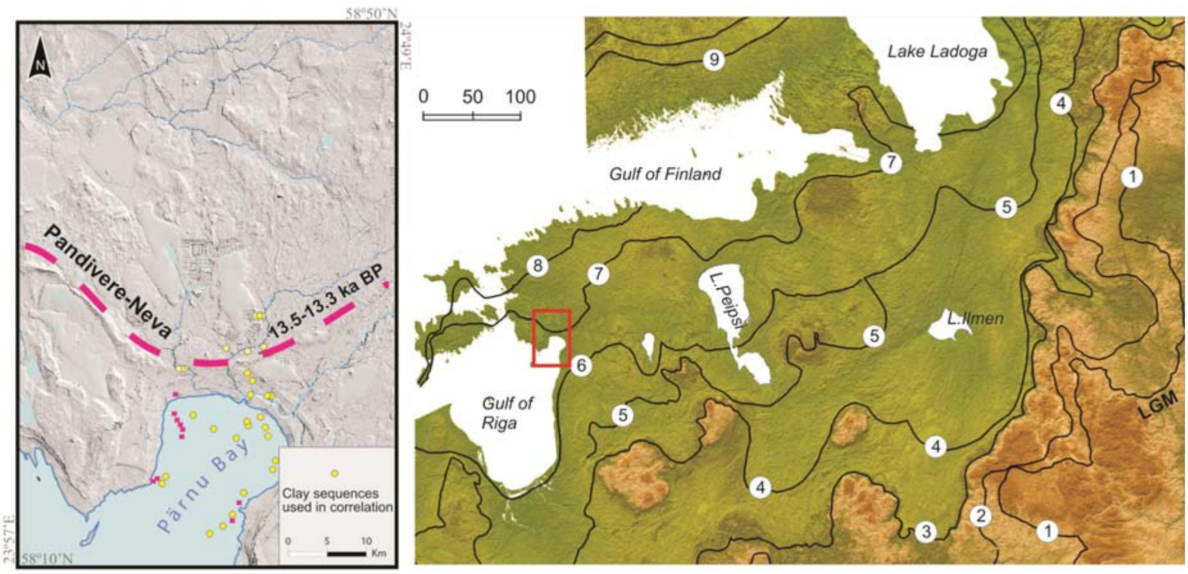

Fig. 1: Location of the study area and the sampling sites in western Estonia on the background of the major ice-marginal zones in the SE sector of the Scandinavian Ice Sheet (Kalm, 2010). 1: LGM; 2: Vepsian in Karelia and western Russia (Baltija, Pomeranian); 3: Sebezha and Krestets in Russia and Karelia (South Lithuanian); 4: Haanja–Luga in Russia, Estonia and Latvia (North Lithuanian); 5: Otepää; 6: Valdemarpils and Sakala in Latvia and Estonia; 7: Pandivere–Neva in Estonia, Russia and Karelia; 8: Palivere; 9: Salpausselkä I (Rugozero in Karelia).

In Pärnu chronology two main series of varves (E, B on Fig. 2) with gradual transition (C) in between could be distinguished. Summer layers dominate (52–90% of individual varve thickness) within thick (18-155 mm) varves in the lower portion of clay up to the year ca 130 of the local chronology. This series of varves is represented by a greenish-grey silty summer layers with alternating silt and sandy silt laminas or in places ripple bedding. Winter layers consist of reddish-brown massive clay. Seasonal layers are easy to distinguish. The upper series of varves from the year ca 150 onwards in the local chronology is characterized by a decreased total varve thickness (10-40 mm) compared to the underlying varves and the dominance of the winter layer (60-90%) within a couplet. In the upper portion of this group visual distinction between the varves and seasonal layers is problematic. This is why the true number of varves in this group is usually greater than shown in any of the varve graphs. Locally the upper contact of the varve series is erosional. The transition between the two series consists of ca 20 varves between the years ca 130 to 150 in the local chronology (Fig. 2). This group of varves consists of greenish-grey massive silt in the summer layers and dark brown massive clay in the winter layers. The most characteristic feature of this group of varves is rapid decrease in total varve thickness with the corresponding change in relation of seasonal layer thickness within a varve. In this group of varves winter layers start to dominate.

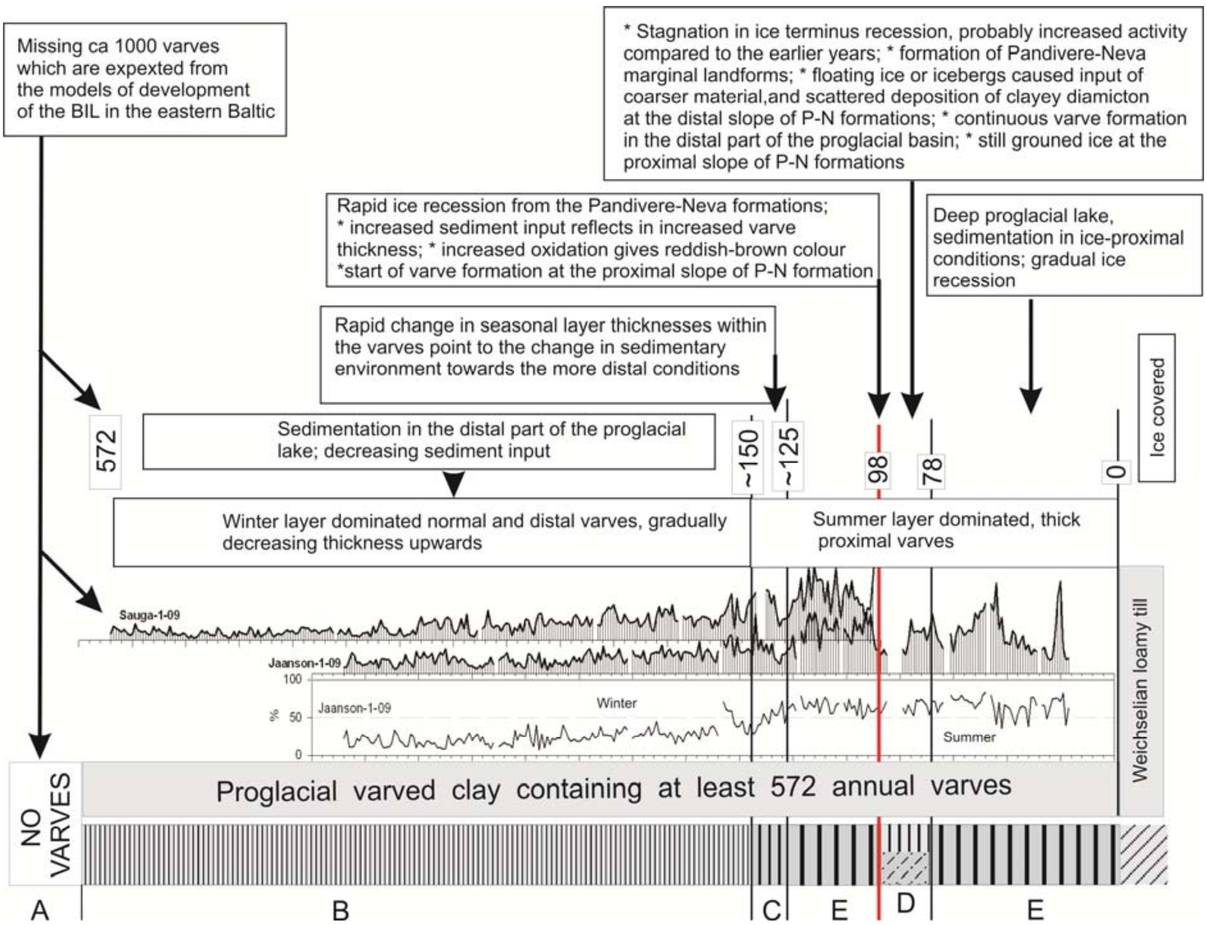

Fig. 2: Principle scheme displaying different varve groups, varve thickness changes and the changes in relation of seasonal layer thickness within the varves together with the interpretation of proglacial sedimentary environment in Pärnu area, western Estonia.

According to the varve correlation two groups of varve graphs could be distinguished: those representing sequences from the distal side and those representing sequences from the proximal side of the Pandivere-Neva ice marginal formations (Fig. 2). Accumulation of varved clays started ca 100 years earlier at the distal part. A massive clay unit with corresponding 20 silty varves in some sequences precedes the beginning of varve formation at the proximal part of the basin and is interpreted as an ice-drift material during the ca 20 years stagnation of the glacier margin at the Pandivere-Neva line. Ice proximal conditions on both sides of the recessional formations (within 30 km distance) ceased simultaneously within ca 20 years reflected in the decrease of the total varve thickness accompanied with the beginning of the winter layer dominance within a single varve. Periodic varve thickness variations in the proximal part of the chronology are driven by the thickness of summer layers while winter layer thickness remains rather stable through the whole chronology (Fig. 2). It is why the varve thickness changes are attributed to the proximity of the ice-terminus rather than to the palaeoclimatic signal explaining also the complications in correlation of Pärnu chronology with the Lake Peipsi, Luga and Neva varve chronologies in the eastern Baltic.

Poster

Change in character of marine varved sediment prior to and following Baltic Ice Lake drainage, southwest Sweden

Mark D. Johnson and Hanna Wibourgh

Marine varved clay was deposited in western Sweden proximal to the retreating Scandinavian Ice Sheet and below the marine limit at the end of the Weichselian Glaciation. The varves consist of gray, silty clay layers (interpreted to be summer layers) that grade into slightly more clay-rich and red winter layers. These red-to-gray marine varves are not uncommon in western Sweden and are often succeeded vertically by massive clays.

West of Billingen and immediately north of the Middle Swedish end-moraine zone near Götene, Sweden, a bed of poorly sorted sand and gravel interrupts the varve sequence. This bed has been interpreted to be sediment from the catastrophic drainage of the Baltic Ice Lake. The bed is in-turn succeeded vertically by varved clay that grades from red summer layers to gray winter layers, opposite to that of the pre-drainage varves, but similar to varves in the Baltic basin.
The change in varve structure is certainly due to the fact that the slightly brackish glaciomarine water in front of the ice sheet was replaced, after drainage, by the fresh water draining from the Baltic basin. XRF measurements reveal similar elemental composition and annual variations in both the pre- and post-drainage varves. We believe that the amount and timing of organic material delivered to the site of deposition was the dominant factor in controlling the color change.

Poster

Seasonal and centennial Sr-anomalies in carbonate sediments as an environmental proxy for Lake Shira (South Siberia) during the last 2500 years

Ivan Kalugin, Andrey Darin, G. Tretyakov and D. Rogozin

Sedimentation history of saline lakes efficiently reflects environmental change in the catchment area especially for wet-arid conditions. Evaporates, generally originate as the result of chemical precipitation, are usually deposited because of salinity oscillations connected with evaporation. Chemical sediments are composed of different carbonates that allow quantitative assessments of physicochemical conditions and biological production. Shira Lake is a good and representative object for detailed modelling of weather and climate conditions due to its locally recorded hydroclimatic information stored in annually laminated sediments. Actually, the carbonate biochemical mineralization in Shira Lake shows not only seasonal but also centennial pulses every 450-500 years. Thermodynamic estimations of the rock-water multi-system in agreement with local conditions and source matter is the base for interpretation of measured geochemical parameters in the sediments in terms of environmental indicators like e.g. temperature, salinity or pH. At the same time data for quantitative environmental reconstruction on an annual basis become available by a modern scanning X-ray fluorescence technique for the sub-millimeter microstratigraphic study of varves.

Meromictic Shira Lake is situated in a semi-arid climatic region of South Siberia. It has a closed plane-bottom basin (9.4 x 5.3 km^2) with brackish water (total salinity up to 19 g/l) and a small inflow, the Son River. Continental climate conditions provide mean July temperatures of 18^{o}C and mean January temperatures of -20^{o}C. A long-term stratification of the water body with an intra-annual chemocline depth range from 11-16.2 m is observed as well as historically documented lake level oscillations of up to 7 m (Rogozin et al., 2010).

Coring: A sediment column of 155 cm in length is recovered by a hammer-appointed corer from the deepest (24 m) central part of the lake (54^o 30.35'N, 90^o 11.32'E, 352 m a.s.l.). The uppermost non-disturbed interval (22 cm) was taken by a box-corer for a detailed analysis and correlation between geochemical indices and meteodata used for calibration of a transfer function.

The sediment has a thin laminated structure, where black layers with clay, carbonate and organic matter are coupled with white organic free ones. The thickness of couplets varied from 2 mm in the uppermost 20 cm of the core to 0.4 mm close to its bottom. Clastic components (quartz, feldspar, mica, chlorite) are irregularly distributed by dust and flood events.

Six visible light intervals depleted of organics are revealed along the core. They are 45-120 mm in thickness and are repeated every 200-250 mm (Fig. 1). Dark and light sediments are different in water content as well as in rock-forming element composition (Table 1). The decrease in Na_2O and MgO content of the washed samples means removing of soluble NaCl and $MgCl_2$ components. Also loss on ignition (LOI<500^{o}C) is lower in light sections confirming the lack of organic matter (Fig. 1).

Tab. 1: Chemical composition of bottom sediments from Lake Shira (in wt.%).

Sampling depth (mm)	Sediment	SiO_2	TiO_2	Al_2O_3	Fe_2O_3 tot	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Sum	S sulfate	S sulfide	CO_2	CaO/ MgO
	dark, dried	31.11	0.45	8.18	3.76	0.12	7.08	12.51	4.33	1.63	0.18	29.45	98.8	1.9	0.16	16.7	1.8
70-120	dark, washed	34.12	0.48	8.98	4.37	0.13	6.08	13.32	1.4	1.86	0.19	28.73	99.66	0.69	0.07	12.73	2.2
	light, dried	23.64	0.3	5.53	2.37	0.12	11.43	20.72	1.68	1.13	0.15	32.83	99.9	0.62	0.09	24.49	1.8
130-145	light, washed	23.66	0.3	5.77	2.66	0.12	11.76	20.3	0.83	1.19	0.16	32.83	99.58	0.29	0.04	20.64	1.7

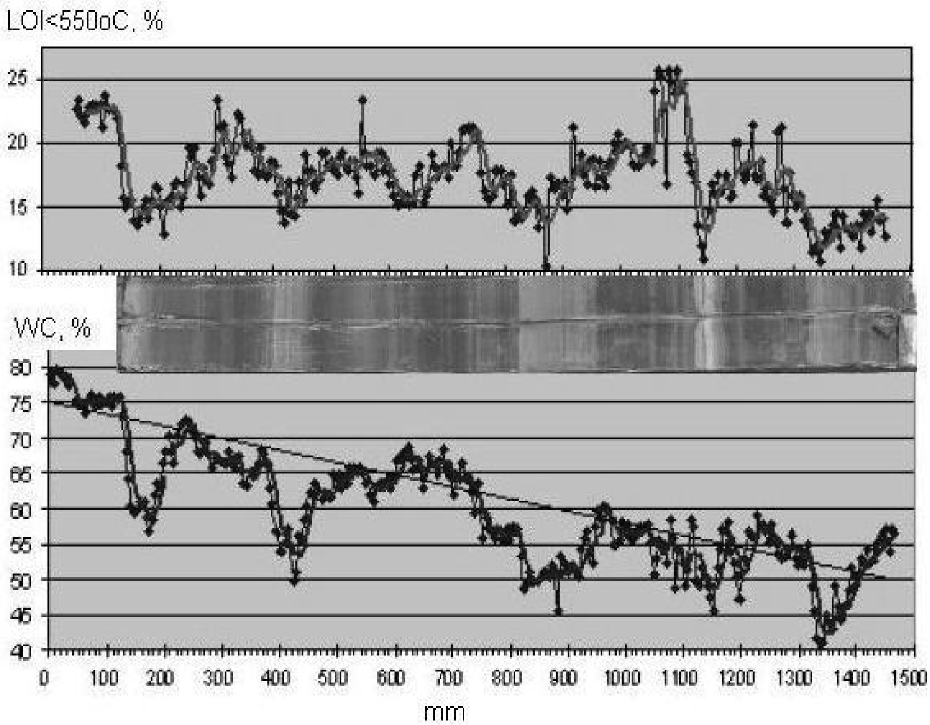

Fig. 1: Loss on ignition (LOI<550^{o}C) and water content in sediments of core Shira-2009 (photo in the middle of picture). Horizontal scale is the depth of the core (in mm). Light intervals are visible on the photo, they are also marked by measurements.

Correspondingly, calcite (18-30 wt.%) and monohydrocalcite (13-14%) predominate in the black muds coloured by organics and hydrotroilite, but dolomite (54%), less calcite (11%) with a touch of strontianite are concentrated in the light layers.

An age-depth model is built for the last 2450 years. It is based on ^{137}Cs and ^{210}Pb dating in the uppermost part of the sediment column subsampled in steps of 5 mm as well as by three radiocarbon dates (Fig. 2).

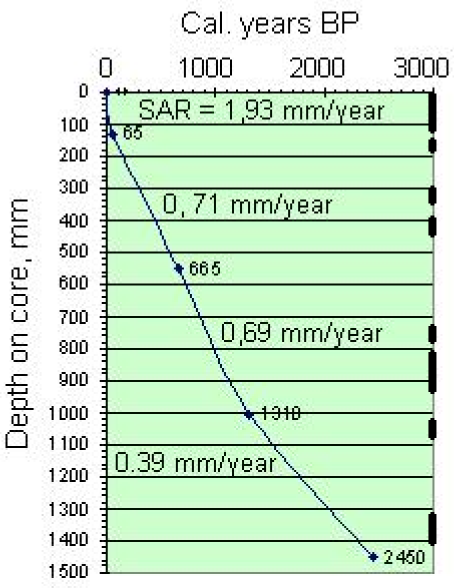

Fig. 2: Age-depth model for lake Shira sediments. The date of 65 years is evaluated by varve counting and ^{137}Cs dating. Radiocarbon dates at 665, 1310 and 2450 cal. BP are received from the Poznan radiocarbon laboratory (lab № Poz-34105, -34106 and -34816). Intervals with varve counts along the core are marked on the right of the picture.

The position of the ^{137}Cs peak marking the year 1963 agrees with the age calculated by the amount of thin layers, which confirms the annual origin of the lamination. Moreover, there is an opportunity to check the annual rhythms by their strong geochemical signal – e.g. the Sr content as determined for seasonal oscillations (see: Darin et al., this issue). Evaluation of the sediment accumulation rate (SAR) is controlled by counting of the best recognisable varves as estimated for 8 intervals along the core (Fig. 2), each of them includes 50-144 individual annual rhythms. Three radiocarbon dates (Lab. Poznan, Poland) show the same SAR. Systematic deviation of calibrated ^{14}C years BP from the varve age is ca 1200 years, which was accepted for the age-depth model. It is possible, that the reservoir effect is conditioned by soluble source matter supplied by ancient carbonate bedrocks, which are typical for the catchment area. A correction on decreased linear compaction of white intervals containing low water percentages is also executed (see Fig. 1) for a uniform time-scale building.

Minor element composition is analysed in solid blocks applying micro-XRF with the Synchrotron radiation method (scan XRF SR) at the Institute of Nuclear Physics (Novosibirsk, Russia) and at the ANKA-FLUO station (Karlsruhe, Germany). The scanning steps for measurement varied from 0.02-0.10 mm for the calibration interval to 0.2-0.5 mm along the entire length of the core.

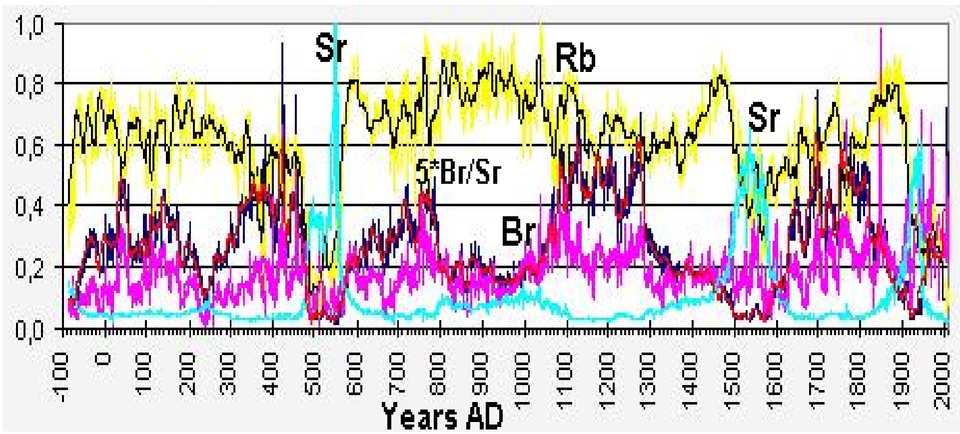

Fig. 3: Elemental indicators of the sediments for the last 2100 yrs.

The most informative components statistically chosen from a big dataset of 20 analysed elements are shown in Fig. 3. As usual (Kalugin et al., 2007), Rb corresponds to clastic components, Br to organics, and Sr to carbonates. Actually, this geochemical time series allows marking anomalous light intervals (see Fig. 1).

Computer physicochemical simulations in the natural rock-water-gas multi-system of lake Shira is executed by the "Selector" software (Karpov et al., 1997), a method used for thermodynamic potential minimization under a local equilibrium state.

Thermodynamic estimations demonstrate that the surface water of lake Shira (Kalacheva et al., 2002) is not in equilibrium with air. So following excess, solid phases have to be precipitated (Table 2).

Tab. 2: Estimated content of precipitated minerals under temperature change.

	T (^oC)				
	25	20	15	10	5
Magnesite	0.8313	0.8298	0.8289	0.8271	0.8248
Mixed lamellar Mg-silicate	0.0023	0.0022	0.0022	0.0021	0.002
Strontianite	0.004	0.0053	0.005	0.0062	0.0077
pH	8.64	8.69	8.79	8.85	8.87

Such temperature dependence for the solubility product of strontianite (Fig. 4) contributes to concentrate Sr in sediments during the cold season due to a decreasing temperature and increasing water salinity through the ice cover as well.

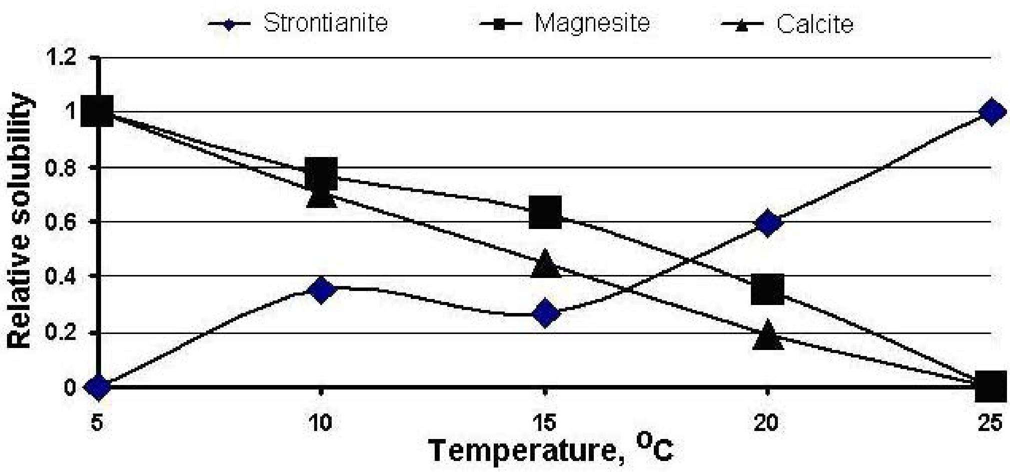

Fig. 4: Solubility diagram for carbonates (modified after Garrels and Christ, 1965).

The salinity effect on Sr concentration calculated for the same system shows a positive correlation between evaporation in % and the strontianite content in the solid phase (Fig. 5).

Dependence is revealed between the Sr content and the lake level documented since AD 1920. An inverse negative relationship between the Sr content in the sediments and the lake level has a correlation of -0.60 (1950-2007). This means that periodical shallowing results in both increase of water salinity and concentration of Sr in the sediments. The lowermost lake level in AD 1926 had -6 m relative to present times, but salinity was higher at ca 27 g/l (Kalacheva et al., 2002).

The light carbonate- and Sr-enriched layers formed during each cold season as well as at the time of extremely low lake level periods of higher saline water every 450-550 yrs. The Sr signal was also measured in similar carbonate sediments of saline lake Telmen situated in Northern Mongolia ~800 km south-east from Lake Shira.

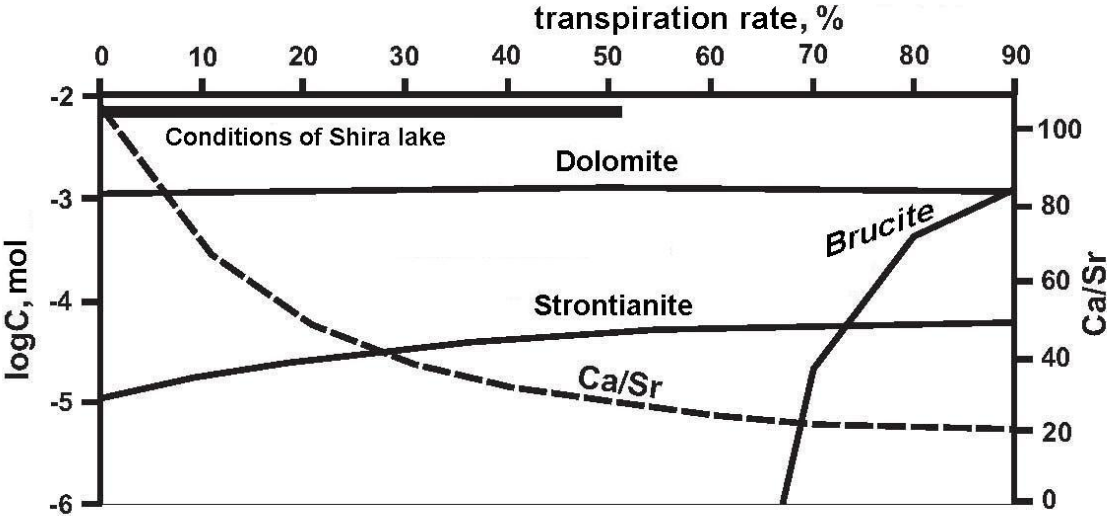

Fig. 5: Solid phases precipitated from Lake Shira water with variable evaporation (transpiration).

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Oral

Annually laminated sediments from Lake Szurpiły (NE Poland) – varve thickness variability during the last 8000 years

Malgorzata Kinder, Dirk Enters, Wojtek Tylmann and Bernd Zolitschka

Annually laminated sediments are an invaluable source of paleoenvironmental data and provide a high temporal resolution in calendar years or even seasons. Varve identification and counting provides not only an absolute time scale but gives also additional information about varve and laminae thickness variability.

The present study describes results based on the sediment cores retrieved in 2007 from Lake Szurpiły (NE Poland). Parallel and overlapping cores were used to construct a composite sediment profile with a total length of 12.39 m. The topmost 8.1 m of the sediment sequence is dominated by annually laminated carbonaceous and organic carbonaceous gyttja. Thin sections covering this part of the profile were scanned on a flat bed scanner in polarised light to allow better identification of the annual layers. Varve counting and continuous thickness measurements of single layers including microanalysis and digital imagery were carried out microscopically on thin sections. The counting error was determined by independent multiple varve counts using the Cybis Coordinate Recorder software. The mean varve thickness for the entire record amounts to 0.76 mm. In general, the varve thickness increases upwards as the result of lower sediment compaction and higher water content in the topmost part of the profile, but also of changes in sedimentation rate resulting from variations in allochthonous supply and lake productivity. In the lower part of the sediment profile (8.1-5 m) the standard deviation of varve thickness is significantly lower, while the youngest sediments are characterized by a considerable diversity. An abrupt change in varve thickness occurred at the depth of about 4 m, when mean varve thickness almost doubled. In the last 2500 years the development of settlements led to further changes in sedimentation rate reflected in the high variation of varve thickness.

Acknowledgements

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Poster

Varve correlation as a tool to understand inner mechanism of slope failures

Marko Kohv and Tiit Hang

Glaciolacustrine or glaciomarine varved clays cause slope stability problems all around the world (Fletcher et al. 2002; Giraud et al. 1991; Van Genuchten and van Asch 1988). Their laminated structure offers a unique opportunity to investigate failure mechanisms, development of the rupture surface and post movement deformation in detail.

Glaciolacustrine varved clay plain in the surroundings of the town of Pärnu, eastern Baltic Sea coast, is recognised as the most landslide-prone area in Estonia. Numerous slope failures took place during the period 2000-2010 and endangered infrastructure and houses. One of the largest landslides, the Audru landslide, was investigated in 2005. Eight varved clay cores were extracted with a strengthened Russian type peat corer (1 m in length and 10 cm in diameter). It was assumed that the laminated structure of the sediment allows tracing the slip surface/zone in a view of discontinuity or deformed laminas throughout the whole cross section of a slide. In the laboratory all 8 cores were placed side by side on the table, core surfaces were cleaned and the correlation between cores was made directly on the sediments. This way marker horizons, marker varves or series of varves were quickly distinguished and a convincing correlation with the location of the slip surface or zone was established.

The proglacial varved clay of the Audru landslide site covers almost horizontally the till surface. The contact with till is gradual, the lowest and most ice-proximal varves contain silt and sand with diffused grains of gravel and some scattered pebbles. The thickness of the clay layer outside of the valley is 10 m and it has a minimum thickness of 3.7 m within a valley. Changing thickness of clay is also reflected in the morphology of the slope which is elevated in the middle of the sliding body and close to the Audru River channel with the depression in between (Fig. 1). Varved clay is covered with fine to medium grained marine sand with organic rich interlayers.

The identified slide surface in correlated sediment sequences has an elliptical shape through the cross profile with the deepest point at 9.4 m below the land surface (Fig. 1). At borehole Bh-4 a ruptured zone is 5 cm thick and 13 m towards the river, at borehole Bh-2, its thickness reaches 1 m. At borehole Bh-X2 two sliding surfaces were found, the upper one is very sharp, visible as a discontinuity inside the varves and the lower one is a 0.5 m thick ruptured zone.

In total 280 varves were counted in the longest varve series. Varves are around 1 to 2 cm thick in the upper complex and start to gradually thicken from the middle complex towards the bottom of the varved clay layer. The lowermost varves are up to 20 cm thick and consist almost entirely of a silty summer layer. Varve-by-varve correlation of cores demonstrates that initially both, the annual varves as well as seasonal layers were slightly tilted towards the river (Fig. 1). A relatively big interval (2.5-2.8 m) of clay is missing in the borehole Bh-5 between the lower and the upper marker varves. Up to 0.4 m of varved clays is missing in the upper part of the Bh-X2 sequence compared to Bh-2.

The most significant morphological feature of the varved clay surface is the deep sand-filled depression (Fig. 1). As the uppermost dehydrated clay layer and the uppermost series of thin distal varves are still present in the varve series under the depression, this depression could not have been formed due to fluvial erosion. Our varve correlation demonstrates that the depression was formed because a 2.8 m thick interval of clay from the middle part of the clay sequence was pressed out during the sliding event(s). This portion of clay is characterised by the high (up to 50% of total soil weight) silt content. As the fine-grained sands and silts are known to develop soils most prone to liquefaction (Coduto 1988), the missing clay interval probably liquefied due to rising pore water pressure at the beginning of the mass movement and was pressed out into the river channel as the sliding event developed. According to Iverson et al. (1997) high pore water pressures under and probably within the siltier lower portion of the varved clay and loss of cohesion during the failure both enhance the potential for liquefaction.

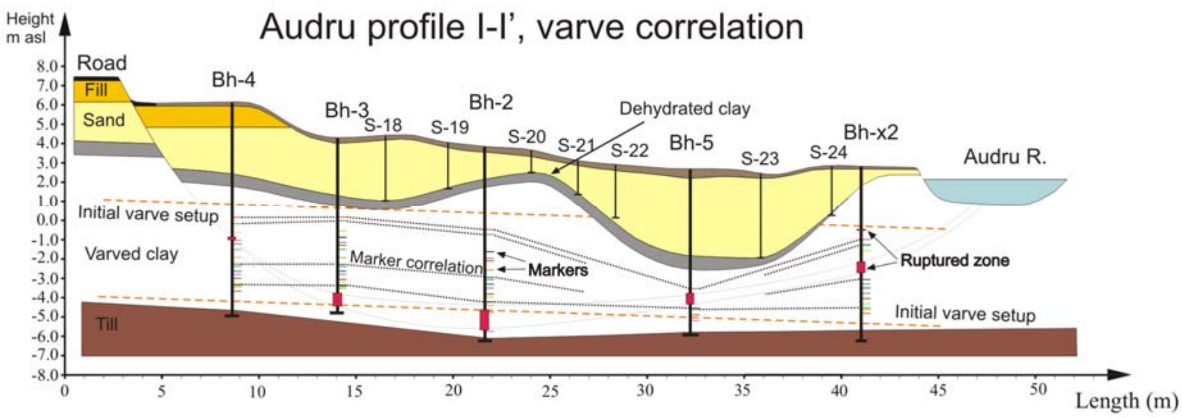

Fig. 1: Cross section of the Audru landslide with the rapture zone identified by varve correlation.

As the aforementioned depression in the clay surface is filled with sand, (re)activation of an old slide and following fulfilment of the depression is the most likely scenario. It is hard to estimate the possible timing of the earlier slide but there should have been enough time for smoothing the slope surface and for erosion of the ‘paleo’-toe from the channel. One option may be dating of organic remains within the marine sand that could give a minimum age of the sand cover. Morphology of the ground surface displays a minor 0.5 m high scarp close to the sand-filled depression and this reflects the amount of clay which was pressed out during the last sliding event. Reactivation of old slides is a common phenomenon reported by various authors (Fletcher et al. 2002; Sjöberg 1996).

Oral

Sedimentation changes in a complete Holocene lacustrine record in the Sahara: Varve thickness, seasonality and event layers – Problems of identification, interpretation and chronology.

Stefan Kröpelin, Jens Karls, Jan Kuper and Martin Melles

Lake Yoa (19.03°N, 20.31°E, 380 m a.s.l.) is a groundwater-fed lake in the hyperarid eastern Sahara halfway between the Tibesti Mountains and the Ennedi plateau. Kröpelin et al. (2008) revealed that the bottom sediments contain a unique archive of climatic and environmental change in the Earth´s major desert. The 7.5 m sediment record of OUNIK03/04 which covers 6,100 years has been extended to a maximum drill depth of 15.7 m during a 2010 coring campaign within the framework of the Collaborative Research Center (CRC) 806 “Our Way to Europe - Culture-Environment Interaction and Human Mobility in the Late Quaternary”. The long core (Co1240) contains the first complete terrestrial record of climate variations from the onset of the early Holocene humid period to the present. Sediments mainly consist of fine to very fine laminae in the millimeter to sub-millimeter range and bedded layers up to 2 cm in thickness. They expose shifts in thickness but also changes in clastic and geochemical composition. These differences and the occurrence of a few event layers in the lower part implicate significant changes during lake basin evolution as well as problems in varve counting. Here we present our interpretation of varve formation in Lake Yoa and an initial varve chronology in combination with ^{14}C ages including an overview on applied methods and their usefulness with the Co1240 record.

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Keynote

Lake and catchment process studies in the Canadian Arctic to improve our understanding of the formation and environmental signal of clastic varves

Scott F. Lamoureux

Varved sediment records hold tremendous potential as paleoenvironmental records in regions where other high resolution proxy records are not available and can contribute to a richer understanding of environmental change and processes when combined with other proxy records elsewhere. Clastic varves are often interpreted as proxies of hydroclimatic processes: a combination of one or more climatic or meteorological processes that generate sufficient hydrological response that sediment delivery and deposition to the lake is affected. Sedimentary parameters used typically include mass accumulation and particle size, and innovative methodological developments have allowed these sedimentary indicators to be assessed within finely laminated sequences. These techniques continue to advance the interpretation of varves to finer detail that includes subannual units and multiple sedimentary facies. While most clastic varved records have used statistical regression techniques to interpret the varve-climate relationship, few records have been investigated from a process perspective, and fewer still have sustained process studies for more than a two years due to cost and logistical reasons. Although process studies are not an absolute requirement for interpreting clastic varve records, there remains a compelling rationale for pursuing them where possible, to enhance and verify the environmental signal, as well as to discover new interpretations or signals within the varves.

The longest process-oriented varve study to date (known to the author) has been undertaken in the Canadian High Arctic, a large region where a number of clastic varve records have been published and several new records are currently in preparation. Process studies at the Cape Bounty Arctic Watershed Observatory (CBAWO) on south-central Melville Island (74°55'N, 109°35'W) began in 2003 and have continued to the present. The study area is composed of paired watersheds that drain into similar lakes that both contain long varve sequences. Parallel measurements have been undertaken to characterize the processes associated with climate, hydrology, sediment transport, water chemistry, limnology and sedimentary deposition in the lakes. These studies, undertaken in adjacent watersheds with similar glacial and marine history, bedrock, vegetation, topography, weather and lakes are further intended to assess the reproducibility of the processes and signal in the sedimentary records. Key records related to varve formation that have been generated during the melt seasons 2003-2010 include: meteorology, river discharge, suspended sediment transport, suspended sediment grain size, water chemistry, lake water column properties, underflow dynamics and sediment trapping. Collectively, these data reveal a number of key process, linkages and insights in this system with implications for the interpretation of clastic varves. These can be generalized into: hydrometeorological controls over sediment transport; limnological controls over sediment deposition; and geomorphic controls over sediment availability and composition.

Hydrometeorological controls: In the Arctic environment, stream flow is generated primarily from snow melt during the spring and it is during this period that the majority of sediment is transported to lakes. The principal control over the volume of water and the maximum discharge rate is catchment snow water equivalence (SWE). There is considerable interannual variation in SWE at CBAWO, ranging by over a factor of three during the eight year study period. During that time, while incoming radiation and air temperature control the daily discharge characteristics, there is no significant correlation between energy parameters and discharge at the seasonal level. Of particular note, the relationship progressively diverges as stream flow begins to wane as energy becomes increasingly available for melt due to exhaustion of snowpack in the catchment. Annual sediment yields suggest a close correspondence between SWE, sediment yield and sediment deposition in traps at the lake bottom, although the statistical power of the relationship is limited to the short data set (n=8). Notably, in some years, rainfall plays an important role over sediment yield, and in the unusual case of 2009, a single two-day event was responsible for more than 80% of the annual yield. As is the case with other studies, low intensity rainfall does not generate a substantial runoff response, and available data suggest a non-linear response in sediment yield to rainfall.

Limnological controls: Sediment inflow to the lake undergoes multiple pathways to the ultimate deposition location where the sedimentary record is obtained. At CBAWO, trapping shows systematic consistency between accumulation rates and sediment fluxes into the lake at multi-day timescales. Sediment flows are dominated by underflows during peak discharge when sediment load is highest. These flows, despite strong density contrasts with lake water, are relatively slow moving, and form shallow underflows with velocities typically below 2 cm/s in the middle of the lake. These underflows may be isolated from the sediment bed in the early runoff season by shallow anoxic, high conductivity water that accumulates in the lake bottom during winter. This bottom water is eventually flushed by underflows, but this may occur after peak sediment input into the lake. Sediment inflows with lower sediment concentrations disperse as interflows or overflows, resulting in increased suspended sediment deposition through the water column as the season progresses and delays in deposition. The low measured velocity of sediment flows in the lake and trapping show a significant proximal-distal attenuation of sediment accumulation that varies between events. Hence, proximal deposition sites have both higher overall accumulation rates, while more distal sites may exhibit threshold effects where individual inflow events are not recorded by deposition. Finally, limited winter data suggests the potential for subaqueous events with substantial potential for deposition. For example during the 2008-2009 winter, under ice cover, three major sedimentation events were recorded, and resulted in one discernable unit in the sediment record.

Geomorphic controls: The potential for long term changes in sediment supply due to landscape and channel alteration cannot be assessed by short term process studies. However, the impact of landslides, river damming and localized disturbance in the watershed has been investigated after a period of permafrost disturbance in 2007. Results indicate most slope disturbances have limited downstream sediment yield impacts, while bank erosion can be enhanced by disturbance for periods of years and increase sediment yield. Despite these measureable effects in the fluvial system, overall sediment yield impacts are relatively subtle and appear to be smaller in magnitude than the inherent interannual variation in yield in the Arctic environment.

Overall, process studies point to the key hydroclimatic processes that affect sediment accumulation and varve properties and can aid in calibration of the varve paleoenvironmental signal. However, even in comparatively simple settings like the Arctic, the primary process for sediment delivery can switch from nival to pluvial in a given year, and in some years, both contribute sediment. Recognizing sedimentary properties associated with these inputs, along with the effects associated with changing lake and catchment conditions, will require closely coordinated process and novel sedimentary analysis approaches. The apparent complexity of clastic varves revealed by long term process studies provides insights for interpreting the paleoenvironmental record and cautions against overly simple interpretations. However, these studies also indicate that substantial opportunities exist to develop novel records of environmental change from varves in this setting and elsewhere.

Oral

Lake Van, Turkey: Evidence for a lake level drop of 500 m in the period 20-15 ka BP

Günter Landmann and Stephan Kempe

Lake Van, the largest soda lake on Earth and the 3rd largest closed lake by volume, is located on the Eastern Anatolian High Plateau, Turkey (Fig. 1). As a terminal lake, its level reacts very sensitively to climate changes and its depth of 451 m allows it to survive even pronounced dry periods. It is thus the major climate recorder in the Near East. Results of 19 sediment cores taken from different water depths were used to reconstruct the lake level history (Fig. 2; Tab. 1; Landmann, 1996; Landmann et al., 1996). All cores taken from the main basin and most of the cores from shallower depths can be correlated by means of twelve tephra layers deposited by volcanic eruptions but also by other conspicuous marker layers and lamination patterns. Because slumping and turbidites occur frequently in this tectonically active region, careful correlation between cores is important to assure the completeness of the sediment column of each core.

A high stand up to 70-80 m above the present lake level is documented by terrace sediments (Schweizer, 1975; Valeton 1978), yielding a floating varve chronology of 606 years fixed by ^{14}C-dating to the period 20.1-20.7 cal. ka BP (Kempe et al., 2002). This varved section is underlain by sandy gravel marking the transgression of the glacial lake and overlain by a slumped, 6 m thick section representing the start of a pronounced regression of the lake.

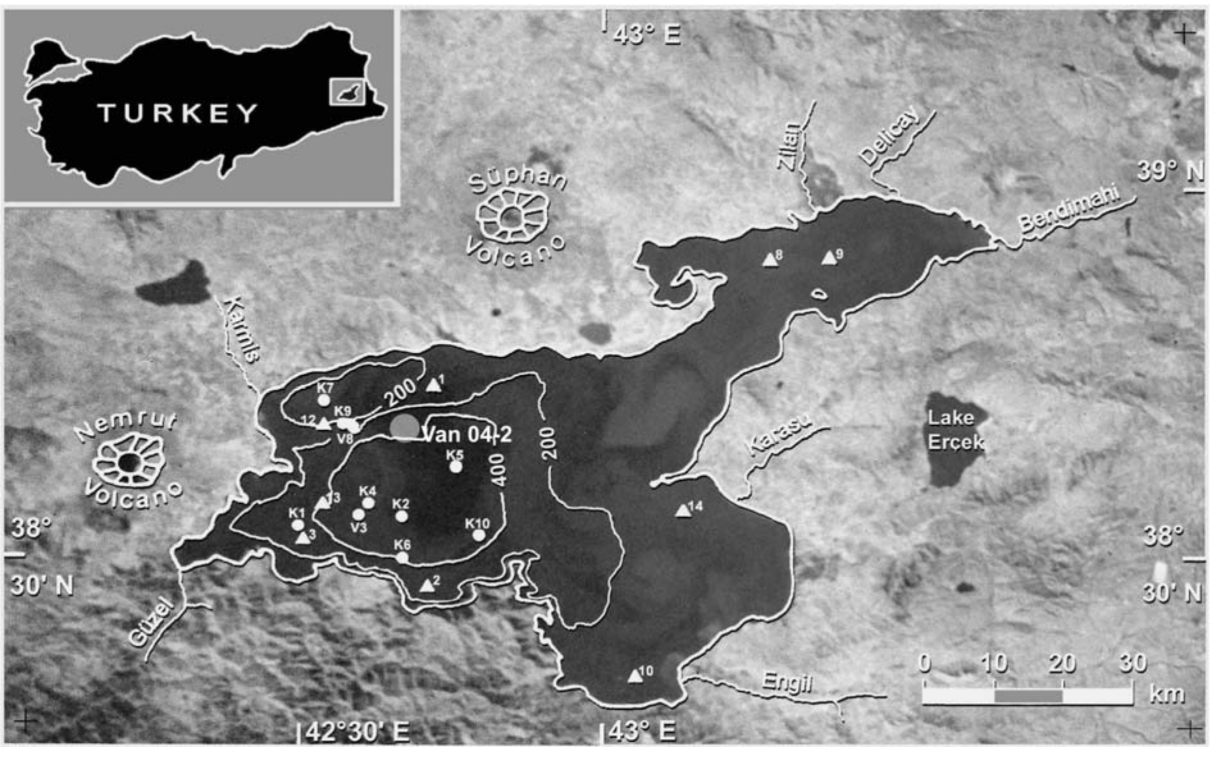

Fig. 1: Map of Lake Van with the location of cores taken in 1974 (triangles), in 1990 (circles) and of core VAN 04-2 (Litt et al., 2009; grey circle).

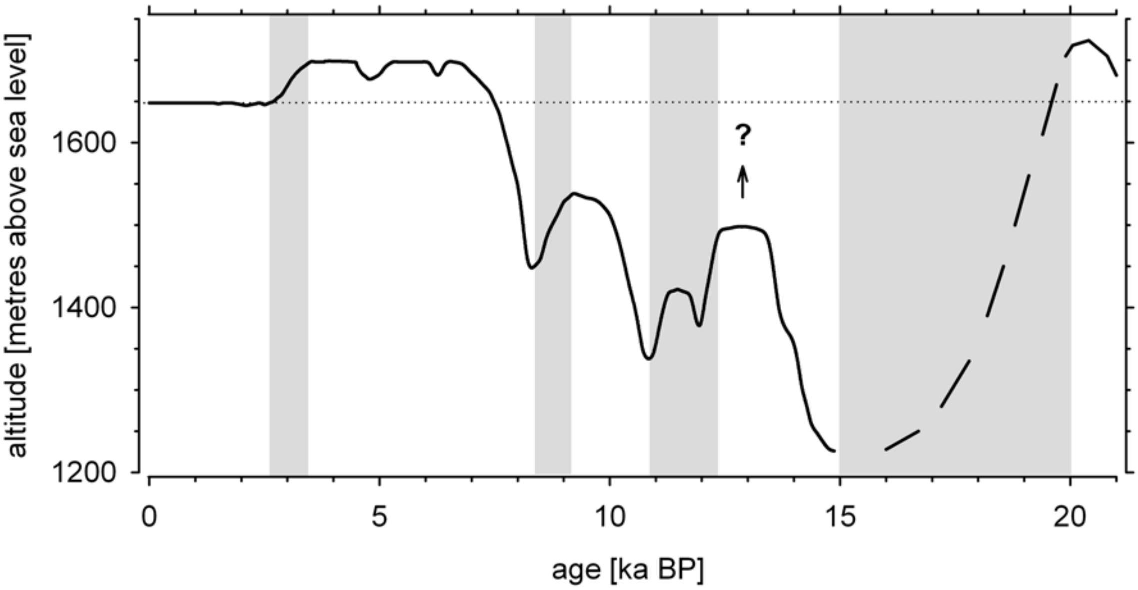

Fig. 2: Lake level fluctuations of Lake Van in the past 21 ka (redrawn after Landmann et al., 1996). Shaded areas mark major periods with a negative water balance. Maximum depth of Lake Van today is 451 m; the dotted line gives the present lake level at about 1650 m a.s.l. The white arrow marks the time period when the Lake Van level was below 1222 m a.s.l. as discussed here.

Tab. 1: Features used for lake level reconstruction (Landmann et al., 1996; Reimer et al., 2009).

Feature	Interpretation	Remarks
on/offset of varves	water depth at core locality >/< 40 m	several dated levels from cores of different depth
Artemesia pellets	salinity 80-100 per mill	dated ca. level
archaeological sites	Urartu high stand	ca. dated level
terraces above present level	level still stands	highest terrace is dated by ^{14}C (Kempe et al., 2002)
sublacustrine terraces	level still stands	not dated
pollen data	e.g., Van Zeist & Woldering (1978)	climate proxy
increasing Mg-carbonates	Regression	increasing salinity
increasing terrigenous material	Regression	shorten of distance from river mouth
increasing $\delta^{18}O$ of carbonate	Regression	data from Lemcke (1996)
increasing porosity	Transgression	decreasing salinity

In the paper we present new evidence that the lake fell dry at around 15 ka BP, i.e. within 5 ka after the lake reached its glacial high stand 70-80 m above its present lake level. This evidence is derived from sediment cores covering the last 15 ka. Sediment of the deep main basin is continuously varved back to 14.7 ka BP. Two cores (K10 and K6; Fig. 1), penetrate the laminated layers and reach hard, not laminated sediment that contains:

- Clasts of 1-3 cm large pumice lapilli and up to 5 mm large pyroxene phenocrysts. Concentration of particles >1 mm increase significantly within the not laminated layers demonstrating the increase of transport energy.
- Ooids with a nucleus consisting of clay minerals and an aragonitic cortex. The micritic aragonite of some ooids reveals concentric structures showing enhanced Si, Mg and Fe concentrations. Aragonitic ooids were also described from the Great Salt Lake, Utah, where the Mg/Ca ratio of the water is >20 (e.g., Fabricius and Klingele, 1970). For comparison the Mg/Ca ratio of Lake Van is >40 today (Reimer, 1995). According to Füchtbauer (1988) recent ooid formation takes place almost exclusively in warm, very shallow (1-2 m) water.
- Coated grains with a nucleus formed mainly from clay minerals and a zonal cortex consisting mainly of Fe and S. The diameter of the nucleus is about 100 µm, the thickness of the cortex ranges from 38-70 µm. Shrinkage cracks appear between nucleus and cortex. The multi-phase structure of the grain allowed only semi-quantitative analysis. Microprobe mapping revealed a zonal structure of the cortex with maximum concentration of Fe and S inwards, decreasing and replaced by Si, Al, Mg and traces of P towards the outer rim. Smaller grains (<10 µm) showing high concentrations of Ti and Ca are distributed on the surface, whereby the first are especially found on the nucleus and the latter especially on the cortex. Due to its spherical shape and the element composition we assume that the cortex has been primarily build as pyrite which is now weathered. Pyrite is known to form by early diagenesis under reduced conditions and weathers fast in contact with oxygen.
- Formation of secondary minerals. Semi quantitative EDX analysis of a fragmented grain, 1.2 mm long and about 0.8 mm wide, detected mainly the element Fe (56-59 wt.%) and traces of S, Si, Na, F and Mg. The main element composition resembles those of goethite, a weathering mineral common in tropical soils.
- Iron oxide schlieren indicating that the sediment was oxygenated. Today, the zone of sulphate reduction starts immediately below the water-sediment interface (Reimer et al., 2009). Such situations may have prevailed for the last 13.4 ka as revealed by an abrupt increase of the organic sediment fraction at that time. Only sediments older than this were oxygenated.
- Ostracod shells from four different unknown species of the family Limnocytheridae. Adult (size 0.3-0.6 mm) and juvenile shells of ostracods are well preserved, suggesting that these sediments were not transported. Recent ostracods of the family Limnocytheridae are found in habitats having a salinity of 0-10 ppt. Since the species have not yet been determined, the salinity of their habitats can only be estimated but may be 18 ppt at most (Ian Boomer, University Birmingham, personal communication).

These textures are interpreted as being the result of a lake level regression to below 428 m and a consecutive transgression. This interpretation is supported by the pollen record showing a very low total concentration of pollen and spores within the unvarved sediment section but high concentration of *Artemesia* and Chenopodiaceae (Van Zeist and Woldering, 1978; Wick et al., 2003; Litt et al., 2009). Pollen grains from steppe plants such as *Artemisia* and chenopods are common during cooler and/or drier phases (Litt, personal communication).

A low lake level during the Late Glacial period is also deduced from high concentration of terrigenous material within the sediment of the unvarved section.

Sedimentation velocity of clastics depends mainly on grain size and density. Coarse and dense particles are deposited close to the river mouths while fine particles are distributed lake-wide. At Lake Van, this scheme leads to an increase of terrigenous material (and annual sediment deposition) with decreasing distance from shore. High concentration of terrigenous material therefore indicates a low lake level, equivalent to a short distance between river mouth and core locality.

Core K6 (Fig. 1; total core length 992 cm) can be correlated with core K10 down to the core depth of 920 cm, corresponding to an age of about 13,650 a BP (Landmann, 1996). Below, it contains a slumped section (920-935 cm) followed by regularly laminated sediment supposed to represent the shallow lake phase. Accumulation rate within this section is 10.8 mm a^{-1}, which is more than 20-fold higher than the average accumulation rate for the past 14.7 ka.

Evidence for this regression in the period 20-15 ka BP is also derived from pore water chemistry. Salinity in all cores reveals a linear increase downcore reflecting upward diffusion of salt (Reimer et al., 2009). During the regression increasingly concentrated brines formed that penetrated into the pore space of the sediment by replacing older pore water of lower salinity. Water balance calculations suggest that a lake level drop of 500 m within less than 5000 years can not be explained by low precipitation alone but must also have been caused by a higher evaporation than today. A simultaneous lake level drop is also reported for Lake Lisan, the precursor of the Dead Sea (e.g., Landmann et al., 2002).

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Keynote

Quantitative environmental reconstruction based on biotic proxies in varved sediments

Andre F. Lotter

Varved lacustrine and marine sediments allow investigating past environmental change at an annual or even seasonal resolution. The analysis of biotic proxies at such high temporal resolution allows exact pinpointing of the crossing of ecosystem thresholds as well as studying the resilience and timing of recovery of ecosystems with regard to external and internal disturbances.

In my lecture I shall discuss the advantages and limitations of some botanical and zoological proxies that are commonly used to reconstruct in a quantitative way past climate change and eutrophication. I shall illustrate the use of biota-based transfer functions with some selected case studies.

Poster

Distribution of Pleistocene glaciolacustrine deposits in southwestern Croatia

Ljerka Marjanac and Tihomir Marjanac

Pleistocene lacustrine fresh-water sediments are found throughout Croatia, although in its northern part they were revealed only by drilling (Šercelj 1969, Sokač 1976, Babić et al. 1978, Sokač et al. 1982). In this short review the emphasis is given to south-western Croatia where many extensive outcrops of typical glaciolacustrine sediments occur (Fig. 1). Recently, studied sites (1 to 6 in Fig. 1) are located along the northeast and southwest coasts of the Velebit Channel and along the southwest coast of the Novigrad Sea and represent remnants of Middle Pleistocene proglacial lacustrine sediments. Other sites (7 to 12 in Fig. 1) are presented upon the data from General Geological Maps of Yugoslavia and respective explanation books (Majcen & Korolija 1973, Ivanović et al. 1976 and 1978, Grimani et al. 1976, Sokač et al. 1976), and upon the data published until the 1990ies. Most of these deposits were recognized as "Neogene Süsswasserbildungen" (Neogene freshwater sediments) and marked on the Austro-Hungarian Geological Maps of Croatia (Schubert 1905, 1907, 1912), and breefly reviewed in Table 1.

Karst poljes Kninsko polje, Mokro polje, Žegarsko polje and Erveničko polje are filled with glaciolacustrine sediments which were successively deposited following the retreat of the Middle Pleistocene glaciers. The age attribution is based on ostracod assemblages studied by Malez & Sokač (1968), Malez et al. (1969) and Sokač (1975), and mammal findings reviewed by Malez (1968). The early Pleistocene (Villafranchian) was also documented in Kninsko polje and Strmica (Fig. 1, localities 11 and 12; Malez et al. 1969, Šimunić 1970). Malez (1968) compared the lacustrine succession of Strmica with the Leffe basin in Italy.

Nevertheless, much greater significance for the reconstruction of Pleistocene environmental and climatic changes as well as for the extent of the Dinaric glaciation (Marjanac et al. 2008), have the glaciolacustrine deposits at Novigrad Sea (Fig. 1, locality 5; Fig. 2C) described by Marjanac et al. (1990) and Marjanac & Marjanac (2004, 2006), varved sediments at Ždrilo (Fig. 1, locality 4; Fig. 2A) that are currently studied (master thesis in preparation by I. Adžić), and glaciolacustrine sediments in alternation with proglacial deltaic conglomerates at Seline (Fig. 1, locality 2; Fig. 2D). Their age is 350 ky at minimum as achieved by Uranium series dating of secondary calcite cement sampled in the overlaying ground moraines at the Ždrilo locality. This leads to the conclusion that the sediments were deposited before or partially during the Mindel/Elster glaciation (MIS 12), which will hopefully be shown by detailed future studies. These glaciolacustrine sediments (Fig. 1, locations 1-6) are found above and below the present sea level (Table 1) and have been greatly destroyed and disturbed by the advancing ice, which is documented by overlaying ground moraines visible at locations Kusača cove, Ždrilo and Novigrad (Fig. 1, locality 1, 4 and 5).

Further detailed studies of varved sediments at Ždrilo and varve-like sediments at Seline and Novigrad will greatly improve our knowledge about glaciations and climate changes in the Mediterranean region. The age of moraines and the assumed age of glaciolacustrine sediments with well preserved fossil leaves of cold climate flora

(Adžić et al., this volume) are new documents of the extensive glaciation of the Dinarides in the Middle Pleistocene, which call for reconsideration of our perception of climatic and paleogeographic conditions in the Mediterranean during the Pleistocene.

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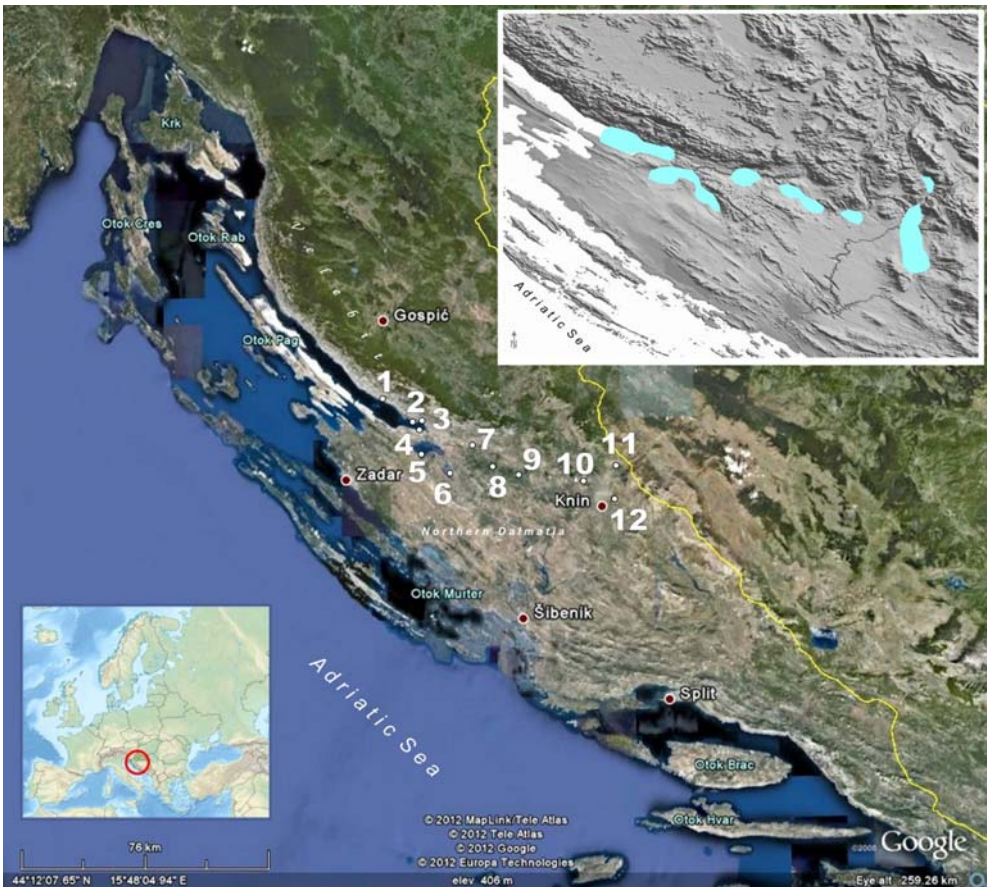

Fig. 1: Location of south-western Croatia where glaciolacustrine sediments are found at 12 locations listed in Table 1. The map at the top right corner shows the possible extent of glacial lakes.

Tab. 1: Review of most important occurrences of Pleistocene lacustrine deposits in south-western Croatia. Most of them were first recognized as Neogene freshwater sediments, and by later studies were interpreted as of Middle Pleistocene age.

	Sediments / paleoenvironment / stratigraphy		
Locations *(Fig. 1)*	*Registered on Austro-Hungarian geological maps of Croatia in the scale 1:75.000*	*Registered on General geological map of Yugoslavia in scale 1:100.000*	*Recent study, largely unpublished*
1 - Kusaèa Cove 0 - 10 m a.s.l.	Neogene freshwater sediments (Schubert 1907)	not registered	glaciolacustrine sediments, Middle Pleistocene, under study
2 - Seline coastal cliff 0 - 6 m a.s.l.	Neogene freshwater sediments (Schubert 1907)	not registered	proglacial lake sediments (proximal varved-like deposits; proglacial deltaic conglomerates), Middle Pleistocene, under study
3 - Provalija 1 - 2 m a.s.l.	Neogene freshwater sediments (Schubert 1907)	not registered	poorly preserved Seline-type sediments, under study
4 - Ždrilo 0 - 10 m a.s.l.	Neogene freshwater sediments (Schubert 1905)	not registered	varved sediments (clay/silt/sand) of proglacial lake, Middle Pleistocene, under study
5 - Novigrad coastal cliff 0 - 20 m a.s.l.	Old Quaternary sands and marls (Schubert 1905)	not registered	varve-like unit with dropstones (silt and clayey silt) and ripple laminated unit (sands, silt, rarely clay), proglacial lake deposits in association with moraines and glaciofluvial deposits, Middle and Upper Pleistocene; still under study (Marjanac et al. 1990, Marjanac & Marjanac 2004)
6 - Karin 0 - 40 m a.s.l.	not registered	not registered	laminated clayey silt deposits, glacial lake, Middle Pleistocene, under study
7 - Bilišane 20 - 90 m a.s.l.	Neogene freshwater sediments (Schubert 1905)	Middle Pleistocene (Riss glacial) lacustrine marls and clays (Ivanović et al. 1973)	revision in plan
8 - Ervenièko polje	Neogene freshwater sediments (Schubert 1912)	Middle Pleistocene (Riss glacial) lacustrine marls and clays (Ivanović et al. 1973)	revision in plan
9 - Žegarsko polje 50 - 90 m a.s.l.	Neogene freshwater sediments (Schubert 1912)	Middle Pleistocene (Riss glacial) lacustrine marls and clays (Ivanović et al. 1973)	revision in plan
10 - Mokro polje 200 m a.s.l.	Neogene freshwater sediments (Schubert 1912)	Middle Pleistocene (Mindel - Riss) lacustrine marls and clays (Malez & Sokač, 1969)	revision in plan
11 - Strmica	Neogene freshwater sediments (Schubert 1912)	Lacustrine chalk and swamp-lacustrine sediments with mamals and gastro-pods (Villafranchian, Mindel glaciation), clay with gastropods of Mindel-Riss interglacial (Grimani et al. 1972)	revision in plan
12 - Kninsko polje	Neogene freshwater sediments (Schubert 1912)	Lacustrine chalk and swamp, lacustrine sediments with mamals and gastropods (Villafranchian, Mindel glaciation), clay with gastropods of Mindel-Riss interglacial (Grimani et al. 1972)	revision in plan

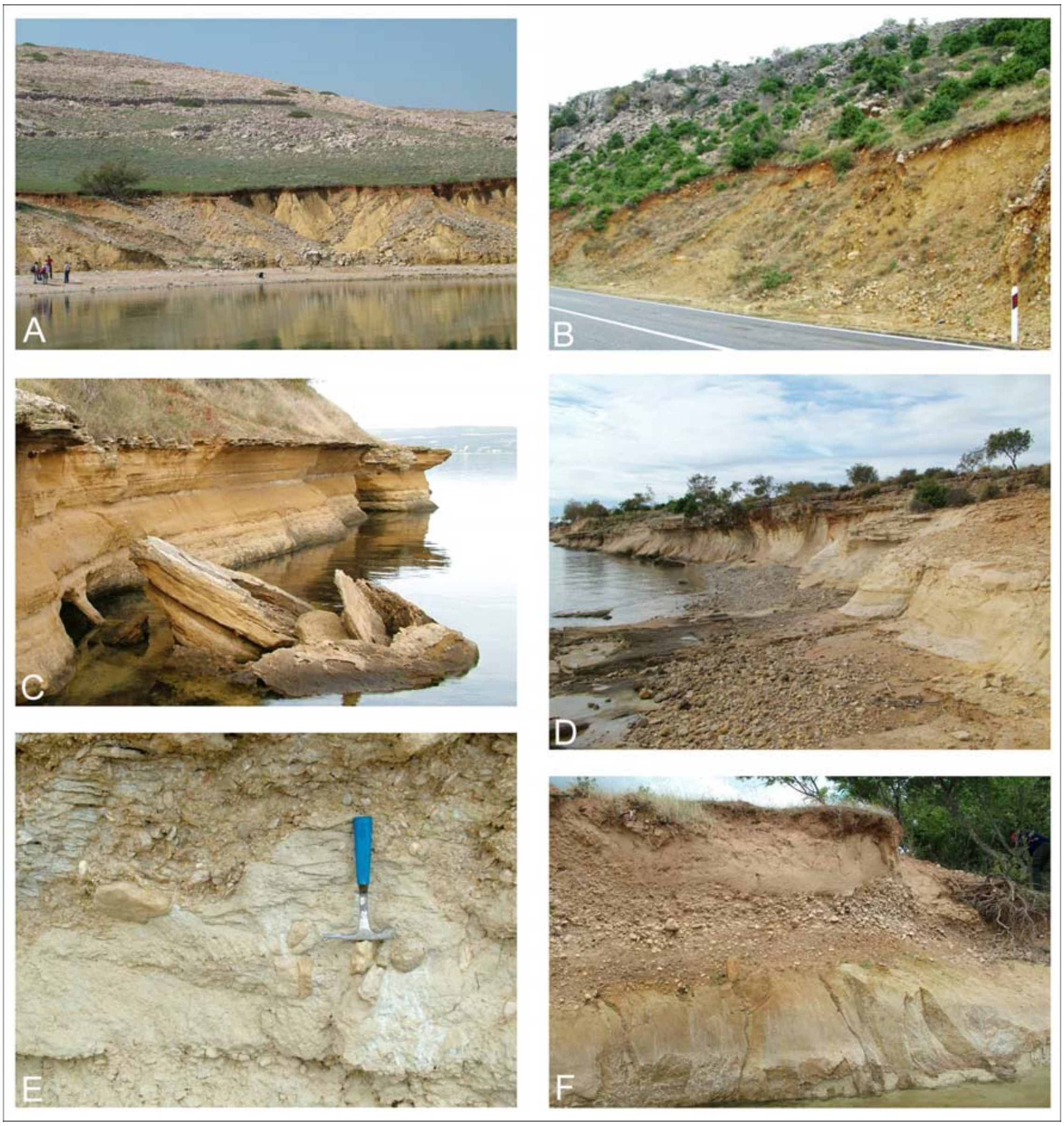

Fig. 2: Outcrops of Middle Pleistocene glaciolacustrine sediments in southwestern Croatia. A) Varved sediments with fossil flora and fauna (distal facies) at location 4 - Ždrilo; B) Laminated silt/clay sediments disturbed by overlaying ground moraine at location 1 - Kusača cove; C) Varve-like sediments with dropstones at the coastal section of location 5 - Novigrad; D) Varve-like sediments with gastropods and bivalve moulds (proximal facies) at the coastal section of location 2 - Seline; E) Laminated clayey silt sediments disturbed by overlaying ground moraine at location 6 - Karin; F) Clayey silt lacustrine sediment covered with paleosol and younger glacigenic deposits, exposed at location 9 - Žegarsko polje.

Oral

Varve data base (VDB)

Antti E.K. Ojala, Pierre Francus, Bernd Zolitschka, Richard Behl, Marc Besonen and Scott F. Lamoureux

Despite their potential to provide high-resolution information about the past variability, varved records are only sparsely used in regional and global climate reconstructions. The most important attribute of varved sequences is that they provide an inherent and continuous timescale – the varve chronology – and high temporal resolution for paleoenvironmental and palaeoclimate studies. To improve our general understanding of the fidelity of the varve chronologies, we compiled a varve data base (VDB) consisting of available and published varved sediment records (Ojala et al., submitted). We aim at assessing the worldwide distribution of varved sediment records and at determining the key characteristics of these sequences, including how many varves they contain, the methodology used to create a varve chronology, its error estimation, and the independent dating methods used to assess the accuracy of varve chronologies. We set two basic criteria for varved sediment sequences to be included in the VDB. First, the varve chronology needed to be adequately published in a peer-reviewed international scientific journal or book. Second, the temporal extension of a varve chronology was at least 100 years.

Among the 108 sites presently included in the VDB, varved records typically cover a period of 1000-2000 years and are 200-500 cm long (Figure 1). Their varve chronologies are often based on counting of varves either from epoxy embedded sediment blocks and thin sections or from fresh sediment surfaces and photographs. The VDB indicates that only 57% of published records are providing quantitative error estimations for the chronology and that chronological errors associated with counting sedimentary varves fall generally between 1 and 3%. With millennial-long records, it is unrealistic to reduce the error significantly below ±1%. However, with a careful documentation of varves and by applying radiometric surface sediment dating methods and using historical events as time markers, there is the potential of having shorter, centennial-long, varved records with a very precise age-depth control. We found no indication that varve chronologies would have been statistically dependent on the varve thickness or temporal extension of a varved sequence or substantially more accurate and precise in some parts of the world than in others. The VDB analyses also indicate that close to 90% of the published varve chronologies have been cross-checked with some independent dating methods.

Finally, our analysis of the VDB shows that there is still room for further improvements in order to increase the credibility and the fidelity of varve chronologies and, thereby, also their applicability in climate reconstructions. It is of high importance that varve chronological errors are estimated and their uncertainties are adequately reported when the records are presented and published.

The established VDB is an effort of the PAGES Varves Working Group (VWG) and is available on-line at http://www.pages-igsbp.org/workinggroups/varves-wg.

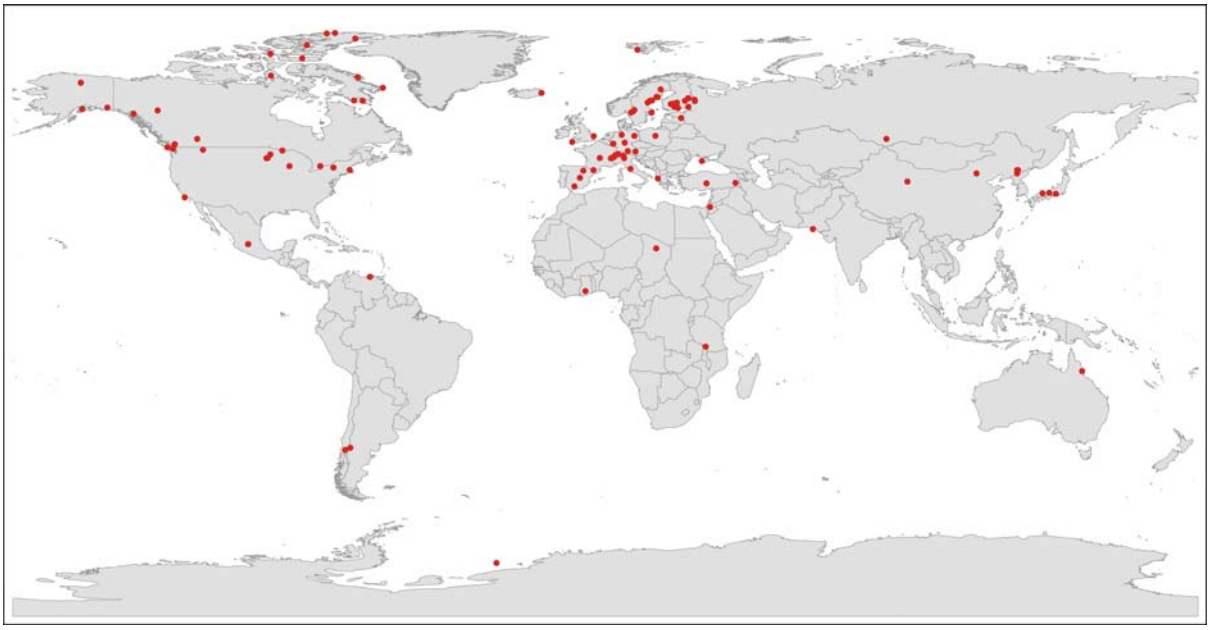

Fig. 1: Worldwide distribution of 108 published varved sediment records (in the VDB) extending in duration to more than 100 years.

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Poster

The Lake Nylandssjön project (N Sweden): Understanding relationships between environmental variables and properties of recent varves

Ingemar Renberg, Christian Bigler, Veronika Gälman, Malin Kylander and Dominique Maier

Nylandssjön (62°57′N, 18°17′E) is a small (0.28 km^2) dimictic boreal-forest lake, located at the coast of the Gulf of Bothnia in northern Sweden. The lake is a circum-neutral, soft-water lake with a phosphorus concentration of about 20 µg L^{-1}, and regular oxygen depletion occurs in the hypolimnion during summer and winter (Gälman et al. 2009). In the 17.5 m deep basin varves (Fig. 1) have been formed since the beginning of the 20th century due to cultural eutrophication (Renberg 1986).

Research activities in Nylandssjön started in 1978, and were intensified in 2001 when a monitoring program was launched. Since 2001, samples have been taken at about 200 occasions, covering a wide variety of parameters including water quality (oxygen profiles, water chemistry), plankton and sediments (sediment traps, freeze cores).

The first freeze core was taken already in the late 1970ies, and the series from 1979-2011 includes cores from >20 different years.

The aim of the research is to better understand varve formation processes and how signals of environmental conditions are incorporated and stored in the varves. The ultimate goal is to improve the ability to infer past environmental and climatic information from varves.

Fig. 1: Varved sediment from Nylandssjön retrieved using freeze core techniques in January 2004.

We are working with three main topics:

- <u>Diagenetic processes</u>

  How is ageing of the sediment affecting the varve properties? To address this question, we use our series of >20 stored freeze cores, spanning the time interval from 1979 to 2011.

  Although varve thickness decreases over time, the internal varve structure is preserved (Gälman et al. 2006). For example, single varves are still easily recognizable after up to 50 years. Furthermore, considerable amounts of carbon and nitrogen (20-30%) are lost from the varves in the course of the first 20 years (Gälman et al. 2008), also affecting the isotopic composition (Gälman et al. 2009).

- Chemical composition of varves
  How is the chemical composition (annual and interannual stratigraphy) of the varves linked to environmental conditions (lake, catchment and weather)? This is research in progress, which will be discussed in the poster.
- Calibration of biological remains
  See contribution by Bigler et al. (this workshop).

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Oral

"A tale of two crater lakes": comparing varved records for the last 15 ka BP from Cappadocia, Turkey

Neil Roberts, Samantha Allcock, Jessie Woodbridge, Matthew Jones, Jonathan Dean Warren Eastwood, Melanie Leng, Hakan Yiğitbaşıoğlu, Fabien Arnaud and Pierre Sabatier

Varved lake sediments offer a chronological precision and accuracy comparable to the best natural archives of climatic and environmental change (e.g., ice cores, speleothems). However, replication of lake sediment records is less common than, for example, with tree rings. Consequently it may not always be easy to separate local, site-specific factors, such as basin infilling and catchment erosion, from those of wider regional significance (e.g. climatic change). Central Turkey contains a number of volcanic crater lakes basins, and the sediment records of two of these are mostly varved. These therefore offer an opportunity to compare systematically two highly-resolved lake sediment records 25 km apart between Late Glacial times and the present-day.

Eski Acıgöl (1,270 m asl; 38°33'01"N, 34°32'41"E) is now dry, but contains a ~20 m sediment record spanning the time period since the Last Glacial Maximum, when the present crater was formed. The lake sediments are continuously laminated below 640 cm, except for a diagenetically altered nodular layer of Late-Glacial age, but non-laminated above 640 cm. This site therefore offers a highly-resolved record of environmental change during the upper Pleistocene-early Holocene climatic transition, in particular (Roberts et al. 2001; see Fig. 1). The palaeoclimatic signature at Eski Acıgöl has been superimposed on a long-term natural trend towards basin infilling, and it is not always straightforward to separate these two processes.

Nar lake (1,363 m asl; 38°22'30"N; 34°27'30"E) is larger, older, deeper and – importantly – has varves forming at the present-day. This has allowed a very detailed analysis of environmental changes during the Late Holocene (last 1,720 years) using stable isotopes, pollen and diatoms (Jones et al. 2006; England et al. 2008; Woodbridge and Roberts, 2011). Equally significant, it has been possible to monitor the lake and varve formation using sediment traps, data loggers, etc. since 1998 (see Jones et al. 2005, Woodbridge and Roberts, 2010). Because of its greater age and larger volume, basin infilling has interfered much less with the Nar lake sedimentary record. On the other hand, part of the lake catchment is actively eroding, which has led to the creation of a fan-delta on its southern edge and to the deposition of turbidite layers on the lake bed.

In summer 2010, we undertook a long coring programme at Nar lake using a UWITEC piston corer, and obtained a composite sedimentary record 21.69 m long, spanning the last ~15 ka. More than 80% of these sediments are laminated, the main exceptions being units 2 (593-754 cm, 2628 to ~4000 yr BP) and 6 (1974-2013 cm, equivalent to the Younger Dryas); unit 3 (754-1141 cm) includes thick laminations which may not be annual in origin. This Nar10 record therefore extends the overall time range covered by varve dating, albeit discontinuously. Comparison of the sediment records (Fig. 1) shows significant differences in the history of varve formation between the two lake basins, largely related to sedimentary infilling of Eski Acıgöl crater which ultimately led to lake shallowing and holomixis in this basin. On the other hand, there are also important points of convergence between the two varve records where a common climatic causation can be inferred, especially when supported by other proxy data, such as stable isotopes, diatoms and sediment chemistry/mineralogy. They include

- ~4.2 to ~2.5 ka BP. This time period, corresponding archaeologically to the Middle and Late Bronze Ages and early Iron Age, was marked by shallow water conditions in both lakes. It led to a break-down in meromixis at Nar, and to highly saline-alkaline conditions at Eski Acıgöl which caused diatom dissolution and the formation of primary dolomite and talc (magnesium silicate), probably by skarnification. This must have been the driest climatic period of the Holocene.
- A significant climatically-induced drop in water levels between 7 and 5 ka BP, which led to the permanent ending lake stratification and increase in lake salinity at Eski Acıgöl, and to a major change in sedimentation style at Nar.
- A period of deepwater conditions and varve formation between 11.6 and 7 ka BP in both lakes, reflecting a Neolithic climate wetter than at present.
- A period of lower water levels coinciding with the Younger Dryas, although lake regression ended lake stratification only at Nar. Eski Acıgöl remained deep enough for continuous varve formation during this time interval, in part because the basin was still contained only a limited sediment infill.

In summary, when possible, two varved lake records in combination are better and more informative than either one of them on their own!

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Tab. 1: Crater dimensions and ages.

	Eski Acıgöl	**Nar**
Lake age	~25 ka BP	>100 ka BP (estimate)
Diameter	1.1 km (crater) 400 m (lake)	1.5 km (crater) 700 m (lake)
Current lake depth	0 m	21 m (2010)
Modern ^{14}C age	3000 yr	15,000 yr

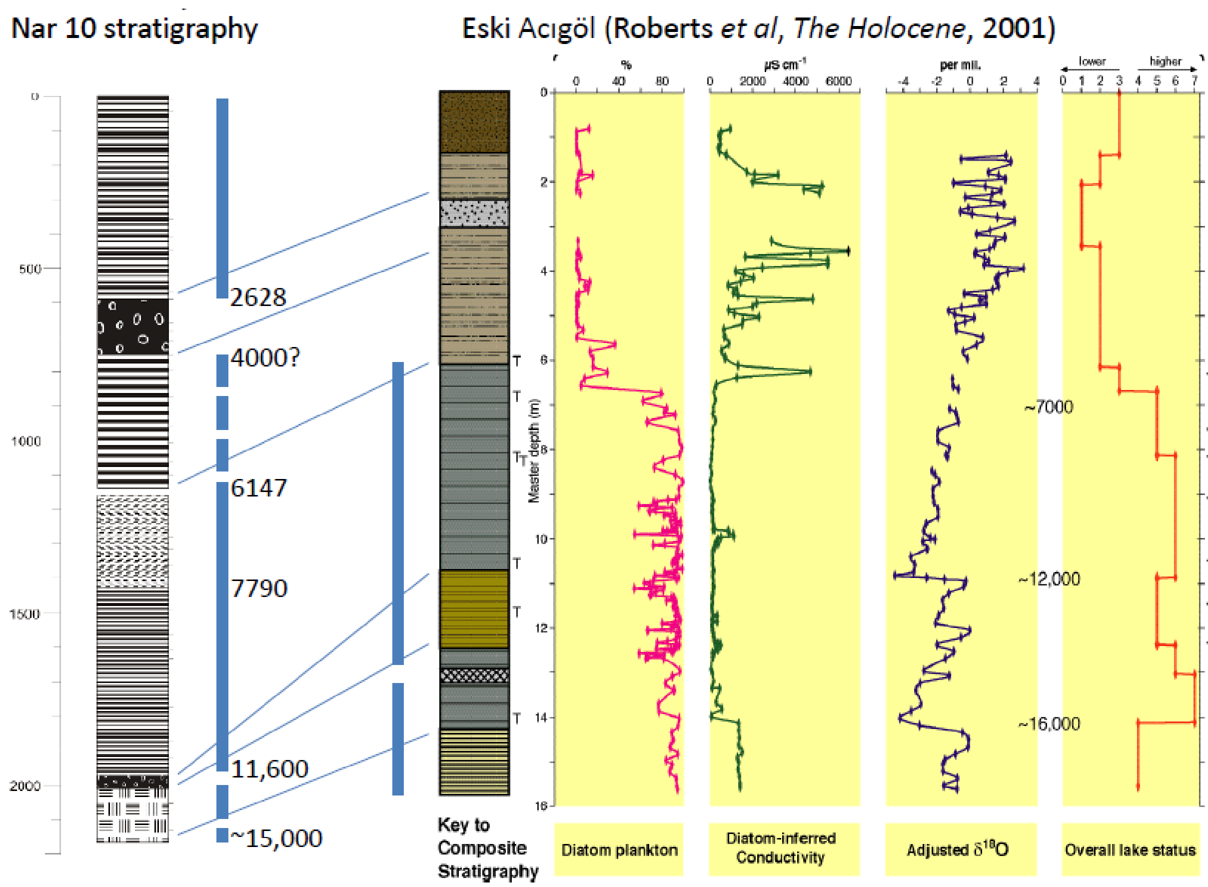

Fig. 1: Comparison of lake sediment records from Nar and Eski Acıgöl craters. Varved sections are marked with vertical (blue) bars. Ages in yr BP. Time lines show correlations.

Poster

Discovery of a Quaternary paleolake at Cassis (SE France)

Carole Romey, Pierre Rochette, Claude Vella, Bruno Arfib, Cédric Champollion, Philippe Dussouillez, Daniel Hermitte and Jean-Claude Parisot

Lower Provence and the Massif des Calanques are a key area in the understanding of the Mediterranean climate change mechanisms and the study of human impact on the local environment during the Quaternary. However, a continuous continental record of paleoenvironmental conditions in coastal Provence was not previously available.

Looking for such a record, we discovered in a coastal alluvial plain a small paleolake filling a sinkhole that occurred in a marl sequence topping pure limestones at an altitude of 80 m, and in a distance to the sea of 2 km. The sedimentary record is unique with a high-resolution archive of climate change, the evolution of vegetation and the recurrence of fires across the Massif des Calanques during the last glacial cycle. It is also an archive of the mechanisms operating in a small catchment area in coastal Provence. The catchment area of about 8 km² is located on two distinctive lithologies: Barremian limestone facies Urgonien in the western part and Aptian marls in the eastern part. The sedimentary sequence of 50 m is mainly resulting from the alteration of marls. The sediment is poor in organic matter (Corg ~0,1%) and it consists of 5 m of an oxidized brown clay deposit which covers 5 m of oxidized lacustrine clay of yellowish brown color. This oxidized sequence is at the top of 40 m of lacustrine laminated gray clay with sandy past. The thickness of the laminae ranges between 0.2 mm and 2 cm. Cretaceous marls are at the base of the sequence. The presence of marl pebbles in the last meters of the sequence reflects the collapse of the sinkhole. The lacustrine clay was probably deposed during stages isotope stages 2 to 4 (48 ± 3 ka BP ^{14}C age at 23 m depth), whereas the brown clay deposit was interpreted as a Holocene paleosol.

A combination of surface observation, drilling and geophysical studies (gravimetry and electrical resistivity tomography) allows to constrain the geometry of the paleo-polje that has formed during the glacial period. The lake diameter was likely of in the order of 200 m. It evolved from a deep lake to a swamp (probably Holocene, dating in progress) and it was drained in Roman Times for agriculture.

The relationship between the paleolake, rooted at circa 100 m below surface according to gravimetric modeling and the underground karstic river of Bestouan is strongly suggested by underwater exploration and hydrologeologic investigations.

Oral

Missing varves in Santa Barbara Basin due to intermittent oxygenation and drought prior to the 18th century

Arndt Schimmelmann, Larianna Dunn, Ingrid L. Hendy and Dorothy Pak

Santa Barbara Basin (SBB) is well known for producing high quality paleoclimate reconstructions, but the validity of correlations between the basin and other regions rests upon age model accuracy. Yet in SBB, two independent and well-established chronologies based on varve counting and radiocarbon dating do not consistently agree between ca. 150 AD and 1700 AD. We compared 49 mixed planktonic foraminiferal carbonate and 20 terrestrial organic carbon ^{14}C dates to the traditional varve chronology, to extend the high-resolution paleoclimate chronology of the basin back ~2,000 years. The terrestrial ^{14}C dates based on charcoal and land plant fragments provide constraints on the ^{14}C reservoir ages of marine carbonates which contribute the largest error in the radiocarbon chronology. There is a consistent (R^2 = 0.96) undercounting of varves between ~1700 and 150 AD based on our new ^{14}C chronology, indicating that some traditionally counted laminae couplets are likely multi-year laminations similar to the current sediment in Santa Monica Basin (SMB). Loss of countable varves may occur when elevated bottom water oxygenation permits intermittent low-level bioturbation (like in SMB), and also when low riverine input and infrequent winter storm activity during drought intervals fail to supply a siliclastic winter layer.

Poster

Using corroborative proxies to validate varve chronologies

Tania Stanton, Ian Snowball, Lovisa Zillén, Stefan Wastegård, A. Nilsson, Raimund Muscheler and P. Reid

Annually-resolved archives allow the determination of high-resolution, temporal, reconstructions on a number of geological data sets. With climate change becoming an ever increasing topic of concern, the need for accurate and precise time control on proxy records has become important in order to achieve a complete and full understanding of interactions between different records, and the leads and lags in systems. Varves (in their various forms) are important archives, allowing the possibility of annual control on such data sets.

In Fennoscandia there is an abundance of annually laminated lakes, and we have been working with one particularly good record from a central Swedish lake in the province of Värmland: Kälksjön (Stanton, 2011; Stanton et al., 2010). The lake contains clastic/organic varves and provides a record back to approximately 9200 cal. yrs BP. Rather than simply accept the completed varve count, we pursued a systematic attempt to validate the chronology, so that it could later be used with confidence for further analyses.

From the outset, the sediments seemed clear and very well preserved, and it was expected that proxy validation would indeed corroborate our initial count. This was not the case, however, and it became clear that it is not possible to know whether or not a varve chronology is correct – however perfect the laminations seem – without further investigations using complementary methods.

The first attempt at validation used the traditional method of radiocarbon dating, which can exhibit dating problems – particularly problematic in bulk sediments – due to the re-working of old carbon in lake sediment systems. Lacking any macrofossils (none were found in Kälksjön's cores), which give much more reliable results for dating, we were only able to date bulk sediment samples. As expected (and as confirmed by cross-checking with other results), the radiocarbon analyses gave ages that were too old.

Validation using tephra was also attempted. Microtephra analysis was carried out on a number of samples in the hope that three mid-Holocene Icelandic tephras (Hekla 4, Hekla-S/Kebister and Hekla 3) would be found as marker horizons, but the analysis yielded no results.

The sediments of Kälksjön do, however, have another property that is particularly well preserved, which is a strong and stable natural remanent magnetisation, dominated by an excellent carrier of remanence, in the form of single-domain magnetite, probably produced by magnetotactic bacteria (Stanton, 2011). Using magnetism as an additional validation technique revealed an inconsistency in timing between the inclinations and declinations of Kälksjön and those from a Fennoscandian directional master curve, primarily made up of annually-laminated archives with very high quality palaeomagnetic records (Snowball et al., 2007). Using a simple correlation program to remove human interpretation, it was discovered that approximately 270 varves seemed to be missing from the late Holocene (Figure 1).

Lead samples were then taken from the Kälksjön record in order to explore the well-documented pre-industrial lead pollution signal often archived in European sediments. Such lead data are an excellent indicator of human technological advancement: lead production increased rapidly during the Greco-Roman period, declined when their civilisations fell, increased once more in mediaeval times, and later during the industrial revolution in Europe. This compelling record of historical lead usage has been found in many well-dated Swedish lake sediment sequences, peat deposits and soil profiles (Renberg et al., 2000). There is good historical dating of this period in human history, and the cross-referencing of this isochron with the Kälksjön lead record meant that it would be possible to anchor the Kälksjön chronology in time.

Analyses did produce positive results, and both the lead concentration and stable isotope ratio ($^{206}Pb/^{207}Pb$) curves could be matched to another well dated varved Swedish lake (with a sufficiently large dataset to be amenable to comparison using statistical correlation) showing clear peaks of pollution (Stanton et al., 2010). The correlation results showed a clear offset of ~250 years in the latest 1000 years of the varve chronology and therefore corroborated the supposition that some varves were undetected in the sequence and, moreover, that they were undetected after AD 1000 (Figure 2).

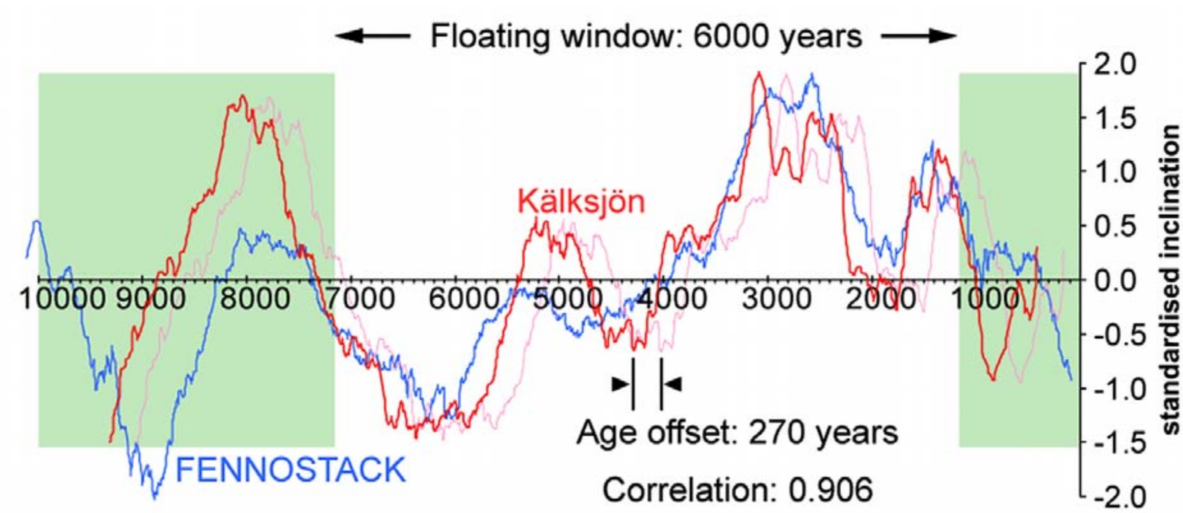

Fig. 1: Example of a floating window correlation graph of the Fennoscandian master inclination curve (Snowball et al., 2007) versus Kälksjön's varve-derived inclination curve. A smoothing window of 150 years has been applied to both datasets. This correlation indicates that Kälksjön is missing 270 varves in the late Holocene (after Stanton et al., 2010).

To work out whether the varves were simply missing from the very top of the sequence, Caesium 137 measurements were carried out on the youngest portion of the sequence (~AD 1935-2000). Two relatively well-resolved ^{137}Cs activity peaks in the Kälksjön varve data occur in 1963 and 1988, recording, respectively, the 1963 fallout maximum from the atmospheric testing of nuclear weapons, and the significant amounts of fallout from the 1986 Chernobyl nuclear power station accident. The detection of these historical markers corroborated the annual nature of the Kälksjön varves and validated the most recent 45 years of the varve chronology (Stanton et al., 2010).

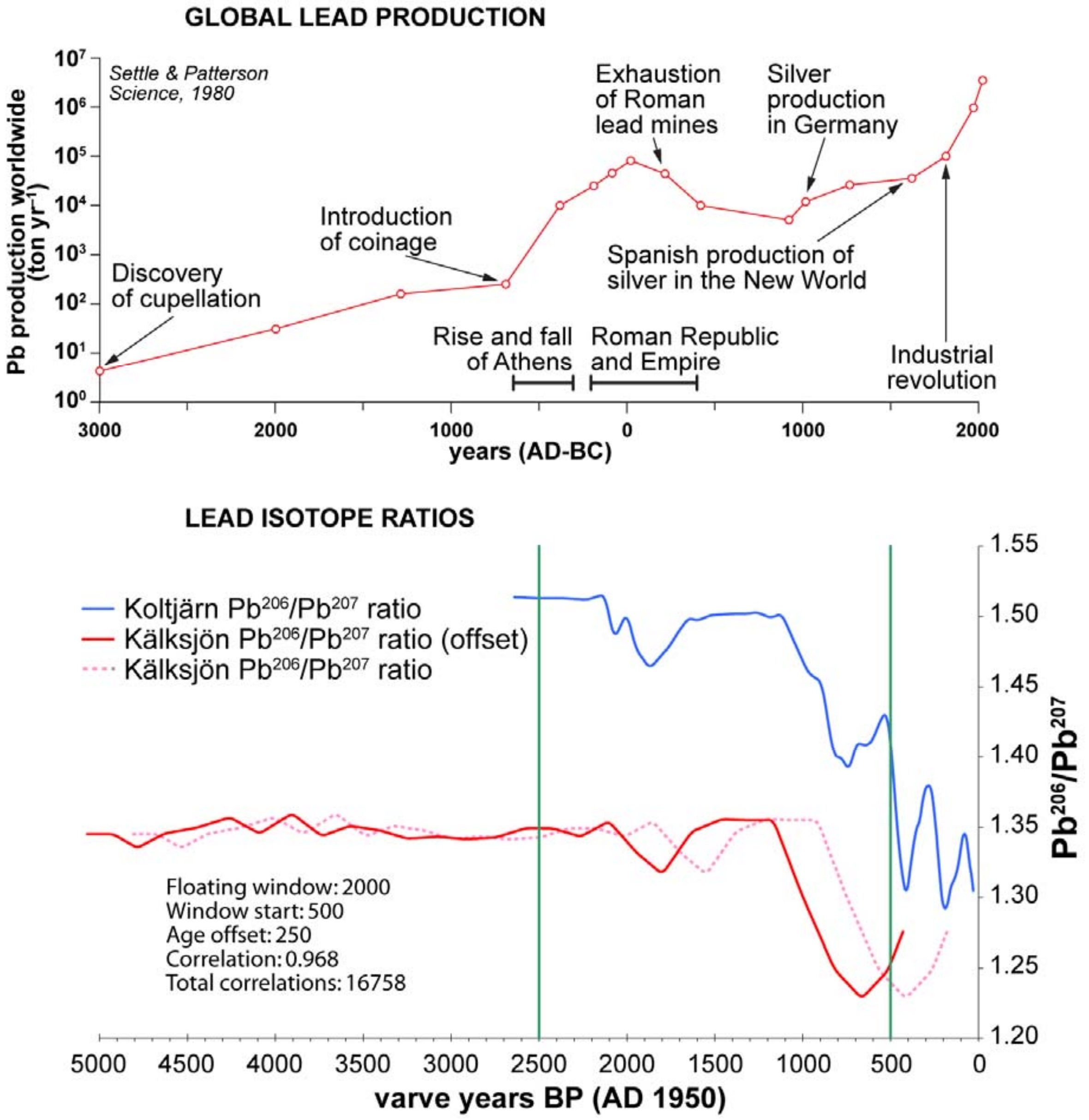

Fig. 2: A global lead production curve (after Settle and Patterson, 1980) and the correlation graph of Koltjärn (Brännvall et al., 1999) versus Kälksjön's $^{206}Pb/^{207}Pb$ ratio data. A floating window correlation of 2000 years gives an offset of 250 years, indicating that Kälksjön is missing that number of years after AD 1000. A smoothing window of 50 years has been applied to both datasets (after Stanton et al., 2010).

In the case of Kälksjön, we do not know exactly where the missing varves lie, only that lead and caesium analyses verify that they are missing between AD 1000 and AD 1963. Using the correlations of both the magnetic and lead data, the chronology was therefore corrected by 270 years (taking the larger of the two error estimates from the statistical correlation) and was equally distributed between these dates. It is probable, however, that the undetected or missing annual laminations lie in the uppermost few hundred years of the chronology, because intensified human impact in the form of agricultural activities has obscured the sedimentary record at this point. In the resulting clay layer it is very difficult to count annually-laminated varves (even when using sophisticated imaging techniques).

Further correlation between inclination and declination data of Kälksjön and the Fennoscandian master stack, suggested that a possible over-counting of varves had occurred prior to 8000 cal. yrs BP, and another curve correction was carried out: 230 varves were subtracted evenly from the pre-8000 year record.

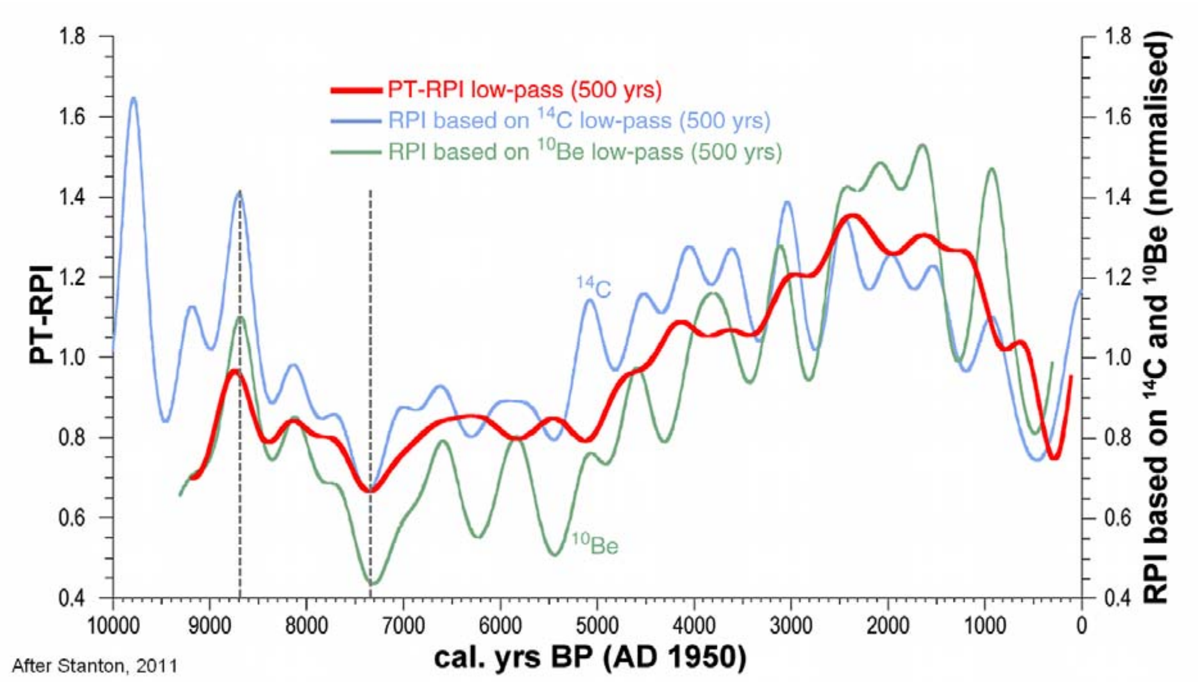

Fig. 3: Comparison of the pseudo-Thellier relative palaeointensity (PT-RPI) and $^{14}C/^{10}Be$-based geomagnetic field reconstructions on timescales longer than 500 years. The records are normalized to approximately the same maximum values of the field around 2500 cal. yrs BP. The ^{14}C- and ^{10}Be-based records were calculated as described in Muscheler et al. (2005). The ^{14}C-based record was updated using the new ^{14}C calibration record (Reimer et al., 2009) and by filtering with a higher cut-off frequency. The good comparison between the three records at 8.7 kyr and 7.4 kyr supports the adjustment of the Kälksjön chronology (after Stanton, 2011 and Stanton et al., 2011).

In a later study (Stanton, 2011; Stanton et al., 2011), another validation technique was carried out which verified the dating (using the Kälksjön chronology from Stanton et al., 2010) of certain peaks in the palaeointensity record. To determine which features of the geomagnetic field were real, a corroborating proxy in the form of the cosmogenic radionuclide record, was used (Figure 3). The smoothed palaeointensity curve was compared with a reconstruction of the geomagnetic field intensity based on the cosmogenic radionuclide records for ^{14}C and ^{10}Be, revealing a striking comparison between peaks at 8.7 kyr, and troughs at 7.4 kyr, lending strong corroborative support to the adjustment of the Kälksjön chronology.

Using alternative proxies to determine the accuracy of a chronology shows that it is always important to look objectively at a varved record and to use – when possible – other means of corroboration in order to validate a chronology. By minimising the human subjective interpretation of a sequence – using mathematical correlation techniques and similar methods, for example – enhances the quality and reliability of the record.

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Oral

Sediments of Lake Van – a high-resolution archive of changing climate, volcanic events and seismic activity in Eastern Anatolia for the last 500,000 yrs

Mona Stockhecke, Flavio S. Anselmetti and Michael Sturm

Varved sedimentary records have shown their high potential to reconstruct abrupt and global climate change within the marine realm (e.g. Cariaco Basin, Santa Barbara Basin). Continental counterparts, consisting of long and varved lacustrine records can be found in the subsurface of some deep lakes, such as Lake Van. This lake is a 440 m deep closed soda lake situated in a climatically sensitive semiarid and tectonically active region in Eastern Anatolia, Turkey. Paleoenvironmental interpretations of a 5 m long Holocene varved sequence (Landmann et al. 1996, Litt et al. 2009, Wick et al. 2003) together with the underlying thick seismic section as imaged by a seismic survey (Cukur et al., subm.) supported Lake's Van sediments as a key target of the International Continental Scientific Drilling Program (ICDP). The ICDP project Paleovan aims to reconstruct the climatic, tectonic and volcanic history of Lake Van (Litt et al. 2011). Driven by an international and interdisciplinary scientific team, two sites, Ahlat Ridge (AR) and Northern Basin (NB) were drilled in summer 2010 recovering sedimentary records of 220 and 140 m, respectively. A total of 800 m of sediment cores were opened, described and photographed in spring 2011 at the IODP core repository in Bremen. Lithologies of up to five parallel cores (multiple coring) were correlated and a composite profile was defined giving priority to core quality and continuity. Macroscopic and microscopic observations including SEM/EDX analysis were used for the lithological core descriptions. Every 20 cm, discrete samples for geochemical analysis and sediment blocks of selected intervals for micro-facies analysis were taken. Preliminary argon dating of single-crystals from thephra layers collected in core catcher samples yield basal ages of ~500,000 years. Using this rough age model, geochemical measurements indicate that TOC is high in warmer periods (interglacials/stadials) and low in colder peridos (glacials). These TOC fluctuations match marine isotope stages (benthic δ^{18}O-stack; Lisiecki and Raymo; 2005) and extrapolated Holocene sedimentation rates.

Here, the sedimentological and stratigraphic framework of the AR composite profile will be presented (Fig. 1). Special emphasis is given to the laminated intervals as recovered from different interglacials/interstadials (Fig. 2). The 219 m long AR composite profile consists of ~80% lacustrine sediments, ~10% of volcaniclastic deposits and 10% gaps interpreted to be coarse-grained volcaniclastic that are difficult to be recovered. Eight major lacustrine sediment types (~900 layer) were differentiated and separated from the volcaniclastic deposits (300 layer). Impressive color transitions (Fig. 1B) and a repetitive pattern of similar lithological successions occur throughout the record. The sharp and great downcore lithologic variability is indicative of highly and rapidly changing depositional conditions forced by lake level and other climate-driven changes and by tectonic events over the past 500,000 years. In total 33 m of the composite profile are laminated at the sub-mm scale and consist of carbonate-rich clayey silt. Laminated intervals occur episodically and the onset/cessation of these laminations represents threshold crossings indicative for abrupt climate or tectonically-induced morphologic changes.

In the modern environment, varve formation is characterized by a spring-summer-autumn deposition of the light-coloured autochthonous carbonate layers and the dark organic-rich laminae in winter (Stockhecke, 2008). Past laminated lithologies are assumed to be formed roughly under similar conditions but differences occur, which reflect changes of seasonal conditions through time. The modern autochthonous carbonate-rich regime dominated the sediments above 200 m, whereas the section below is dominated by a carbonate-poor diatomaceous mud. Below 210 m, a gravel-rich unit containing fresh-water gastropods and mussels is interpreted to be deposited in beach-like conditions and reflects the early transgressive state of the lake´s history. The partly varved lacustrine record enables, for the first time, to reconstruct the environmental and climate conditions captured during several glacial/interglacial cycles at a mid-latitudinal continental realm.

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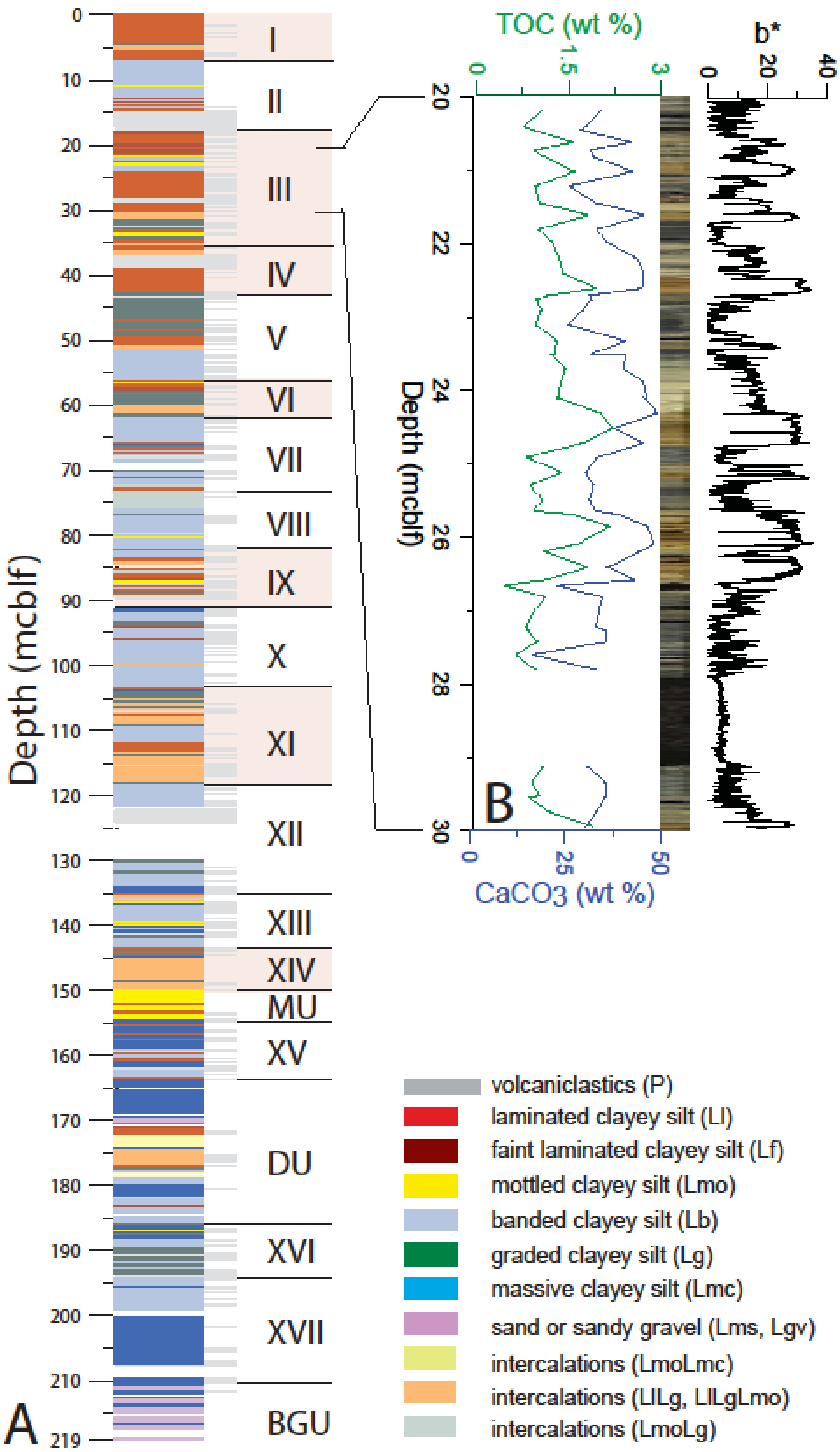


Fig. 1: A. Lithostratigraphy of the Ahlat Ridge (AR) composite profile (in meters composite below lake floor; mcblf) and lithostratigraphic units (I-XVII, MU: Mottled Unit, DU: Deformed Unit, BGU: Basal Gravel Unit). B. Enlarged interval from 20 to 30 mcblf with geochemical data (20 cm sampling resolution; green TOC, blue $CaCO_3$, in wt.%), high-resolution photographs and b* color data.

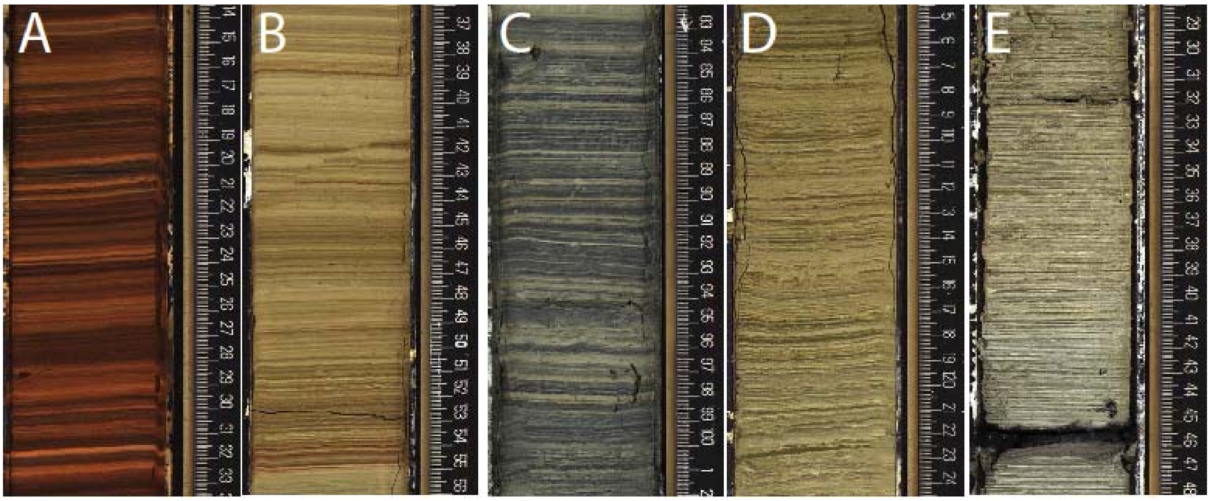


Fig. 2: Five core photographs of sub-mm thin laminated clayey silt from different depths of the AR composite profile. A. 2A_2H_1 13-33 cm, B. 2E_6H_2 36-56 cm, C. 2D_9H_3 82-102 cm, D. 2D_39A_2 104-124, E. 2D_46A_1 28-48 cm.

Poster

Nonglacial varves recorded in a lake sediment sequence from Southern Norway

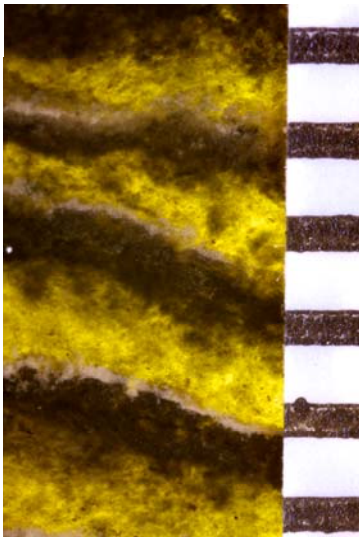
Eivind Støren and Svein Olaf Dahl

Nonglacial varves are, to our knowledge, not previously described in Norway. Preliminary results from nonglacial lake Sagtjennet in east southern Norway reveal, however, a laminated sediment sequence indicating a varved chronology. Based on high-resolution geochemical and radiographical analysis we whish to discuss possible processes causing the formation of these laminations/varves, and thus create a basis for annual-resolution paleoenvironmental reconstructions.

The climate in southern Norway, located at the western flank of the North Atlantic is relatively warm and humid due to the westerly storm tracks. Located leeward (east) of large mountain areas (>2000 m a.s.l.) our study area is, however, at present in a precipitation shadow and dominated by a continental climate regime with dry and cold winters and relatively warm summers. Spring snowmelt and occasionally heavy summer rainstorms dominate the hydrological regime. Lake Sagtjennet is located at 180 m a.s.l. on a river plain c. 400 m from, and only a few meters above, the river Glomma. The catchment area (c. 6 km^2) is covered by till, glaciofluvial and eolian deposits.

Preliminary analyses of sediment cores (c. 5.5 m long) retrieved from lake Sagtjennet indicate laminations throughout the Holocene, except from a period during the early part of the record when light laminae are missing. Macro photography reveals a three-part division of the laminae (Figure 1). Using high resolution ITRAX X-ray fluorescence (XRF) core scanning as well as radiographic methods such as computed tomography (CT) and magnetic resonance (MR) we will analyze the composition of the three types of lamina and discuss the influence of sedimentological, hydrological and climatic mechanisms on the formation of the stratigraphy.

A



B

Fig. 1: Photography of laminated sequences in a sediment core from lake Sagtjennet, Southern Norway. A) Photo graphy of a 5 mm long thin section of sediments with light from underneath. Note three different types of lamina (a-c). B) Photography directly on sediment core (scales in millimeter).

Keynote

Climatic Inferences from Dendroecological Reconstructions and Comparison with Charcoal in Layered Sediments

Thomas W. Swetnam

Varves and tree rings have much in common; most notably the potential for seasonal to annual temporal resolution. Geological and ecological “rhythmites” such as varves and tree rings, are generally formed by seasonal to annual processes, but this can not be assumed to be true in specific cases where this has not been previously established through independent, multiple lines of evidence (Baumgartner et al. 1989, Zolitschka 2007). The potential for testing and combining information from multiple types of rhythmites has long been appreciated, extending back at least to Gerard De Geer’s and Andrew Ellicott Douglass’ investigations and correspondence in the early 20th century. Compilations of multiple annually-resolved climate proxies (e.g., tree-rings, ice layers, coral bands, lacustrine and marine varves, etc.) has been achieved in recent years most notably in broad-scale (hemispheric) temperature reconstructions (e.g., Mann et al. 1999, Rutherford et al. 2005), and in radiocarbon calibrations (Reimer et al. 2004, Leavitt and Bannister 2010). Despite the need and opportunity to combine tree-rings, varves, and other annually resolved records in paleoecological, and archaeological studies, progress has been slow, and examples of fully integrated, multi-disciplinary studies of these types are somewhat rare.

In this presentation I will (1) review some basic methods of dendrochronology as a prelude to (2) description of specific examples of applications of tree-ring and sedimentary charcoal studies in the western U.S., and from elsewhere. These examples will be used to (3) identify both successes and challenges in multi-proxy studies of ecological systems, and most notably the need for closer cooperation and collaboration among paleoecologists and paleoclimatologists in studies of fire, climate and human systems.

Historical Development of Methods

Andrew E. Douglass established the field of dendrochronology early in the 20th century when he develop a method of "crossdating" ring-width patterns from many different trees growing in many different locations within the Southwest region of the United States (Douglass 1919). Crossdating simultaneously demonstrated the existence of a broad-scale ("top-down") control of rhythms of tree-ring growth, and established the dating accuracy of replicated, crossdated and compiled ring-width chronologies. In the case of the semi-arid Southwest, environmental moisture (i.e., precipitation) was shown to be the most common limiting factor controlling the width of tree-rings from lower-forest border, semi-arid sites (Fig. 1).

In the century of scientific work following Douglass' original breakthroughs in establishing the archaeological chronology for the great "pueblo" ruins and cliff dwellings in the Southwest, dendrochronologists have applied the basic methods and principles of dendrochronology to studies in numerous fields, including geology, climatology, and ecology (Fritts and Swetnam 1989, Schweingruber 1996, Hughes et al. 2011). In recent decades, major advances have developed from compilations of hundreds of tree-ring chronologies of ring-width, wood density, and isotopic measurements into regional, continental, and global scale networks (e.g., see the International Tree-Ring Data Bank at http://www.ncdc.noaa.gov/paleo/treering.html).

Network approaches in the study of regional and broader-scale phenomena, such as climate controls of ecological processes and pattern, have now been extended to dendroecological data sets, most notably forest fire histories. These data, extending from site-level studies up to watershed, mountain range, regional and potential broader-scale, offer good opportunities for multi-proxy comparisons and investigations.

Fire History in the Western US, and Global Networks from Tree-Ring and Sedimentary Records

Fire scars (wound lesions on the lower boles of trees) provide records of past forest fires that burned through forests, but generally did not kill all of the trees. These kinds of records are most common in *Pinus* dominant forests, but extensive reconstructions also have been developed in some oak, larch, sequoia, and other forest types. Western North America has the most extensive and numerous sites where multiple fire scarred trees have been sampled, dendrochronologically dated, and compiled into fire chronologies. These networks of data can be assessed at various spatial and temporal scales, revealing different kinds of information at the different scales (Fig 2.).

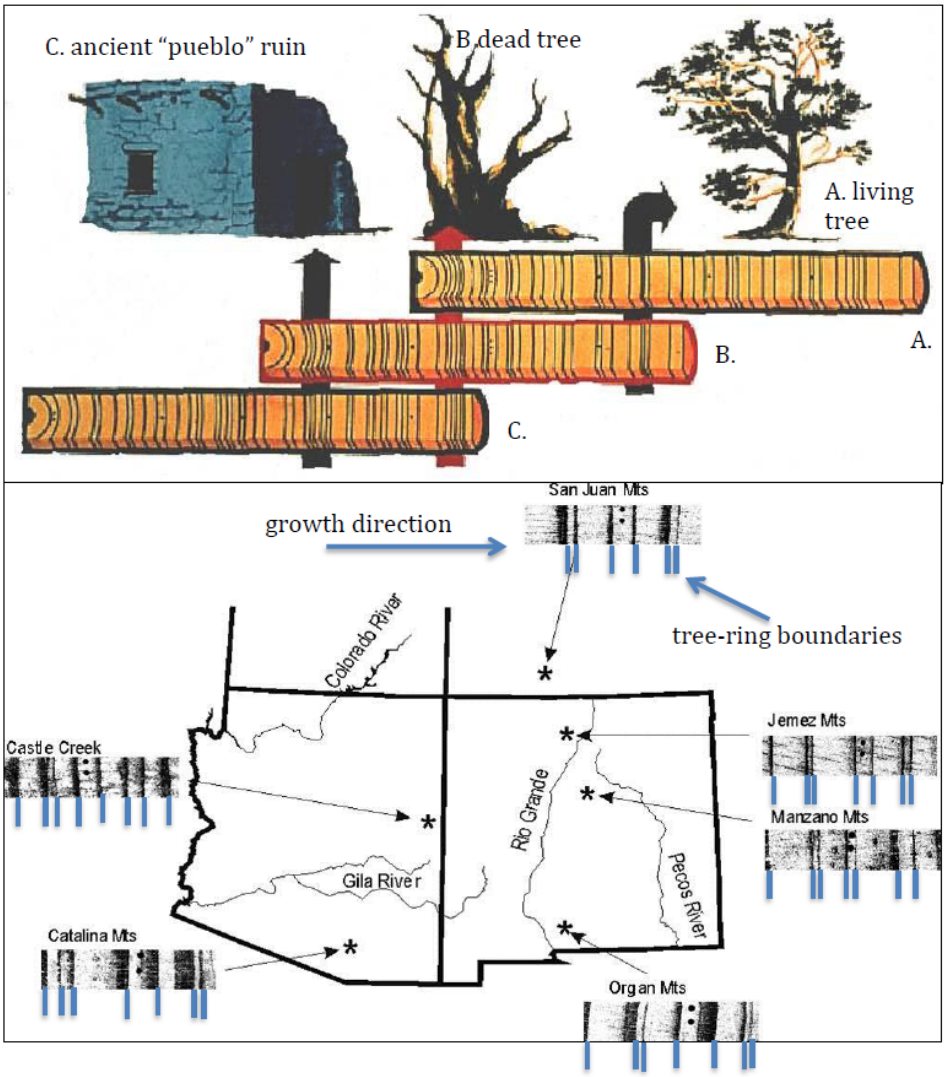


Fig. 1: Upper panel: The basic concept of "crossdating" and "bridging back in time" is shown, where ring-width patterns can be matched between tree-ring samples from the same region, including from (A) living trees (when the most recent annual ring corresponds with the date of sampling), (B) the ring patterns of a dead tree, and (C) the ring patterns from the wood timbers from an ancient dwelling. The method, therefore, can provide calendric dating of previously unknown death or cutting dates of trees (B or C). Lower panel: Crossdating of ring-width patterns can be observed over large regions, such as the southwestern United States (the states of Arizona and New Mexico are shown; about 1,000 km from west to east borders). Photographs of actual tree-ring width patters from a distinctive period of alternating wet and dry years from circa 1747 to 1753 C.E. are shown. The two black dots (pin holes) are placed in the 1750 ring. The wet/dry switch in 1747/1748 is the greatest one-year change in estimated precipitation in most tree-ring chronologies from the Southwest over the past 500 years, and 1748 was also the most extensive fire year in the region as determined from the tree-ring/fire scar network (figure modified from Kipfmueller and Swetnam 2001).

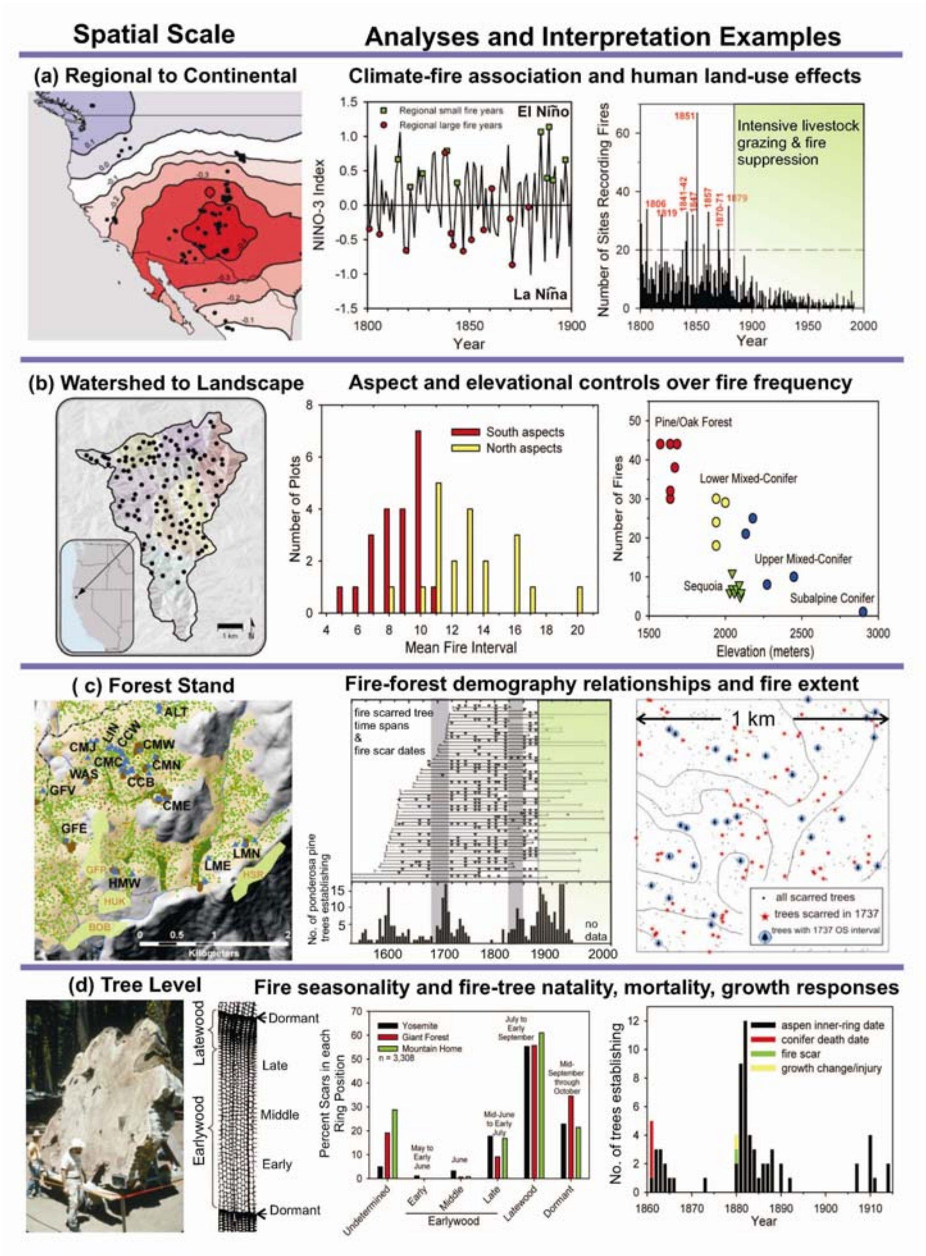


Fig. 2: Fire scar analyses can be carried out at multiple spatial scales, providing different types of ecological, climatic and human-historical information at the different scales. (a) At regional to sub-continental scales, extensive fire-history networks are analyzed in aggregate to identify widespread fire-climate associations and human land-use effects. (b) Watershed and landscape networks can be used to explore topographic controls, such as aspect and elevation, on fire regimes. (c) At forest-stand scales, fire-scarred trees and tree ages can be sampled systematically or randomly to investigate fire-forest demography relations and patterns of synchrony related to fire spread. (d) Studies of individual trees can identify the seasonality of historical low-severity fires, tree-ring growth responses (releases and suppressions), and dates of tree recruitment or death. (This figure and most of the caption is from Falk et al. 2011; and see supplementary materials there for more detailed descriptions and references to this figure.)

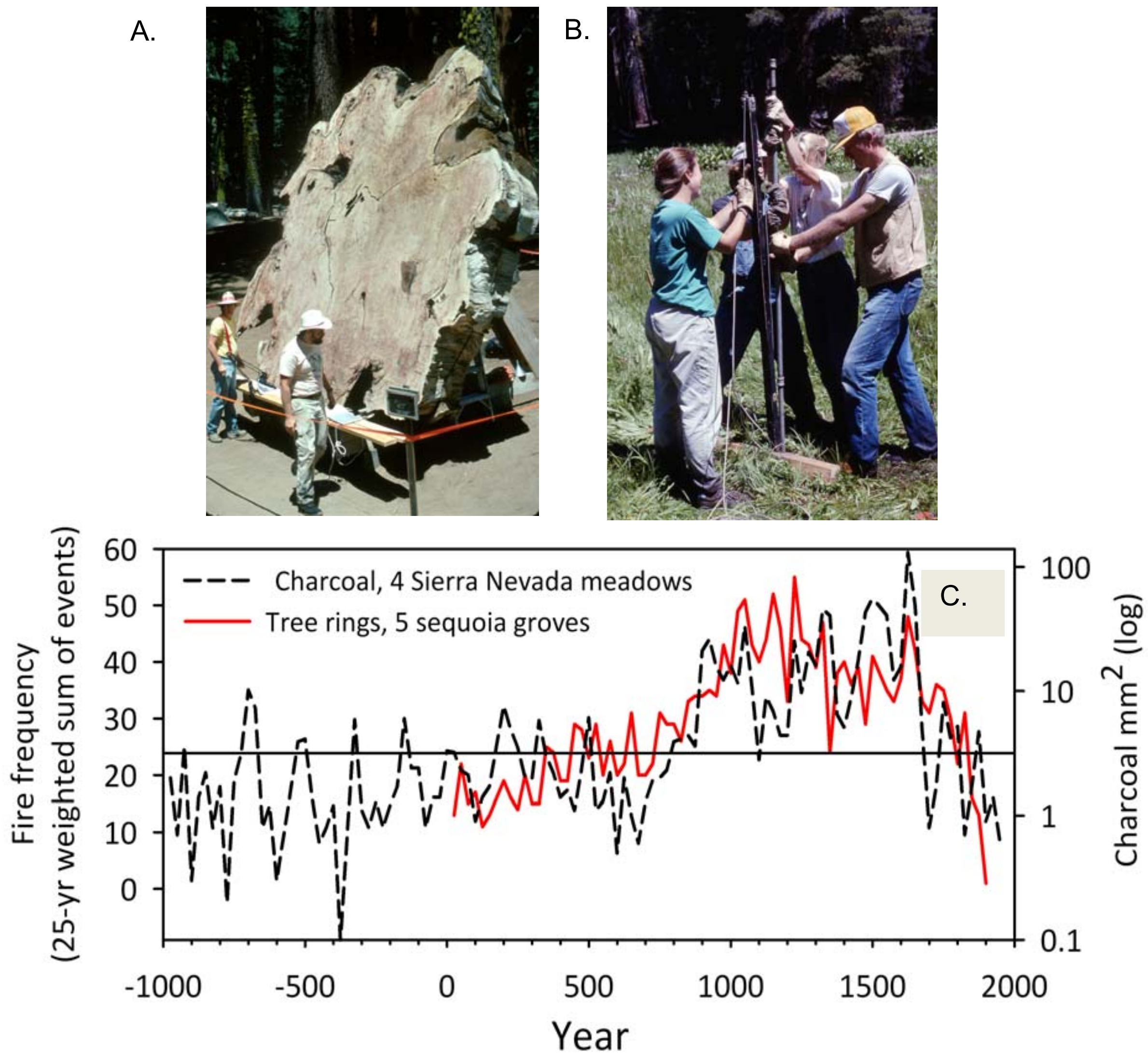


Fig. 3: Upper Photographs: Fire scars within the tree rings of giant sequoia trees in 5 groves in the Sierra Nevada, California, USA were compared with charcoal concentrations in sediment cores taken from wet meadows in the 4 of the same groves. The sequoia cross section at upper left (A) spanned the period 260 B.C.E. to 1950 C.E., and it contained 133 different fire dates. At right (B), Dr. Scott Anderson and students obtain a core from a wet meadow in the Giant Forest. Lower Graph (C): Comparison of the tree-ring based and sedimentary charcoal based fire histories in 25-year bins (the sedimentary charcoal record was not in varves) (The photos and figure are modified from Swetnam et al. 2009).

An important potential use of tree-ring based fire history in connection with charcoal observations in sediments (whether in varves or other) is in testing of decadal to centennial and longer-term patterns in both records. Greater confidence in identification and interpretations of temporal/spatial patterns can be achieved if the pattern is replicated between different proxies (e.g., Fig. 3). Further, the tree-ring record may in some cases provide higher temporal resolution (to the season), and spatial resolution (square meters), thus aiding in identifying processes and mechanisms that can be used in interpreting sedimentary records with which the tree-ring record is in accord. Sedimentary records are generally much longer temporally than tree-ring records, often spanning the Holocene or much longer.

Hence the "bridging back in time" approach is likely to be a key in paleostudies for providing the longest, most high-resolution records available, and the most robust and well-supported interpretations of these records. This includes the use of the most detailed and accurate modern observations in recent decades which span the globe, to tree-ring records spanning centuries, to varves and other sedimentary records spanning millennia.

I will conclude my presentation with a brief description of new opportunities and challenges in combining tree-ring and sedimentary-based fire and climate records at regional to global scales, and the increasing importance of combined human-environment studies in collaborations with archaeologists and historians.

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Oral

Quantifying abrupt climate events in a varved lacustrine record from MIS 11

Gareth Tye, Adrian Palmer, Ian Candy, Mark Hardiman and Peter Coxon

Although varves have numerous applications to many palaeoclimatological questions, they are almost unique in being able to address issues relating to abrupt climate change. Abrupt events, frequently lasting for decadal or centennial timescales, can only be identified within annually-resolved records that contain multiple climate proxies. A key palaeoclimatic question is whether abrupt climatic changes within interglacials, such as the 8.2 ka event, are unique to the Holocene or whether short-term climatic instability is common to most Pleistocene interglacials. In this new study we use a varved record of early MIS 11 (*ca.* 410 ka BP) from eastern England to resolve the climatic characteristics of an “8.2 ka-like” event, previously identified by a sudden decrease in arboreal pollen. Here we use varve chronology coupled with multiple proxies (pollen, oxygen isotopes, chironomids, biomarkers) to characterise the structure, magnitude and duration of this abrupt climatic event. This approach using a varve record will provide a timescale for climate forcing, and for understanding differences in the rate of response by the different proxies. We conclude by discussing the potential problems of deriving comparable climatic data from varve thickness and structure and outline strategies for future research.

Oral

Varved Lake Żabińskie, northeastern Poland: a promising site for high-resolution multi-proxy paleoclimatic reconstructions for the last millennium

Wojciech Tylmann, Martin Grosjean, Benjamin Amann, Alicja Bonk, Małgorzata Kinder and Maurycy Żarczyński

Reconstructing spatial variations in the climate over the last millennium holds the key for understanding the natural variability of European climate. One of the best locations for investigating European climate is northeastern Poland, which explains up to 86% of the variance of winter temperature in Eastern Europe and shows high teleconnectivity to the dominant North Atlantic - European circulation patterns. The aim of the recently established project CLIMPOL (Climate of northern Poland during the last 1000 years: Constraining the future with the past) is a quantitative reconstruction of climate change from varved lakes in northern Poland during the last 1000 years. The reconstruction will be based on laboratory analyses of annually-laminated lacustrine sediments using precise chronology and biological (chironomid head capsules, chrysophyte stomatocysts, diatoms, pollen), stable C- and O-isotopic, sedimentological and geochemical proxies. The obtained results will be calibrated with a modern training set of about 50 lakes (transfer function) and a calibration-in-time approach using instrumental measurements validated with early instrumental and documentary data available. High-precision dating of the sediment record is most critical as it influences directly the quality of the calibration statistics.

Lake Żabińskie located in the Masurian Lakeland was selected as a master site for our project. Preliminary field investigations showed that sediments of this lake fulfill two criteria which are crucial for the annually resolved reconstruction: (1) sediments from the deepest basin are continuously varved, and (2) high sedimentation rates allow for subsampling for the multiple proxies with annual resolution.

This relatively small (40.1 ha) and deep (43.5 m) lake presents features typical for kettle-hole lakes: basin morphology is not complex and shows the maximum depth in the central part of the lake bottom, surrounded by regularly steep slopes. The lake has one major and several minor inflowing streams and one outflow that connects it to the much larger Lake Gołdopiwo. First measurements of physical and chemical properties of the lake water indicate a thermally stratified, hardwater lake with seasonal anoxia in the hypolimnion. The present trophic status can be described as eutrophic.

The core ZAB-11/3 was collected in September 2011 from the central part of the deep basin (54º07'54.5"N; 21º59'01.1"E; 42.8 m water depth) using an UWITEC gravity corer. The total length of the core is 213 cm which covers ca. the last 300 years. The sediment record shows a varved structure of biogenic–calcareous gyttja along the entire length. Although the sediment trap study is ongoing, similarity to other lakes from northern Poland suggests that lamination in Lake Żabińskie sediments is produced by a seasonal biological and sedimentological succession, and can be defined as a biogenic type with pale spring/summer layers composed of autochthonous carbonates (calcite) and dark fall/winter layers made of detritic components. This is confirmed by first results of high-resolution XRF scanning which shows excellent agreement of calcium peaks with the position of pale layers. Lamination is clearly visible after oxidation of the sediment surface. Mean varve thickness is 6-8 mm and varies along the core in the range of 2-10 mm. Based on these promising results we are going to apply a multiple dating approach (varve counting from thin sections supported by XRF scanning results, AMS^{14}C, ^{210}Pb and ^{137}Cs) and age-depth modeling techniques to obtain the most reliable and precise time scale for the reconstruction of winter and summer temperatures in northern Poland during the last 1000 years.

Oral

Fully-automated varve recognition and counting – an interactive software presentation

Michael E. Weber, A. Holzapfel and Michael Molz

Weber et al. (2010) introduced a software package that combines laminae recognition and counting. It consists of a number of Visual Basic macros – the Macro Toolbox – that are executed from within Microsoft Excel (Fig. 1). The BMPix tool extracts color and gray-scale data from BMP images at pixel resolution. The PEAK tool uses the gray-scale curve (or any other data input curve) and performs, for the first time, fully automated counting of laminae. Various algorithms allow for the counting of minima, maxima, halfway passages, and positive and negative transitions in the gray-scale (or color) curve. For varves consisting of laminae couplets, this translates into winter maximum count, summer maximum count, seasonal count, and begins and ends of seasonal counts, respectively. Additional analysis tools help the user to handle the resulting data and to conduct further paleoclimate-related analysis. The software has originally been designed to work with marine and lacustrine varves. However, tests on additional archives such as tree rings and ice cores indicate that the macros can handle virtually any kind of laminated sequence. The only condition is that the image used for the analysis displays the lamination adequately. All aspects of the software, as well as several examples, are detailed in Weber et al. (2010).

Add-Ins

BMPix	Maxima/Minima	Maxima/Minima All Sheets	Replot Diagram
Collect Workbooks	Count Zero	Count Zero All Sheets	Total Layer Count
Extraction Tools	Transitions	Transitions All Sheets	

Fig. 1: The Macro Toolbox displayed under “Add-Ins” in Microsoft Excel. The Toolbox contains all Visual Basic macros that are used by BMPix and PEAK, as well as additional analysis tools (details see text).

During the third workshop of the PAGES Varves Working Group, we will provide an interactive computer presentation on how to run the specific parts of BMPix and PEAK. Therefore, this abstract will provide a step-by-step instruction on how to use the software for practical purposes. The software has recently been upgraded to version 2 and can be downloaded from the Pangaea webserver at (doi.pangaea.de/10.1594/PANGAEA.729700). It is free of charge and the community is welcome to use it. Although the measuring principal remains the same as in version 1, some of the potential bottlenecks have been omitted, various parts have been streamlined and simplified, and new and helpful analytical tools are implemented.

First step – the BMPix tool

Our analysis begins with the BMPix tool. After starting the macro file, the user has to enable macros within Microsoft Excel. They will then appear under “Add-Ins” (Fig. 1). Clicking the upper left button “BMPix” will open a window that asks for a bmp file. This file should contain the image the analysis will be performed on. Loading the image file will display the BMPix window (see Fig. 2). This window will occupy the entire width of the worksheet. We recommend using large, high-resolution monitors to obtain best visual control. The top right section of the window contains the image. On the left side there are a couple of settings that should be adjusted. The measurements are pixel-based. The image in Fig. 2 is 282 pixels high and 6427 pixels wide. In order to convert pixel into depth, the user must set initial depth, terminal depth, and the depth unit (mm, cm, etc.). The box “Measured Section” underneath is generated automatically from the settings defined above. In Fig. 2 it is 0-100 cm.

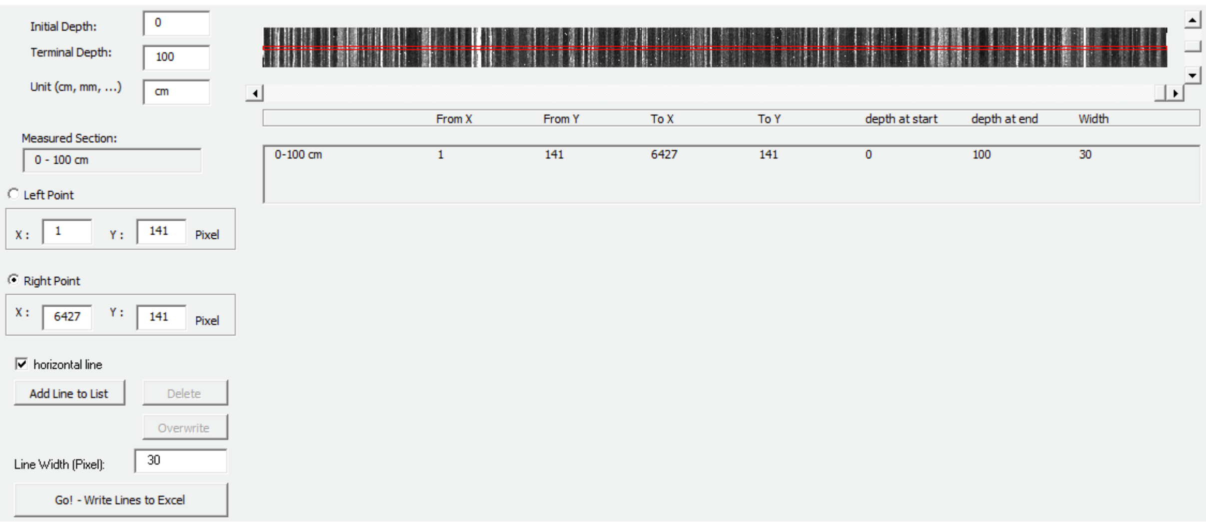

Fig. 2: The BMPix window. Left shows various settings that are adjusted during the analysis. Top shows ice-core image (courtesy of S. Rasmussen) with red lines indicating the width over which a gray-scale line is generated.

Further down on the left side, the user can adjust the left and right point of the analysis (i.e., begin and end of the profile line) either by typing in numerical pixel values or by using the mouse and slider underneath the image. Fig. 2 shows that the measurement starts at pixel 1 and ends at pixel 6427. Another variable is the “Line Width (Pixel)” over which the measurement is integrated perpendicular to the profile.

In Fig. 2 it is set to 30 pixels, i.e. centered at pixel 141, between pixels 156 and 126. These upper and lower limits are displayed as the two red lines. Once all settings are adjusted, the user should click “Add Line to List” and all relevant information of the profile lines will be displayed in the list underneath the image. The list allows for multiple entries, i.e. the user can define several profile lines simultaneously. When all values appear correct, the user should click “Go! – Write Lines to Excel”.

Now Microsoft Excel calculates one gray-scale value for every pixel along the profile line by averaging 30 pixels perpendicular to the profile line over a total length of 6427 pixel. The results will be displayed in a worksheet that opens automatically and contains 10 columns and 6427 rows. In addition, the image that was used for the analysis is now displayed in high-resolution as background of a graph (Fig. 2), containing the profile line (in red) and the gray-scale curve (in blue). Visual inspection of the curve should be used as quality control, i.e. does the extracted gray-scale curve capture the gray-scale variability of the image adequately?

Second step – the PEAK tool

Measurements on a single core section. By clicking “Maxima/Minima”, “Count Zero”, or “Transitions” in the Macro Toolbox (Fig. 1) a menu will open and the user has three choices to start the counting process. This menu asks for the settings for “Smoothing Area (Pixel)” to create a smoothing average, and for a “Minimum Width (Pixel)” and a “Minimum Height” to define the parameters that have to be met in order to be counted as a lamina. Once the settings – in the case used here for “Maxima” – are typed in (or chosen from the default values) the user should click “Go!”. The PEAK tool will now calculate the amount and occurrence of all laminae that meet the defined settings (in this case the maximum gray scale, i.e. the brightest peak) and add three data columns to the Excel Spreadsheet. Also, the position of every detected lamina is displayed on the image as a pink vertical line (Fig. 3).

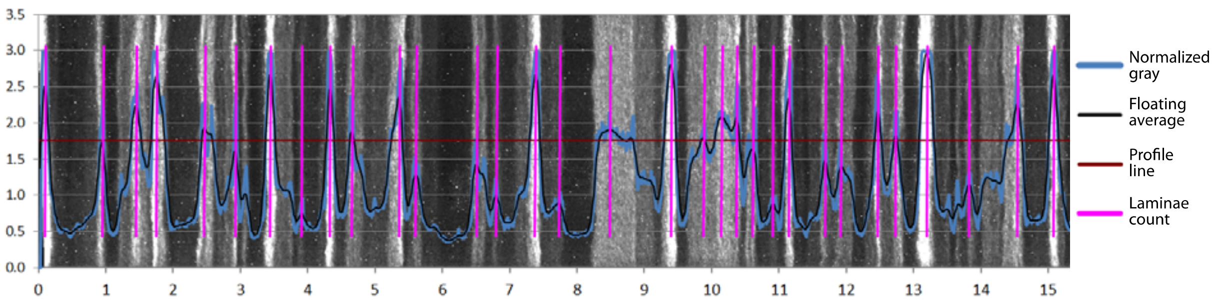

Fig. 3: The PEAK result window (displayed for the “Maximum Count Algorithm”). Underlain image shows upper 15 cm of ice-core image of Fig. 1 (courtesy of S. Rasmussen). Light blue curve gives normalized gray values; dark blue curve shows floating averages calculated from gray values; dark red line indicates center position of profile line; pink vertical bar indicates position of laminae detected under given settings (details see text).

In case the counting result is not satisfying, the user should run “Maxima” again and re-adjust the settings accordingly. In this way, optimization of the setting can be achieved quickly and conveniently. The same routine should be followed if the user wishes to count “Minima”, “Zero”, or “Transitions”.

Measurements on multiple core sections. Usually, laminae counting includes more than just one core section. Therefore, we have established a workflow that allows working on multiple core sections. The first step, however, – running the BMPix analysis – will have to be done on every core section individually. All Excel files of a core resulting from this first step should then be uploading into Excel. By clicking the macro “Collect Workbooks” (Fig. 1), all uploaded core sections will be copied into a single workbook and sorted according to core depth. The user can now define the settings and apply them to all sections of a core by clicking on of the macros “Maxima/Minima All Sheets”, “Count Zero All Sheets”, or “Transitions All Sheets” from the Macro Toolbox (Fig. 1). This operation may take some processing time and at its end, the total layer count over all individual sections is displayed.

Two additional macros in the Macro Toolbox (Fig. 1) are also helpful. “Total Layer Count” will display the amount of laminae counted over all individual sections independently from executing one of the counting macros. “Replot Diagram” will reposition the graph to its default position and will also apply default settings for all graphical elements.

Post processing. At this stage, the counting is accomplished and all results are stored in individual spreadsheets of a single Excel Workbook file. Depending on the resolution of the images, and the length of the core, there may be thousands to millions of data points gathered for gray-scale, and hundreds to thousands of counted laminae. In order to ease successive data processing, we have developed a number of tools, listed under “Extraction Tools” (Fig. 1). “Extract Columns From Active Sheet” lets the user define which columns should be exported for further analysis. Executing this macro will extract all marked columns from the active Excel Spreadsheet. There is an additional option to “Create .txt File” that allows for direct compatibility with other paleoclimate-related analysis tools such as “PanPlot” and “Analyseries”.

“Extract Columns From All Sheets” will extract all marked columns from all Spreadsheets of the Excel Workbook and combine them into a single file. “Condense Data” will open another window “Columns To Condense”, where the user can define a reduction factor for the data. This is specifically helpful when the original data files contain huge amounts of data points. “Depth Adjustment” will merge two or more files and sort the data according to depth.

Reference

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Oral

Reconstructing the seasonality of late Holocene flood events using

Stefanie B. Wirth, Adrian Gilli, Lukas Glur, Flavio S. Anselmetti, Daniel Ariztegui, Anaëlle Simonneau, Emmanuel Chapron, Boris Vannière and Michel Magny

Floods as a result of extreme precipitation events represent a major natural hazard in the Alpine realm, causing enormous financial and social damage. Current climate models predict even an increase in heavy precipitation events in the future as a consequence of global warming (Frei et al., 2006). In particular, an increase in mean winter and a decrease in mean summer precipitation, as well as a potential rise in extreme events during all seasons, are expected (CH2011, 2011). In order to assess this future flood hazard and to provide more data input for climate models, knowledge about the natural variability and the climatic forcing of heavy precipitation events is required. Lacustrine sediments allow such a reconstruction of flood-recurrence rates in the past, reaching beyond the time span covered by instrumental and historic data series. In the special cases of varved lake sediments, even the season in which the floods occurred can be determined.

Lake Ledro is one of the lakes investigated within the framework of the FloodAlp project aiming to reconstruct the Holocene flood history of the Central Alps. In total, 18 lakes are investigated but only few of the sediment records are annually laminated thus offering the possibility to resolve the seasonality of the events. Lake Ledro is located in the Trento Province in Northern Italy and has a surface area of 2.2 km^2 and a maximal water depth of 46 m (Fig. 1). The lake is situated in a carbonate catchment built up by Mesozoic sediments, enabling the production of biogeochemical calcite varves. This annual lamination has been preserved for the past 8000 years and is intercalated by flood deposits of various thicknesses (sub-mm to 38 cm). Thus, based on the stratigraphic position of a flood layer within an annual varve cycle, the season, in which the flood occurred, can be determined (Mangili et al., 2005).

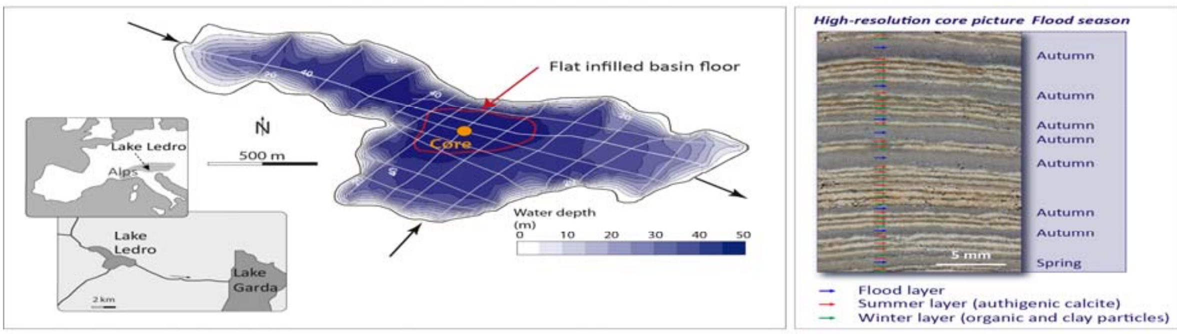

Fig. 1: Location of Lake Ledro with a bathymetric map derived from reflection seismic data (white lines) indicating the core location (left); example of a high-resolution core picture with identified varve components and flood layers (right).

Microscopic varve characterisation is realised using exemplary thin sections in combination with µ-XRF analysis. For continued investigation, i.e. varve counting and identification of the flood season, high-resolution photographs (60 pix/mm) of the beforehand well-prepared core surface are taken (Fig. 1). Varves and flood layers are identified by visual observation of the core surface using a binocular microscope and the high-resolution core pictures. Positions and thicknesses are recorded with the ImageJ software.

The validation of the age model established by varve counting is based on historic events such as ^{137}Cs activity peaks (1986 and 1963 AD), human impact in the form of hydrological modifications (1928 AD), documented earthquake events (2004, 1901, 1891 and 1117 AD) and radiocarbon ages (Fig. 2). Earthquakes are recorded in the sediments as mass-movement turbidites or overthrusting of sediments. At the time horizon of the earthquake in 1117 AD, the varve age model provides an age of 1148 AD, indicating that 31 varve years were not counted or are missing in the sediment record. This relatively small error (minus 3-4%) gives us confidence that potential basal erosion during turbidite deposition is minor. In fact, observations on the sediment reveal no obvious erosion below turbidites that are up to 5 cm thick. However, some erosion (in the range of one to two varve years) is expected below thicker flood turbidites with recurrence intervals of about 300-400 years.

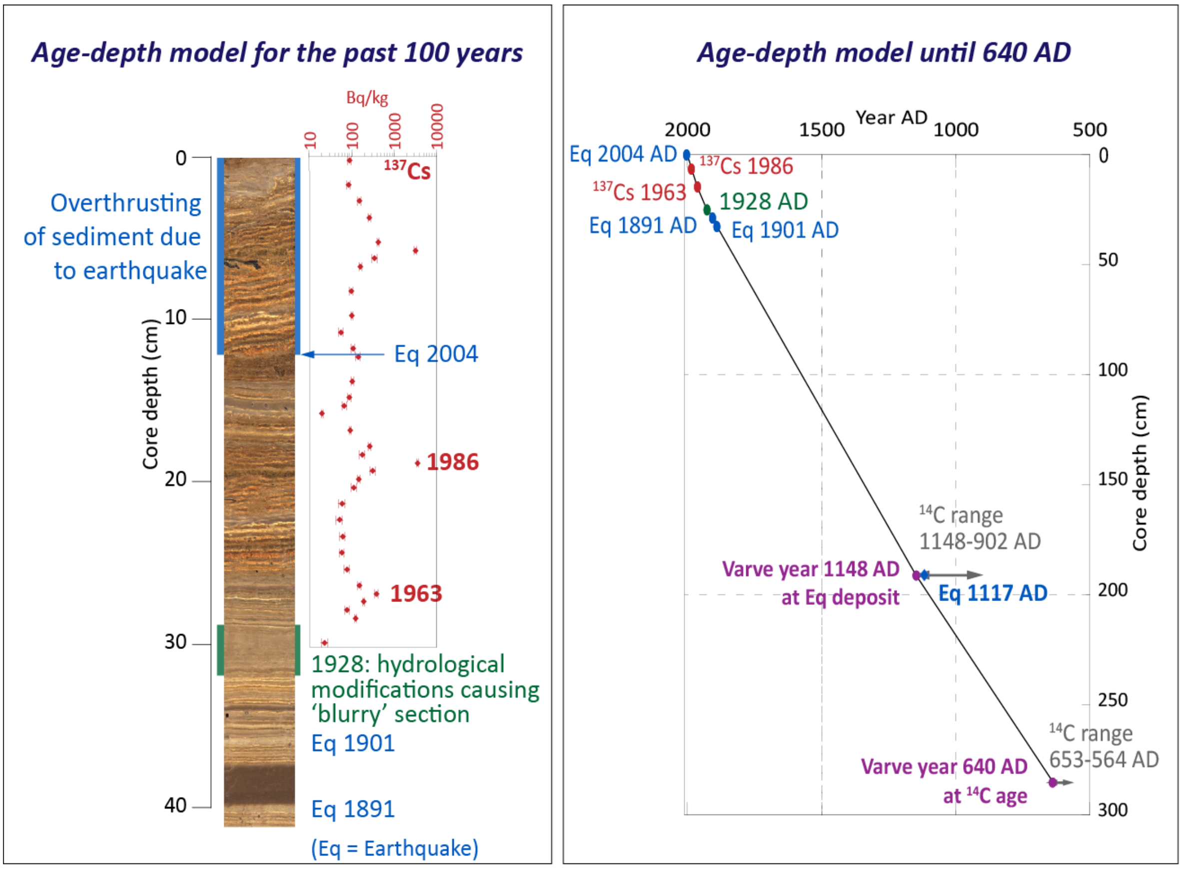

Fig. 2: Age-depth models for the past 100 (left) and for the past 1400 years (right). Varve-independent time markers are used to establish a reliable age-depth model for the past 100 years because human impact (eutrophication, hydrological modifications) altered or even destroyed the lamination. For the past 1400 years, the comparison of the varve age model with ^{14}C ages and an earthquake occurring in 1117 AD indicates an error of the varve age model of about minus 3-4%.

So far, the past 1400 varve years have been analysed. Results reveal a flood pattern dominated by summer and autumn events (86%), which is in good agreement with the reconstructions of flood frequencies in the northern Alps covering the past 500 years by Schmocker-Fackel & Naef (2010). However, there are variations in the seasonal distribution that are particularly expressed in the presence or absence of spring and winter events, e.g. absent between 1100 and 1600 AD. This signal might provide evidence for fluctuations of the North Atlantic Oscillation index, i.e. periods with no or few winter and spring layers possibly correspond to positive phases of the NAO. The flood frequency during the past 1400 years is strongly fluctuating: the highest flood frequencies are observed around 1300, 1550 and 1850 AD, the lowest between 850 and 1150, as well as around 1450 and 1650 AD. There seems to be no systematic correspondence between variations in seasonality distribution and flood frequency, hence, these phenomena are, at least partly, governed by different climatic forcing mechanisms. To better understand the underlying processes this seasonal flood record will be further expanded into the past. Special focus will be put on periods of the Holocene that are attributed with warmer air temperatures, e.g. the Holocene Climate Optimum (~5-8 kyr BP), possibly serving as analogues for the present climate warming.

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Oral

On-line varve image library – two years later

Bernd Zolitschka and Dirk Enters

Launched during the first VWG Workshop 2010 in Estonia we established a website (Fig. 1) showing images of various types of varved and non-varved sediments (macroscopic and microscopic pictures) based on contributions from the “varve community”. It was our intention to show the compositional and structural diversity of varved sediment sequences as well as to summarize the existing knowledge about varves.

Although the scientific community is aware of the great advantages provided by annually laminated sediments in both marine and lacustrine environments (“internal” chronology, high temporal resolution), there is still a widespread lack of knowledge about what can be regarded as a truly varved sediment record.

The misconception between varved versus 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 and minerogenic proglacial 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 composed of seasonal sublaminae (O’Sullivan, 1983; Saarnisto, 1986; Zolitschka, 2006). This large diversity of sediments featuring a “varved” character may have contributed to the conception that every finely laminated sediment sequence must be varved which, unfortunately, is not necessarily and not always the case. A website specifically dedicated to varved sediments could assist researchers which are not very familiar with annually laminated sediments to judge the potential of newly recovered sediment sequences in their cores and outcrops to be varved and to distribute the information about the overall macroscopic appearance, internal structure and composition of varves.

Our website is structured into (1) macrostratigraphy like e.g. core images of annually laminated sediments, (2) microstratigraphy including e.g. regular seasonal sublaminations (Fig. 2) or a documentation of the internal varve structure, (3) event layers like tephra layers, slumps, turbidites or homogenites, and other non-annual sedimentary features, (4) sediment components (biological, minerogenic, artefacts), and (5) so far unknown sediment features or components. Each image is accompanied by metadata which includes a short description containing information about the image, study site, preparation, photographic method, contact person and publication if available. Additionally, some general information about varves is given as well as links to interesting other varve-related or methodological relevant websites. The website of the on-line varve image library is accessible at http://www.geopolar.uni-bremen.de/varves (Fig. 1) and needs your constant input.

Unfortunately, the response and support by the members of the varve community has been rather low so far. Please support our initiative by sending your images, ideas, comments and suggestions to the authors.

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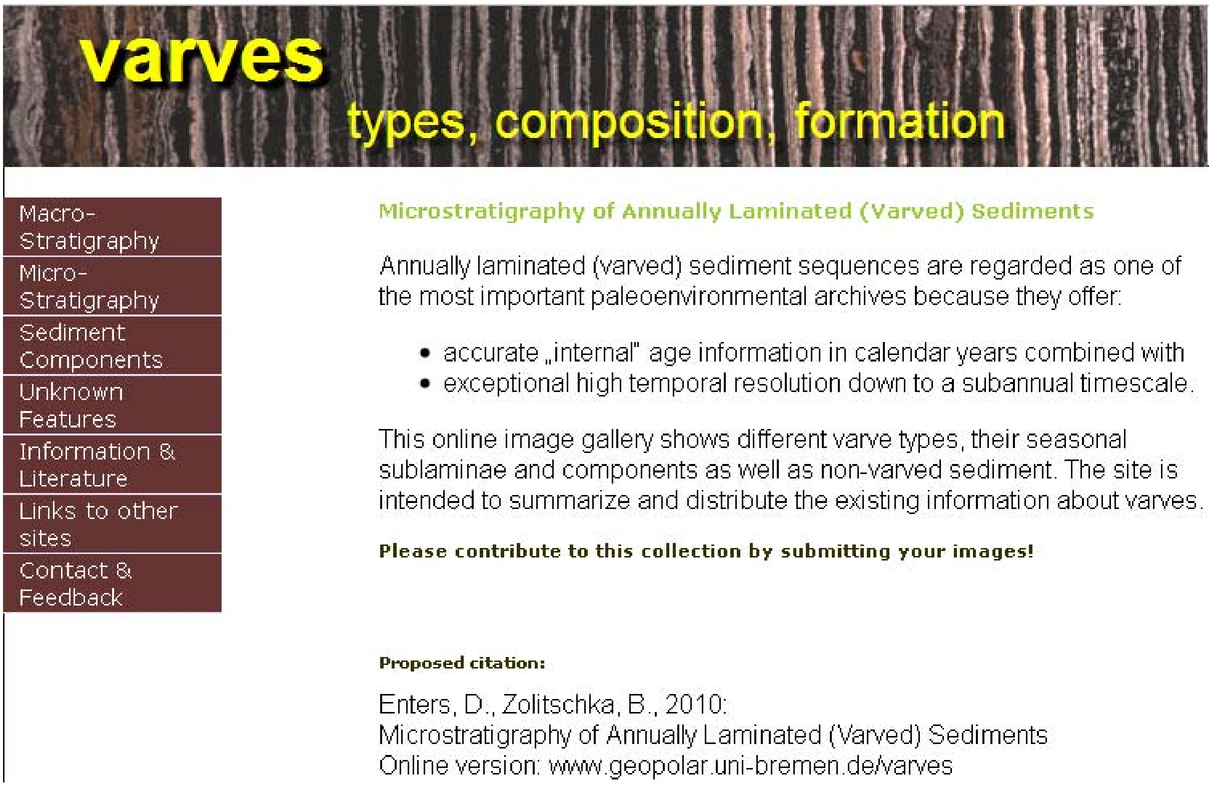

Fig. 1: Homepage of the on-line varve image library at http://www.geopolar.uni-bremen.de/varves.

Polarized light, 40x magnification

Description:

Lateglacial calcite varves.

Study site:

Sacrower See, Potsdam, Germany

Author:

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Publication:

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Fig. 2: Example of a microstratigraphic image from the on-line varve image library.

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