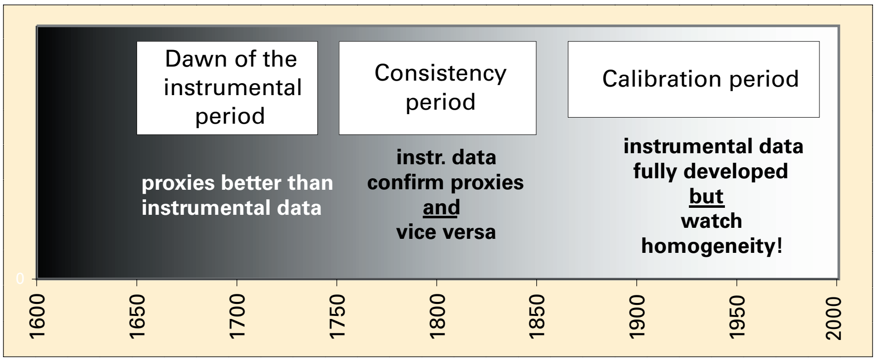

Figure 3: Development of the potential of instrumental climate data for paleo-climate reconstructions.

but also considerable variability in space—horizontally (Fig. 2 left) and vertically (Fig. 2 right).

Figure 3 presents a timeline that summarizes our conclusions on the quality, availability and potential of instrumental data for the reconstruction of climate. There is no question that before the mid-18th century the very rare instrumental information that existed is inferior to high-quality reconstructions based on proxies. The real calibration period started as late as the second half of the 19th century. Since then, well-homogenized and spatially dense instrumental information has been available to calibrate proxy data. For the one hundred years in between, both sources (instrumental and proxy) are reliant on each other, with only a combination of different sources providing reasonable information about past climate variability. That period may therefore best be called the "consistency period".

References

Auer, I., Böhm, R. and Schöner, W., 2001: Austrian long-term climate 1767-2000 – Multiple instrumental climate time series from Central Europe. *Österr. Beitr. Zu Meteorologie und Geophysik* **25**, 147 pp (plus Data- and Metadata-CD)

Böhm, R., Auer, I., Brunetti, M., Maugeri, M., Nanni, T. and Schöner, W., 2001: Regional temperature variability in the European Alps 1760-1998 from homogenized instrumental time series. *International Journal of Climatology* **21**: 1779-1801

Jones P.D., 1994: Hemispheric surface air temperature variations: A reanalysis and an update to 1993. *Journal of Climate* **7**: 1794-1802

Moberg, A. and Alexandersson, H., 1997: Homogenization of Swedish temperature data. Part II: Homogenised gridded air temperature compared with a subset of global air temperature since 1861. *International Journal of Climatology* **17**: 35-54

Peterson, T.C., Easterling, D.R., Karl, T.R., Groisman, P., Auer, I., Böhm, R., Plummer, N., Nicholis, N., Torok, S., Vincent, L., Tuomenvirta, H., Salinger, J., Førland, E.J., Hanssen-Bauer, I., Alexandersson, H., Jones, P. and Parker, D., 1998: Homogeneity Adjustments of In Situ Atmospheric Climate Data: A Review. *International Journal of Climatology* **18**: 1493-1517

For full references please consult:
www.pages-igbp.org/products/newsletters/ref2003_2.html

Climate and Environmental Reconstructions from Scandinavian Varved Lake Sediments

Antti E.K. Ojala[1], Matti Saarnisto[1] and Ian F. Snowball[2]

[1]Geological Survey of Finland; antti.ojala@gsf.fi; matti.saarnisto@gsf.fi
[2]Quaternary Geology, Lund University, Sweden; ian.snowball@geol.lu.se

Introduction

Annually resolved proxy records, such as varved lake sediments, are important archives of past climate variability and environmental change. The primary strength of any varved archive is that it contains a continuous and inherent calendar year timescale that forms a temporal framework for paleoenvironmental reconstruction. In addition, many physical, chemical and biological parameters can be used to accurately infer fluxes. The structure and composition of varves are governed by a multitude of interacting factors in different sedimentary environments that, in the best cases, can be related to external forcing factors and subsequently interpreted as records of regional climate change (e.g. Hughen et al., 2000).

The contemporary annual climate in Fennoscandia has strong

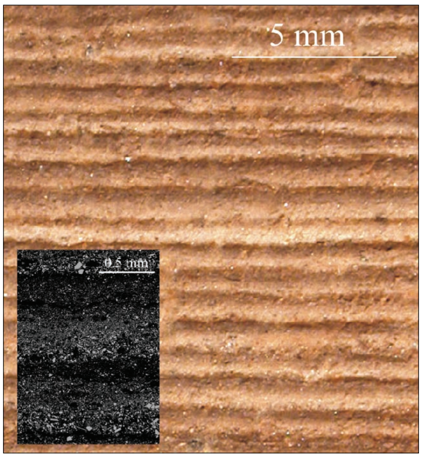

Figure 1: Images of Lake Nautajärvi (central Finland) clastic-organic nonglacial varves at AD 200 taken from the fresh sediment surface (left) and thin-section, using a back-scattered mode of surface scanning electron microscope (right).

seasonality, which causes several months of ice cover on lakes, peak floods during the spring snowmelt, summer (and winter) stratification of the water column, algal blooms and occasional autumn storms. This myriad of factors is the principal cause of distinct rhythmic sedimentation and of the formation and preservation of varves in lakes (Renberg, 1982; Ojala et al., 2000, Zillén et al., in press). Varves in small to mid-sized lakes in Finland and Sweden typically appear as clastic-biogenic couplets (Fig. 1) (Petterson, 1996; Ojala et al., 2000), which sometimes cover the entire past glacial history of the basin, up to 10,000 years or more. A typical Fennoscandian lake varve is composed of an allochthonous fine-grained minerogenic layer deposited as a result of the spring snowmelt, grading into an organic summer layer formed by primary productivity and a thin dark-colored layer composed of fine-grained organic matter that settles during the winter when the lake is ice-covered (Renberg, 1982). In many cases, the varves are best seen after oxidation

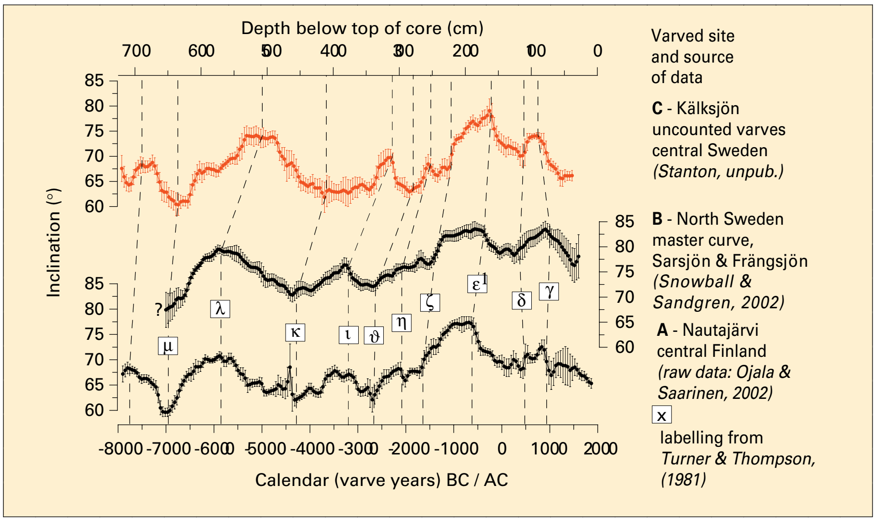

*Figure 2: Precisely dated high-resolution reconstructions of geomagnetic field secular variations for the last 10,000 years, based on a network of varved lake sediments in Finland and Sweden, has resulted from cooperation between the Geological Survey of Finland and the Geological Institute at the University of Lund in Sweden. The example shows a varve dated inclination master curve for Nautajärvi in central Finland (**a**) and a stacked inclination master curve from Sarsjön and Frängsjön in northern Sweden (**b**). Both curves are based on the spherical smoothing of data with a moving time-window of 150 years (Snowball and Sandgren, 2002). The potential to correlate paleomagnetic features and transfer ages with an approximate error of less than 200 years is demonstrated by the comparison with paleomagnetic data obtained from the site of Kälksjön (**c**), which is located in central Sweden and contains uncounted varves. An amalgamated reconstruction of the total field vector (direction and intensity) is the aim of ongoing collaboration. This reconstruction will refine the ages of the regional features and provide a data set that can be used to distinguish solar and geomagnetic influences on rates of atmospheric cosmogenic nuclide production.*

of the sediment, when the annual iron cycle is highlighted.

Recent publications report long clastic-biogenic varved sequences in the lakes of Nautajärvi, Alimmainen Savijärvi, Korttajärvi (Ojala & Saarinen, 2002; Ojala et al., in press; Ojala & Tiljander, in press), Kassjön (Petterson et al., 1999), Sarsjön, Frängsjön (Snowball et al., 2002; Snowball & Sandgren, 2002), Furskogstjärnet, Mötterudstjärnet (Zillén et al., 2002) and Kälksjön (Zillén et al., in press). Counting of the annual laminations indicates that the error estimate of these varve chronologies can be pushed down to ±1%. Such accurate and precise multiple chronologies form an excellent basis for between-lake comparisons of paleodata and provide a template for assessing the accuracy of correlations made using other techniques, such as paleomagnetic dating and tephrochronology (Ojala and Saarinen 2002, Pilcher et al., this issue, Snowball and Sandgren, 2002, Zillén et al., 2002) (Fig. 2).

Basis of Climate Reconstruction

High- and low-frequency variability of the physical properties of clastic-biogenic varves (thickness, density, composition and texture) is mainly indicative of the annual influx of mineral matter into the basins, which depends principally on the rate of catchment erosion and the transportation of detritus during the intense spring snowmelt flood. In the boreal vegetation zone, the intensity of spring discharge is predominately determined by snow storage and the water equivalent of snow in spring (Kuusisto, 1984). Of course, the rate of catchment erosion also depends on the supply of material in the catchment and timing of the most intensive runoff in relation to soil thawing. In contrast to many biological proxies that reflect summer conditions, the physical properties of clastic-organic varves are related to climatic conditions that prevail over the winter months, primarily temperature and the amount of snow that accumulates in the catchments of the individual lakes.

Many of the varved lake sediment sequences under investigation in Finland and Sweden are located in areas that exhibit considerable year-to-year variability of winter temperature and precipitation. One of the phenomena known to regulate winter climate in the North Atlantic–European region is the atmospheric circulation pattern called North Atlantic Oscillation (NAO) (e.g. Hurrel, 1995; Luterbacher et al., 2002). During years of positive NAO, cyclones originating in the Atlantic sweep westwards across Fennoscandia and the Baltic Sea region, causing relatively mild and wet winters. On

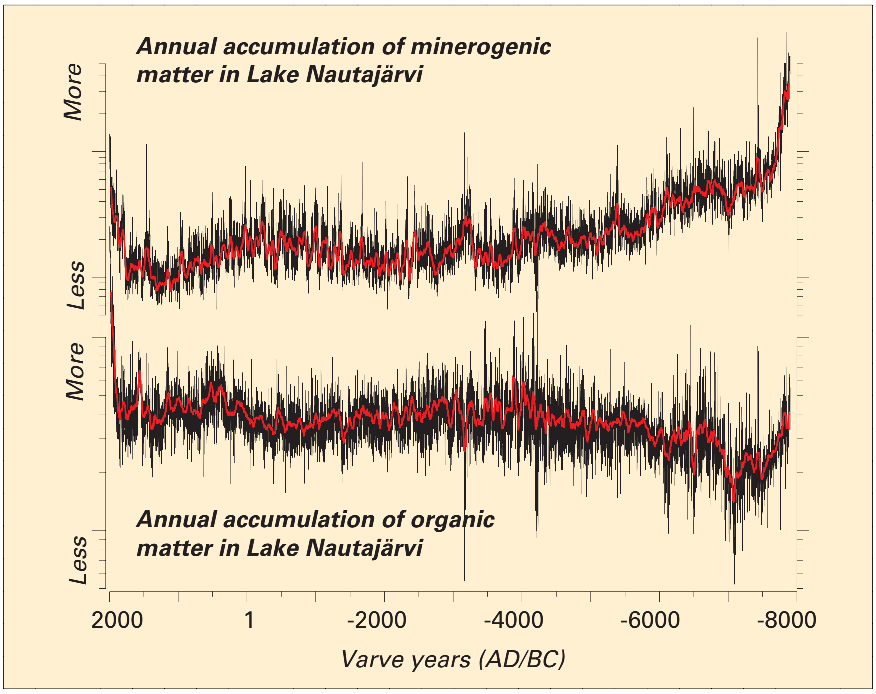

Figure 3: Annual mineral and organic matter accumulation in Lake Nautajärvi central southern Finland since 7902 BC based on studies of relative X-ray density.

the other hand, years of negative NAO are characterized by colder and drier winters. It appears that these lakes are located at a sensitive climatic boundary, where just a few degrees warming during the winter (+NAO) results in a considerably shortened period of snow cover, even to the point where no persistent snow cover forms (Vehviläinen & Lohvansuu, 1991; Vehviläinen & Huttunen, 1997). As a consequence, the peak discharge in spring is severely reduced, catchment erosion is significantly lower and less allochthonous mineral matter is transported and deposited on the lake bottom. One period of weakened spring discharge and erosion has been identified from Finnish varved sediments to have occurred between AD 980-1250 (Saarinen et al., 2001, Tiljander et al., in press). This period coincides with the Medieval Climate Anomaly. Its climate implications are under intensive investigation. However, due to local system dynamics, it is evident that the relationships between external forcing factors and the annual accumulation of mineral/organic matter are neither linear nor stable over time. Post-isolation catchment stabilization, vegetation succession, human disturbance and extreme events like forest fires exert a considerable influence on catchment erosion and the nature of the varved records. At the end of the day, the properties of clastic-organic varves in Fennoscandia reflect the annual flux of mineral matter to the sedimentary basins via a multitude of interacting factors. The main aim of future work is to use a variety of analytical methods, such as high-resolution digital image analysis (e.g. Tiljander et al., 2002, Ojala & Francus, 2002, Saarinen & Petterson, 2002), mineral magnetism (Snowball et al., 1999), pollen, and charcoal analysis to discriminate between the major factors that drive the sedimentation.

References

Ojala, A.E.K. and Saarinen, T., 2002: Palaeosecular variation of Earth's magnetic field during the last 10,000 yrs based on the annually laminated sediment of Lake Nautajärvi, central Finland. *The Holocene* **12**: 391-400.

Ojala, A.E.K. and Tiljander, M., Testing the fidelity of sediment chronology: comparing varve and paleomagnetic results from Holocene lake sediments from central Finland. *Quaternary Science Reviews* (in press).

Snowball, I., Sandgren, P. and Petterson, G., 1999: The mineral magnetic properties of an annually laminated Holocene lake-sediment sequence in northern Sweden. *The Holocene* **9**: 353–362.

Snowball, I.F. and Sandgren, P., 2002: Geomagnetic field variations in northern Sweden during the Holocene quantified from varved lake sediments and their implications for cosmogenic nuclide production rates. *The Holocene* **12**: 517–530.

Zillén, L.M, Wastegård, S. and Snowball, I.F., 2002: Calendar year ages of three mid-Holocene tephra layers identified in varved lake sediments in west central Sweden. *Quaternary Science Reviews* ***21***: 1583–1591.

For full references please consult: www.pages-igbp.org/products/newsletters/ref2003_2.html

^{14}C as an Indicator of Solar Variability

Tomasz Goslar

Adam Mickiewicz University, Faculty of Physics and Poznan Radiocarbon Laboratory, Poznan, Poland; goslar@radiocarbon.pl

Introduction

The quasi-constant concentration of ^{14}C on the Earth is maintained by a balance between its radioactive decay and its production from atmospheric nitrogen. This production is possible due to the high-energy protons from cosmic radiation. Atoms of ^{14}C enter the biogeochemical cycle, where carbon circulates between the atmosphere, terrestrial biosphere and the oceans. Since the characteristic exchange rates between reservoirs and times of circulation within individual reservoirs are significant with respect to the half-life of ^{14}C, radiocarbon concentration on the Earth is not uniform, being the highest in the atmosphere and distinctly lower in the deep oceans.

Charged particles emitted from the Sun produce a magnetic field in interplanetary space. This field inhibits penetration of low-energy cosmic-ray protons into the center of the solar system. As a rule, an increase in solar activity corresponds to a decrease in the flux of galactic cosmic rays impinging on the Earth. The intensity of cosmic radiation in the atmosphere is also modulated by the Earth's magnetic field. To first-order approximation, the globally averaged ^{14}C production rate is inversely proportional to the square root of the geomagnetic dipole moment (Lal, 1988).

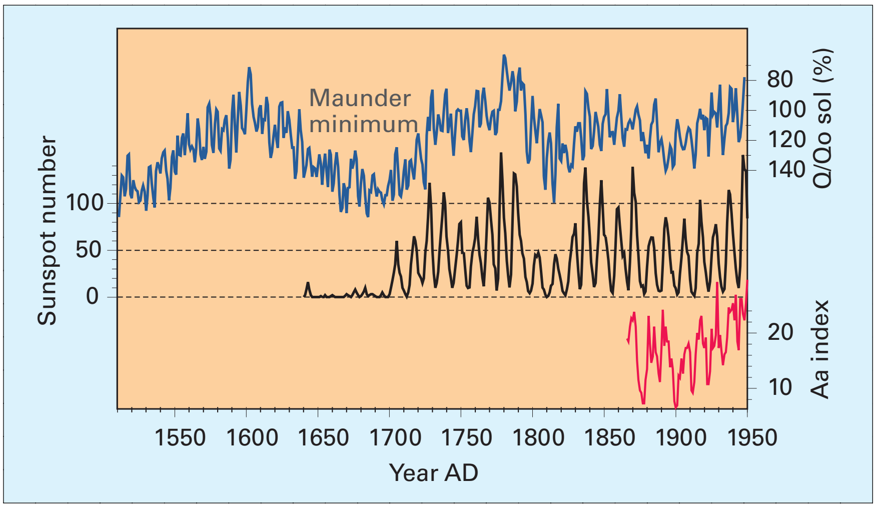

Figure 1: Comparison of radiocarbon production rate (Q/Qo) and records of solar activity in recent centuries.

Reconstruction of Atmospheric ^{14}C Levels in the Past

Past variations in atmospheric ^{14}C concentration have been reconstructed as a "by-product" of radiocarbon calibration. During the Holocene period, this calibration is based on ^{14}C ages of bidecadal or decadal tree-ring samples, dated absolutely by means of dendro-