The geochronology of the last millennium

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ABSTRACT

This constitutes a report on the application of a range of potential dating techniques to recent lake sediments and peats. Replicate cores of annually laminated (varved) sediments have been used to test the accuracy and precision of chronologies based on AMS ^{14}C and palaeomagnetic secular variation, and to provide dated material for pilot studies based on ^{32}Si, ^{226}Ra and tephra analysis. The potential value of both high precision and AMS ^{14}C dates in high resolution peat dating has also been explored and a detailed chronology of accumulation derived for the last 700 years.

INTRODUCTION

Lake sediments and peats that have accumulated over the last 1000 years are of special interest in palaeoenvironmental reconstruction for two major reasons. First, they can provide a fine resolution record of environmental and ecological responses to recent climatic changes independently documented by other lines of evidence. This can contribute to the development and evaluation of models dealing with the likely impact of future climatic variation. Secondly, they provide a way of testing and calibrating methods of palaeoclimatic reconstruction using proxy indicators in the peat or sediment record, since they allow detailed comparison between the proxy evidence and the sequence of climatic changes reconstructed from, for example, instrumental, documentary and tree-ring records.

Both these possibilities require the establishment of accurate and precise chronologies of peat and sediment accumulation. At present, this is possible only for varved lake sediments, provided the seasonality and continuity of the varves can be confirmed. Despite recent advances in the recognition, sampling and analysis of such sediments, this remains a severe limitation and it effectively precludes the most critical work on a whole range of key sites and problems. In the case of peats, fine-resolution chronologies for this time interval have been entirely lacking. The aim of the research summarised here is to address this need for improved chronologies of peat and sediment accumulation over the last 1000 years.

RESEARCH SITES AND STRATEGIES

The area chosen for the study was in northern Sweden, partly because of the presence of well validated varve chronologies for some of the lakes, and partly because of the current interest in high latitude climatic variation.

The lake site, Kassjön was chosen in the light of previous detailed studies (Renberg, 1981; Segerström, 1991). The main basis for our research has been a set of 12 'Russian' cores from the middle of the lake, spanning the period c.800-1900 AD. Varve counts by several researchers confirm that the laminations for the last 1000 years, can be both correlated and dated with an accuracy and precision of c.0.5%. These cores have provided:

a) aggregate samples spanning, respectively, the periods 975-1025 AD and 1390-1440 AD, each within a monotonic section of the dendro-calibration curve and each providing hand picked organic fractions for AMS ^{14}C dating;

b) core segments for palaeomagnetic analysis, concentrating on the period 1600-1900 AD for which the record of palaeomagnetic secular variation is well established (Thompson & Barraclough, 1982);

c) dated sub-samples at 100 year intervals for silica

extraction and ^{32}Si assay on both the biogenic and non-biogenic components;
d) dated subsamples for initial measurements of ^{226}Ra, ^{234}Th and ^{234}U activity;
e) narrowly defined core slices representing the time periods encompassing 18 Icelandic volcanic eruptions between 900 AD and 1875 AD.

The area lies too far north for classic concentric, domed, ombrotrophic mires (cf. Eurola *et al.*, 1984) The peat site chosen, Stor Åmyran is one of the largest and least disturbed northern 'eccentric' bogs or 'aapa' mires in the region and the point chosen for sampling was in an area close to the 'crown' of the mire, in uniform Sphagnum lawn peat between 'strings'. There is minimal risk of either allochthonous organic inwash to this part of the mire or of the recent peat being directly affected by alternations between lawn and 'string' vegetation at the point of sampling. Three contiguous 80cm x 19cm diameter plastic pipes, were sunk in the peat to uniform depth then subsequently dug out, sealed with solid dishes at each end and transported to the laboratory. Two of the three cores have been used to provide 4cm and 2cm thick slices for high precision ^{14}C dating, subsamples of hand-picked Sphagnum leaves and stems for AMS ^{14}C dating, near surface samples for direct gamma assay of ^{210}Pb, ^{137}Cs and ^{241}Am activity and for magnetic measurements, and a suite of samples for pollen concentration analysis. The stratigraphic notes, profiles of magnetic mineral concentrations and plots of depth versus cumulative dry mass, confirm that, for present purposes, the two cores used can be regarded as one. The third, at present, remains unopened.

LAKE SEDIMENTS: RESULTS AND DISCUSSION

Figure 1 summarises the results of the AMS ^{14}C measurements completed so far. No dates on hand-picked fractions are younger than the real ages. The best dates in both samples are, surprisingly, derived from the finest residual particulate fraction. The birch fruit found in the younger sample provides an age range (1 sigma), overlapping the true age. The other components extracted, do not provide a consistent basis for accurate dating over this time interval. The plant fragments (which include angular labiate-type stems, in all likelihood from reedswamp or fen vegetation) in the younger sample, the cladoceran remains in both, as well as the egg capsules in the older sample, provide ages that are too old. These results suggest that even in a soft water lake, 'reservoir' effects preclude the use of aquatic organic material for dating with the accuracy required in this recent time interval. The finest detritus, which has provided the best dates, is thought to be allochthonous but this requires confirmation. More work is required on the apparent age and origin of organic matter in accurately dated sediments from a range of lake types.

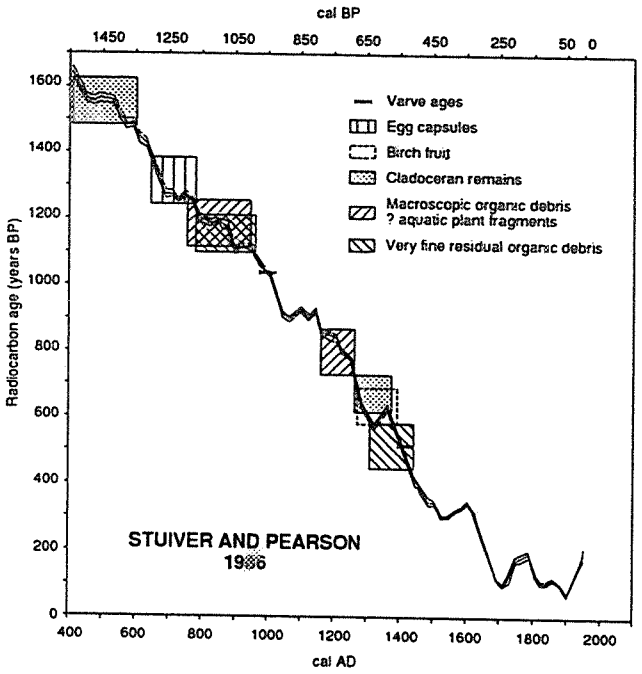

Figure 1. AMS ^{14}C dates on selected fractions from annually laminated sediments from Kassjön, N. Sweden, compared with varve age.

The palaeomagnetic results obtained from the Kassjön sediments are not yet entirely satisfactory. The strength of the NRM, the consistency of the vectors during AF demagnetization and the credibility of most of the inclination measurements for the latitude of the site all indicate the potential of these sediments for testing the pattern of recent palaeosecular variation against the known record, and evaluating this approach to dating (cf. Molyneux *et al.*, 1972). The main challenge is to improve the method used to extract the samples from the core, and work continues to this end. It is difficult to extract samples which record vectors with the degree of accuracy and precision required to provide chronologies over short time intervals where the amplitude of palaeosecular variation is small.

Samples for ^{32}Si analysis have been digested and both biogenic and non-biogenic silica fractions extracted. These samples will be milked for ^{32}P, the β-emitting daughter product of ^{32}Si. Activity will be counted on a dedicated low background detection system in the Physical Research Laboratory, Ahmedabad. The results of this work, which was funded by an additional NERC 'Small Grant', should be available in some 9-12 months. Before there is any prospect of using ^{32}Si as a dating technique for lake sediments, it will be necessary to show that the measurements on the samples of biogenic material (largely diatom frustules) from Kassjön form a monotonic series indicative of a half-life compatible with recent experimental determinations (between ~110 and 175 years).

Work on ^{226}Ra has proceeded to the point where

extraction techniques have been tested and preliminary measurements of ^{226}Ra activity made using alpha spectrometry. These investigations have shown the decay of ^{226}Ra activity in the biogenic fraction of the lake sediments to be complicated by supported ^{226}Ra input from the detrital component. The next stage will be to use a combination of alpha and low background gamma spectrometry to establish the activity ratios between ^{226}Ra and its parents, with a view to calculating the unsupported ^{226}Ra activity and determining the extent to which variations down core are compatible with the known age of the samples and the half-life of ^{226}Ra (~1600 years).

Preparation of the samples selected for tephra analysis has failed to reveal any evidence for Icelandic tephra deposition at the site. This may reflect failure of tephra to reach this northerly site in recognizable quantities.

THE PEAT PROFILE : RESULTS AND DISCUSSION

At the outset, the only approach considered likely to provide a detailed chronology for the period involved 'wiggle matching' (cf. Clymo *et al.*, 1990) ^{14}C 'dates'onto the dendrocalibration curve of Stuiver & Pearson, (1986). The main aim was to shed light on the relative merits of AMS and high precision dates. In the former case, statistical counting uncertainties are greater, but organic matter can be picked from the peat to reduce error arising either from rootlet penetration or from the time transgressiveness of a horizontal slice across sloping stratigraphic boundaries. In the latter case, these two sources of uncontrolled 'environmental' error are greater, but so is the statistical precision of the date. ^{241}Am and ^{210}Pb

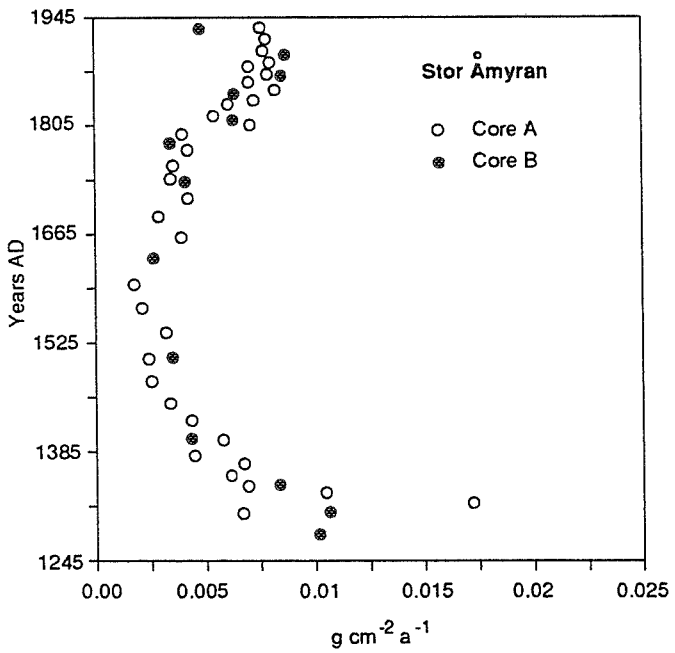

Figure 2. Net, residual, dry-mass 'accumulation' rates derived from a six knot cubic spline model fitted to the ^{14}C dates from Stor Åmyran, N. Sweden.

measurements were used to constrain the ^{14}C-based chronologies near the top of the profile. Close comparison of the AMS and high precision dates on 4cm slices across the transition to post-bomb peat at c. 22cm shows that the latter are much more strongly affected by downward penetration of bomb-carbon, presumably in rootlets. This process may also account for some the discrepancies between AMS and high precision dates lower down the profile.

In the first suite of samples measured, contiguous 4cm slices from Core B were used in order to meet the requirements for maximum precision. This sample interval proved is too coarse to allow the 'wiggles' to be matched. A second set of samples at 2cm intervals were subsequently submitted for high precision measurement from Core A, and provided dates with standard errors intermediate between the earlier ones and the AMS measurements. There are many ways of treating the total data set, but for present purposes, all the dates from both cores have been used to develop a time - depth and net residual mass accumulation model derived from a six-knot cubic spline optimized by simplex and illustrated in Figure 2. All calculations, whether model-based or more 'subjective', and whether based on either core or both, point to rates of net organic matter accumulation much lower between c. 1450 and 1700 AD than above or below. The rates above may be influenced by gradients in the decomposition of organic matter across the acrotelm/catotelm boundary, but the comparison with the rates below is independent of such influences. The period of low net accumulation includes most of the period of consistently depressed spring-summer temperatures (~1570 - 1750 AD) in Briffa's (1992) analysis of the N. Fennoscandian tree ring records.

The mass accumulation rates generated by the model in Figure 2, have been used along with determinations of Pinus and Picea pollen mass concentration to test the approach to peat chronology between dated horizons described by Middeldorp (1982). Our calculations suggest that neither provides a reliable basis for intercalating a chronology between dated horizons (Figure 3).

CONCLUSIONS

For non-varved lake sediments which lack a sufficiently detailed tephrochronology, our results would point to a combination of AMS radiocarbon dating on well preserved and demonstrably terrestrial plant microfossils (where present in sufficient quantities at enough depths), coupled with palaeomagnetic secular variation studies (where the quality of both the record and the subsampling and measurement techniques meet the highest standards), as the best approach to establishing detailed chronologies for the last millennium. Further evaluation of different organic fractions in sediments, progress in testing ^{32}Si and ^{226}Ra as dating methods, and further refinement

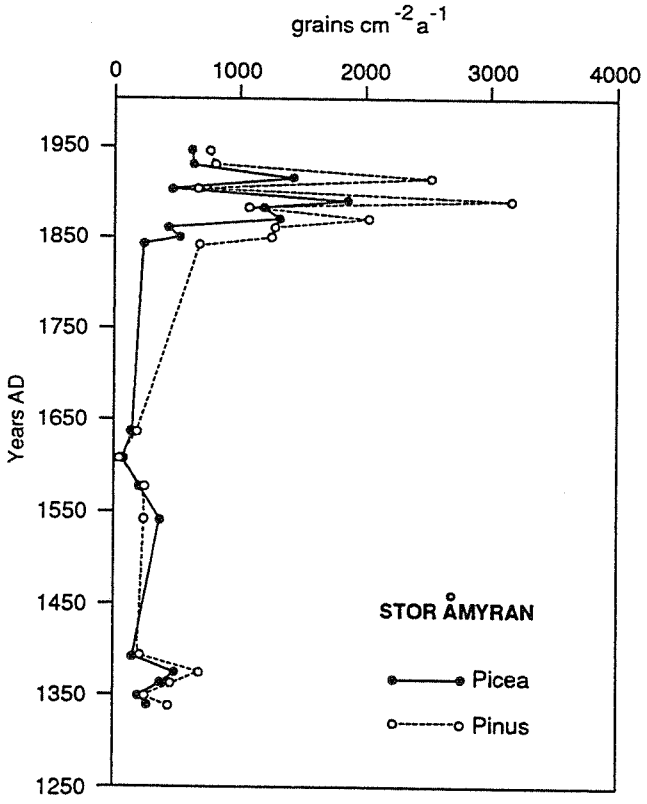

Figure 3. Pollen accumulation rates for samples from Core A, Stor Åmyran, N. Sweden.

of luminescence-based chronologies may eventually improve the situation.

In the case of recent, weakly humified *Sphagnum*-rich peats accumulating at or around 1m per millennium, the best approach to detailed chronology would appear to be AMS ^{14}C dates on contiguous 2cm slices. These would combine the required level of resolution with the advantages of dating selected material chosen to exclude time transgressive components. The high cost of such an approach could be justified in part by the information on net mass (hence carbon) balance to be gained from suites of detailed measurements - information of interest in analyses of biotic responses to and feedback in global climate change models. Lack of well preserved *Sphagnum* remains, or slower rates of peat accumulation, could limit the success of this or, for the time being, any other approach to detailed dating. Increased precision in AMS ^{14}C dates would greatly enhance the power of the approach proposed.

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