Paleoenvironmental Significance of Varved Lake Sediments in Fennoscandia and their Contribution to PAGES Related Programs

A major theme of the previous PAGES newsletter 99–1 concerned the role of lake-sediment archives as providers of continental proxy-environmental/climate data. In this short summary we aim to highlight the contribution that ongoing and continued studies of varved lake sediments in Fennoscandia can make to PAGES related programs, such as PEP III, QUEEN and CAPE. Some of the ideas presented here originated from the "Varve 99" workshop (see previous page).

The construction of an accurate geochronology (by any means) is often a painstaking and time-consuming task. Yet, when a geological archive possesses a continuous and independent calendar year chronology, plus an array of proxy-indicators of environmental and climatic change that can be studied at an annual (possibly seasonal) resolution, the quality and quantity of paleo-environmental reconstruction that can be undertaken increases significantly (as do the economic demands). Excellent examples of research that can be achieved include the studies of the Greenland ice-cores and the construction of regional dendro-climatological time-series from tree-ring data.

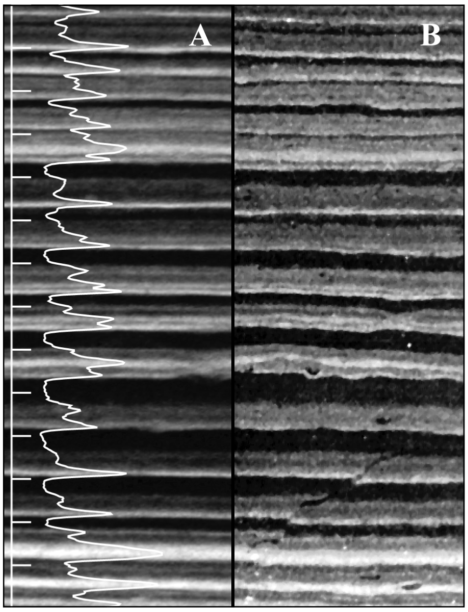

Figure 2: A) X-ray radiograph of 14 mm of fresh sediment recovered from lake Korttajärvi in Finland (depth = 200 cm from sediment surface). Relative X-ray density curve is shown in white. B) Scanned greyscale image of sediment embedded in epoxy resin (same sample as A). Light layers = minerogenic spring season layer (deposited during the snowmelt) and dark = organic summer-winter layer (more organic).

Most freshwater lake-sediments in Fennoscandia were deposited during the late Pleistocene and the Holocene. Dating of these sedimentary sequences has, therefore, relied heavily upon the radiocarbon dating method. However, the existence of annually laminated (varved) lake sediments in Finland and Sweden has been known for several decades. A considerable amount of work has been expended on methodological studies, with respect to undisturbed sediment core recovery as well as subsequent analytical techniques. The most common type of varve structure found in Fennoscandia is: (i) a light coloured mineral layer deposited during the spring snowmelt flood; (ii) a brown summer layer consisting predominantly of relatively coarse grained autochthonous organic matter, and (iii) a dark brown (often black) layer of fine grained organic matter that settles out during the winter, when the lakes are ice covered. Occasionally, thin micro-layers of mineral material can be deposited as a consequence of autumn storms (Figure 1). However, other varve types are known, such as those that contain distinct layers composed of diatom frustules or calcium carbonate. Common to all varves is the absence of post-depositional disturbance (primarily in the form of bioturbation). In many cases culturally induced eutrophication during the last few hundred years initiated anoxia and the subsequent preservation of varves. The individual layers that constitute a single varve thus provide physical, chemical and biological proxies of environmental change at a seasonal resolution. Sites located in the near vicinity of research centers and field stations have often been studied with respect to tracing increasing human influence in the form of agriculture and air pollution. Other studies have investigated the relationships between recent meteorological observations and micro-fossil records, for example pollen, spores and diatom frustules. All these studies have used the inherent calendar year chronology to reconstruct rates of change and to detect lags between external forcing (climate) and ecosystem response. More recently, independent research groups have undertaken systematic searches for varved sequences which may contain excellent records of natural environmental and climate variability over several thousand years or longer. These searches, carried out by research groups at the Geological Survey of Finland, the University of Turku (Finland), Umeå University (Sweden), Lund University (Sweden) and the University of Tallin (Estonia) have been carried out at high latitudes and high altitudes, and in areas with vegetation still dominated by boreal forest. Varved lake sediments extend from northern Norway to south-eastern Estonia, the latter with a predicted temporal range of 14,000 years. Although most of the biological proxies generally reflect summer growth conditions, physical and chemical measurements may reveal information about the winter seasons, such as the length of ice-cover, or the intensity of the spring snow melt.

Each group working with varved lake sediments in Fennoscandia has applied different techniques to study the fine-scale variations in varve composition. The majority of the varves formed prior to human influence are thinner than 1 mm, which means that it is difficult to apply traditional paleo-ecological techniques (e.g. pollen and diatom analyses) at a scale that takes full advantage of the annually resolvable chronology. However, it is possible to calculate the influx values of certain components to produce decadal to millennial scale variations. Analytical tools that have been applied to complete sequences covering several thousands of years include the digital image analysis of photographs, X-ray densitometry and mineral magnetism. It must be stated that these techniques, which have their own advantages and disadvantages, do not effectively separate individual sediment components. On the other hand, these techniques are complementary and can identify periods of rapid change, which can form the focus of more detailed biostratigraphical investigations (Figure 2).

In some respects the availability of so many varved lake sediment sequences in a relatively restricted geographical region forms a bane as well as a boon. Considering the amount of effort invested in an individual site, the question of site-selection is difficult to address and careful consideration must be given to the parameters to be analysed. The Nordic Council of Ministers has recently (1999) funded a networking project, called LAMSCAN, which has been designed to apply fairly rapid and relatively non-destructive analytical techniques to a network of varved sediment sequences in Fennoscandia. This project, co-ordinated by the Department of Quaternary Geology at Lund University, is designed to identify periods of rapid terrestrial climate change, which may have been caused by fluctuations in the North Atlantic oscillation.

There is no doubt that studies of varved lake sediments deposited during the late-Pleistocene/Holocene will produce a variety of data sets that can be compared to other independently dated environmental archives, such as those provided by ice-cores (e.g., GRIP/GISP) and tree-rings (e.g., ADVANCE-10K, see PAGES Newsletter 99–1). However, to attain this goal considerable investment must first be placed in both salaries and analytical costs. It is also essential that a holistic ecosystem framework is adopted so that the paleoenvironmental records preserved in varved sediments are correctly interpreted. Previous and ongoing studies of varved lake-sediment sequences in Sweden and Finland demonstrate (not surprisingly) that lakes and their catchments respond to external (climatic) forcing on an individual basis. The sensitivity of each lake catchment to variations in climate will vary according to the interaction between a multitude of terrestrial and limnological factors, which are site-specific. Preliminary results do indicate that the more infrequent, but major, climatic "events" are recorded in several sites and in similar variables, but that more frequent and less intense climatic variations are recorded on a site-specific basis according to the sensitivity of each ecosystem. This observation has important consequences for the interpretation of paleoenvironmental data from regions where the number of sites is very restricted. It is, therefore, important to remember that: "Lakes are individuals, just like you and me." (Gunilla Petterson, pers. comm. 1999).

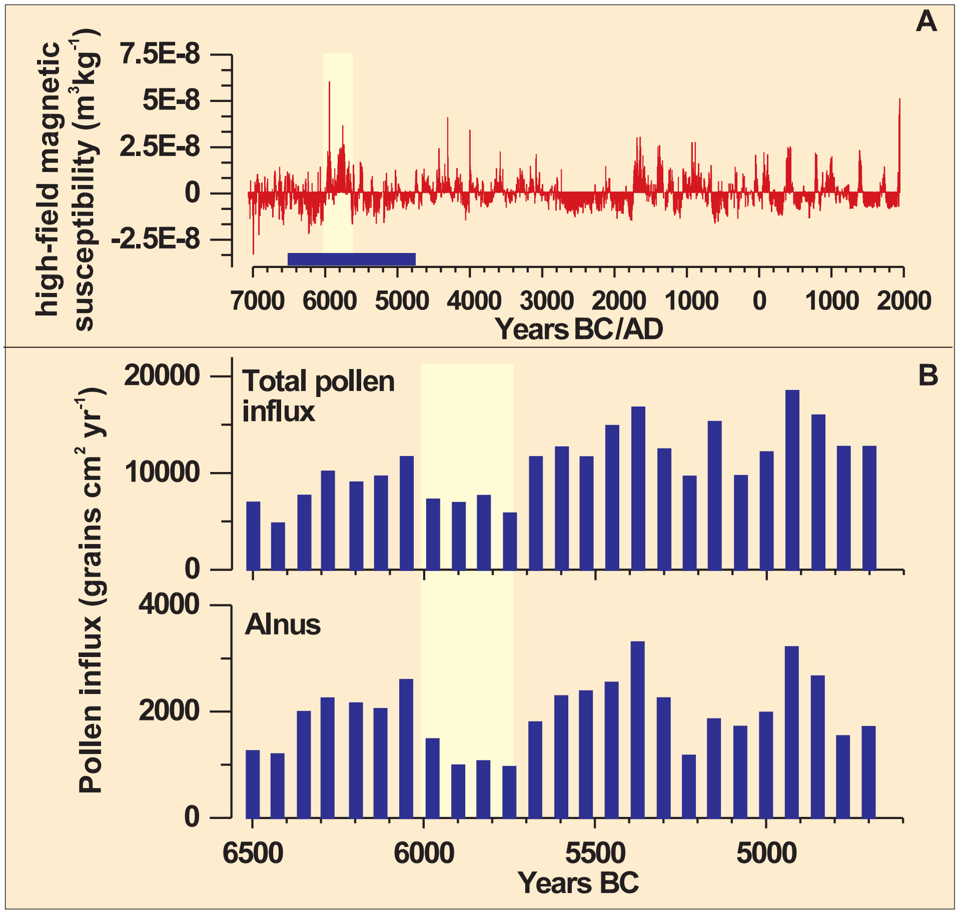

Figure 2: (A) High-field magnetic susceptibility data from a 9000 year varved sediment sequence in northern Sweden (Lake Sarsjön), plotted as the variance around a 5-degree polynomial trend. Peaks in high-field (para)magnetic susceptibility reflect periods of increased mineral deposition during the spring, and probably represent an index of winter precipitation in the form of snow. Note the major peak between c. 6100 and 5700 BC, and the increased variability since c. 3700 BC. (Data adapted from Snowball et al. 1999).
(B) Selected pollen influx values obtained at 75-year intervals over the period highlighted in (A). The total pollen influx values, which are dominated by tree species, decreased during the period of increased winter snowfall. Alnus *(Alder) was near to its northern limit of distribution at c. 6000 BC and the decreased pollen influx values during the subsequent 300–400 years indicate a generally cooler climate (Zillén, L. in prep.). Given dating errors associated with different geochronologies this anomaly most likely correlates to a well-known period of increased glacial activity in the Scandes mountains, and the so-called "8.2 ka" cold event registered by oxygen isotope data in the Greenland ice-cores.*

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