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TESTING THE USE OF BOMB RADIOCARBON TO DATE THE SURFACE LAYERS OF BLANKET PEAT

M H Garnett

NERC Radiocarbon Laboratory, East Kilbride, United Kingdom. Corresponding author. Email: m.garnett@nercrcl.gla.ac.uk.

A C Stevenson

University of Newcastle-Upon-Tyne, Newcastle-Upon-Tyne, United Kingdom.

ABSTRACT. The recently formed surface layers of peatlands are archives of past environmental conditions and can have a temporal resolution considerably greater than deeper layers. The low density and conditions of fluctuating water table have hindered attempts to construct chronologies for these peats. We tested the use of the radiocarbon bomb pulse to date recently accumulated peat in a blanket mire. The site was chosen because the peat profiles contained independent chronological markers in the form of charcoal-rich layers produced from known burning events. We compared chronologies derived from accelerator mass spectrometry ^{14}C analysis of plant macrofossils against these chronological markers. The bomb ^{14}C-derived chronologies were in broad agreement with the charcoal dating evidence. However, there were uncertainties in the final interpretation of the ^{14}C results because the pattern of ^{14}C concentration in the peat profiles did not follow closely the known atmospheric ^{14}C record. Furthermore, samples of different macrofossil materials from the same depth contained considerable differences in ^{14}C. Suggested explanations for the observed results include the following: i) minor disturbance at the site, ii) in-situ contamination of the ^{14}C samples by carbonaceous soot, and iii) differential incorporation of plant material during blanket peat growth.

INTRODUCTION

Peatlands are archives of past biodiversity, climate, and other environmental conditions (Barber 1993). The recently formed surface layers of peatlands are an archive for recent environmental information and offer an opportunity to understand how environmental conditions have been recorded in peat profiles by relating the proxy signals in the peat to recent historical records. Since they have not undergone the same decay and compression, the temporal resolution of surface peats can be considerably higher than deeper layers.

Several techniques are available for dating the surface layers of peats but are frequently hindered due to the low density of the peat and conditions of fluctuating water tables. For example, ^{210}Pb has been used successfully at some peatlands (e.g. Appleby et al. 1997), while at others the technique has failed due to mobility of the Pb (Oldfield et al. 1995). Other radiometric techniques, such as the peak in ^{137}Cs produced by nuclear weapons tests, have similarly proved unreliable due to mobility (Appleby et al. 1997). Although the historical deposition of pollutants such as Pb and Cu has been recorded in peat profiles, these have also been suspected of suffering from post-depositional migration (Clymo et al. 1990); these problems have also affected magnetic profiles (Clymo et al. 1990). The possibility of pollen migration in the low-density surface layers of peats has been demonstrated by Clymo and Mackay (1987), who question the chrono-stratigraphic value of changes in pollen composition in surface peats. Clearly, there is a need for more reliable methods to date the surface layers of peats.

DATING PEATS USING THE ^{14}C BOMB RECORD

Nuclear weapons tests in the 1950s–60s produced enough radiocarbon (bomb ^{14}C) to double the atmospheric content of ^{14}C. Long-term measurements of atmospheric ^{14}C have revealed a distinctive trend with a rapid ^{14}C increase from the late 1950s followed by a peak around 1963 (Levin and Hesshaimer 2000). Subsequently, atmospheric ^{14}C concentrations declined as the isotope dispersed into other components of the C cycle (Levin and Hesshaimer 2000).

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Goodsite et al. (2001) showed the potential of the bomb ^{14}C pulse for dating the surface layers of peats. The technique relies on the fact that stratified peat profiles provide a record of the plants that formerly grew on the mire surface. As the ^{14}C concentration in plant structures reflects the ^{14}C content of the atmosphere at the time of photosynthesis, stratified peat profiles contain a record of past atmospheric ^{14}C concentration. Since large changes in atmospheric ^{14}C occurred as a result of the bomb tests, it should be possible to calibrate the ^{14}C values of the recently formed peat by matching against the record of atmospheric bomb ^{14}C.

Although Tolonen et al. (1992) showed that the bomb ^{14}C pattern was recorded in peat stratigraphy, it was not successfully utilized for chronological purposes until the study on raised mires by Goodsite et al. (2001). No similar study has been performed on blanket peat, yet these peatlands are far more extensive in the UK than raised mires (Immirzi et al. 1992), and provide an important palaeoecological resource. In the present study, we aimed to test whether the bomb ^{14}C pulse could be used to derive chronologies for the surface layers of a blanket peat.

In the test, we compared a bomb ^{14}C-derived chronology with independent chronological markers in the same profile. A site in northern England presented a rare opportunity for this study because suitable independent chronological information had been recorded in the peat profile.

THE HARD HILL EXPERIMENT

The experiment at Hard Hill, Moor House (Figure 1) was established in 1954 to investigate the effects of moorland burning and grazing on the vegetation of mires (for site details, see Garnett et al. 2000). Replicated experimental plots have been treated to different moorland burning regimes for ~50 yr. Since we know the date of all burning events at the site, identification of charcoal layers in the stratigraphy provides an independent dating framework with which to assess the bomb ^{14}C signal.

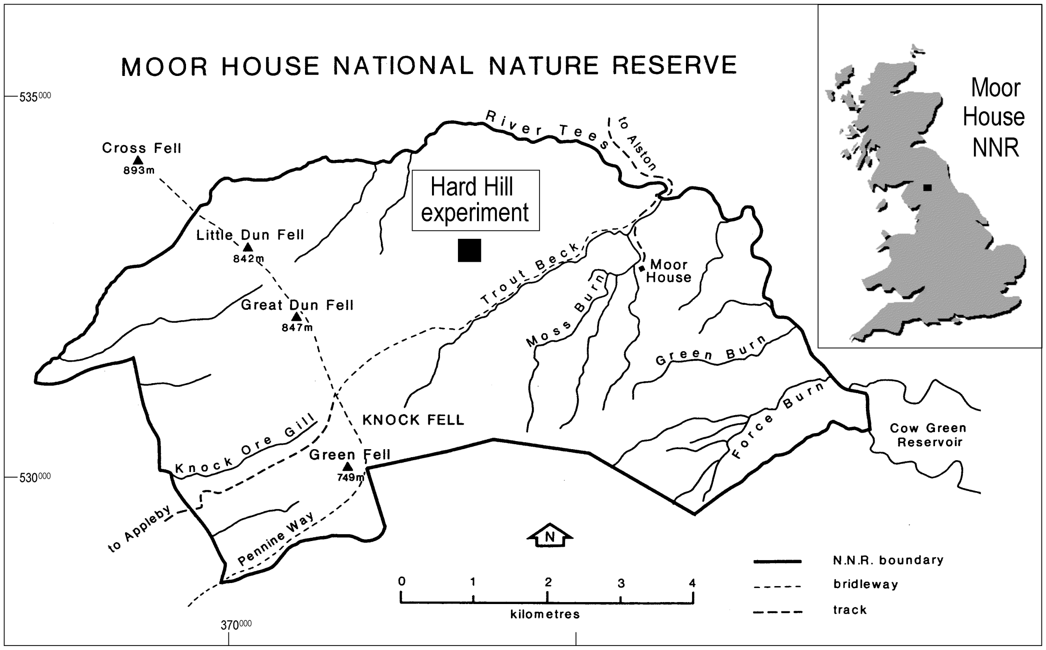

Figure 1 Location of the Hard Hill site within Moor House National Nature Reserve, northern England

All plots at Hard Hill were burnt at the start of the experiment in 1954 and, therefore, all should have a charcoal-rich layer formed as a result of this burning event. Plots which have continued to be burnt at decadal intervals ("burnt" plots) have diminished peat accumulation (Garnett et al. 2000). However, plots which have not been burnt since 1954, and lying adjacent to "burnt" plots, have received pulses of charcoal which have been recorded in the stratigraphy of the surface peat.

METHODS

We recorded the abundance of charcoal fragments in the profiles of 2 plots, one upwind and one downwind (in terms of the prevailing wind) of plots which have been burnt every 10 yr. We also determined the profile of spheroidal carbonaceous particles (SCP). These particles are produced by high temperature combustion of coal and oil and the profile of SCP concentration in sediments reflects regional industrialization; rapid increases in the concentration of SCP have been shown to occur in lake sediments formed in the 1950–60s in this region (Rose et al. 1995). By combining the charcoal and SCP evidence, we determined independent dating points against which we could compare a bomb ^{14}C-derived chronology.

Peat cores were collected in 1997 from 2 lightly sheep-grazed plots which had been burnt in 1954 only. Site A was immediately adjacent and downwind (i.e. to the north-east) of a plot burnt every 10 yr from 1954 and Site B (located ~200 m from Site A) was adjacent but upwind (i.e. to the south-west) of the nearest regularly burnt plot. One short peat core (diameter 10 cm and depth 21 cm) was retrieved from each of the 2 plots, with the coring locations being determined randomly.

The cores were collected by pushing a circular plastic tube into the peat surface and then removing by careful digging. The cores were retained in their tubes, sealed in plastic bags, and returned to the laboratory. A piston device was used to vertically extrude the cores, 1 cm at a time. Each cm of extruded peat was sliced off with a sharp knife, wrapped in aluminium foil, and stored in a refrigerator (~2 °C). A small amount of compression of the peat was observed during coring but was restricted to the surface few cm of the cores.

Rhodes (1998) method was used to quantify charcoal and was performed on sub-samples from each contiguous 1-cm section. After treating the sub-samples, the fragments of charcoal were counted using a microscope (Wild M3Z, Heerbrugg, Switzerland) at 40× magnification. A 10 × 10 square grid graticule was used to group the fragments according to size. SCP were enumerated in the same samples.

Plant macrofossils were selected for ^{14}C analysis at depth intervals which were expected to span the bomb ^{14}C pulse. *Sphagnum* macrofossils were preferentially sought, but where these were scarce, other above-ground plant macrofossils such as seeds and small fragments of heath species (*Erica sp./Calluna vulgaris*) were used. All moss samples were pretreated with a weak acid wash (1 M HCl) and heath fragments subjected to acid-alkali-acid pretreatment (2 M HCl, 1 M KOH, 1 M HCl). All samples were combusted in quartz tubes (900 °C) and prepared as graphite at the NERC Radiocarbon Lab and analyzed using accelerator mass spectrometry (AMS).

RESULTS

Charcoal and SCP Records

Figures 2 and 3 display the profiles of charcoal and SCP concentration in the samples from the study sites. The sites have very different charcoal profiles considered to be a result of Sites A and B being located respectively downwind and upwind of burnt plots; Ohlson and Tryterud (2000) have shown that by far the greatest charcoal deposition occurs either within or immediately downwind of the area of the burn.

Site A

The top 12 cm of the profile from Site A contained much charcoal, as expected, because the site is adjacent and downwind of a plot burnt every 10 yr from 1954. The profile has distinct and regularly spaced peaks in charcoal. Since the most recent burn to have occurred actually on Site A was in 1954, we consider that this event is represented at 11–12 cm because this depth contains the greatest number of large charcoal fragments (indicating a very local fire). It is more likely that the smaller peaks in charcoal concentration above the 11–12 cm depth were produced by burns located near, but not on, the sampling site because large charcoal fragments were less abundant. We considered that these peaks in charcoal concentration represent the decadal burns of the adjacent plot.

The rapid increase in SCP concentration occurred at 8–10 cm depth, slightly above the 1954 charcoal layer. The SCP results are, therefore, consistent with the charcoal evidence; the rapid increase (1950–60s; Rose et al. 1995) occurs above the 1954 charcoal layer but has ceased at 8 cm, just above the layer interpreted as the 1965 charcoal layer (Figure 2). By combining the charcoal and SCP evidence, we considered that the peat profile at Site A provided 4 independent dating points (Figure 2).

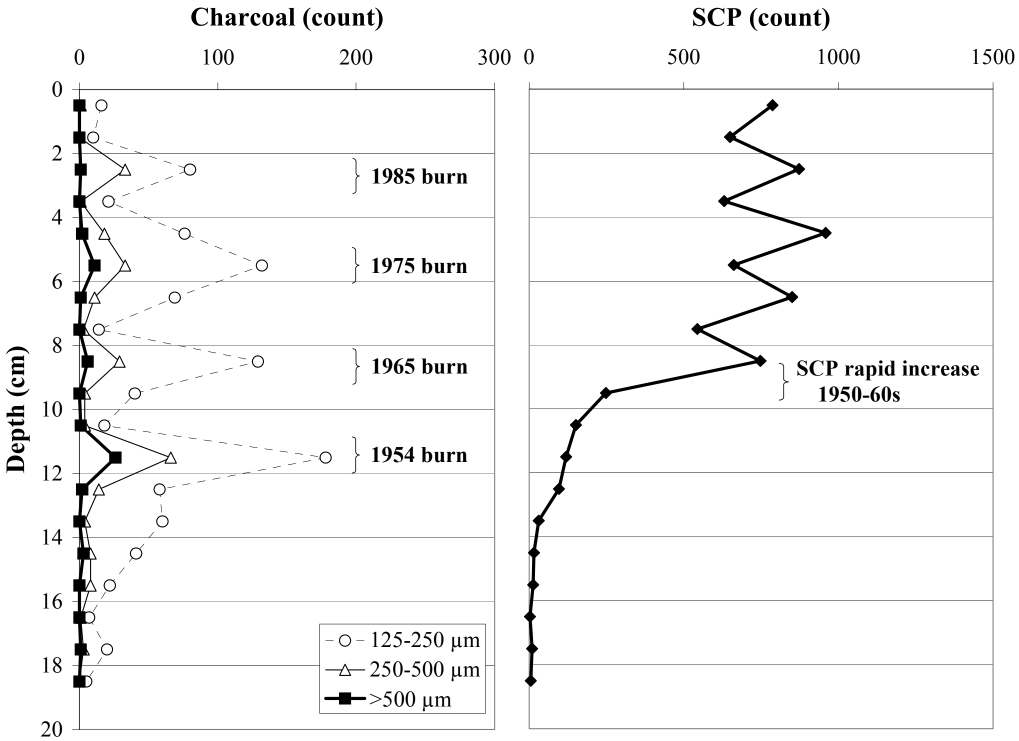

Figure 2 Concentration of different size classes of charcoal fragments and SCP concentration with depth, for Site A

Site B

Depths 9–10 cm and 12–13 cm contained the greatest quantities of large charcoal fragments, indicating a local fire, whereas there was an absence of large fragments above 9–10 cm depth (Figure 3). Since this site was last burnt in 1954, we consider that the most recent layer of large charcoal fragments (9–10 cm) represents the 1954 burn, and that the deeper charcoal-rich layer represents an earlier fire. This interpretation implies that, although the plot was adjacent to sites which have been burnt every 10 yr since 1954, these fires have not been recorded as distinct charcoal layers, probably because Site B lies upwind of the burnt plots.

The SCP concentration at Site B rapidly increased in depths immediately above the 9–10 cm layer, supporting our interpretation that the layer of large charcoal fragments at 9–10 cm represents the 1954 burn. Thus, the peat profile at Site B provided 1 dating point from the charcoal and SCP results (Figure 3).

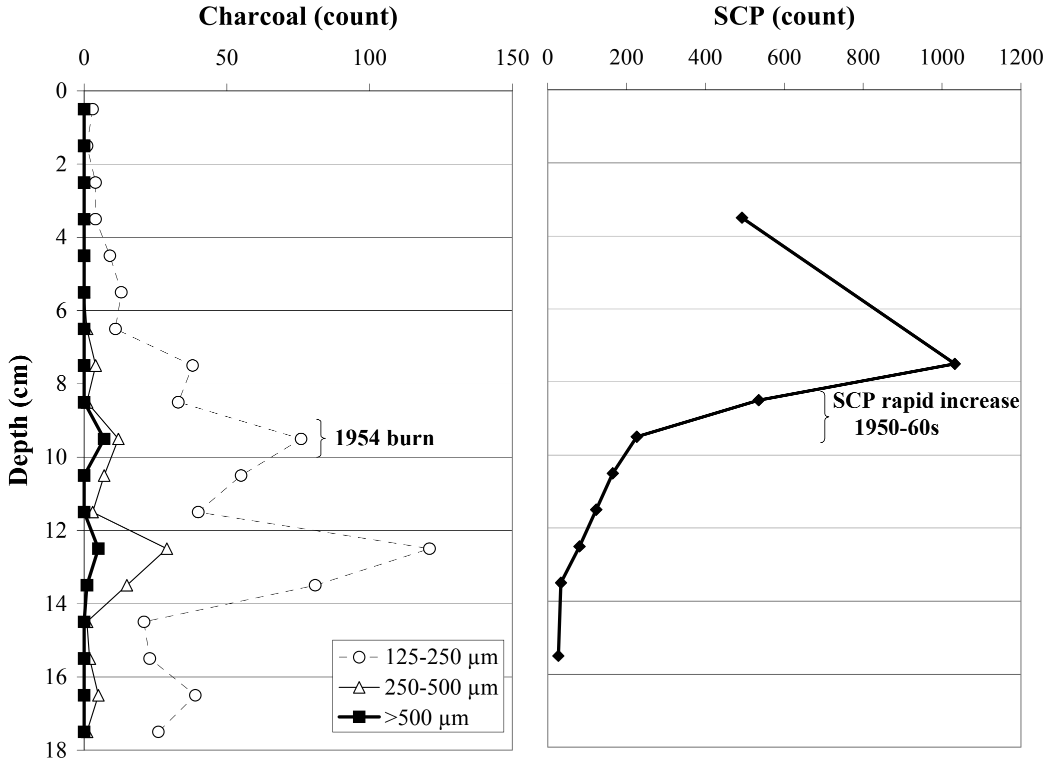

Figure 3 Concentration of different size classes of charcoal fragments and SCP concentration with depth, for Site B

^{14}C Results

Tables 1 and 2 present the ^{14}C results for Sites A and B, respectively. Samples from nearest the peat surface contained bomb ^{14}C (i.e. >100 pMC), whereas samples from below the 1954 charcoal layer had ^{14}C concentrations <100 pMC.

To convert the ^{14}C results to calendar ages, we used a database of atmospheric ^{14}C measurements from the Northern Hemisphere compiled from various sources (Baxter and Walton 1971; Levin and Kromer 1997; Nydal et al. 1980; Walton et al. 1970). We adopted the following calibration procedure: samples with a ^{14}C concentration >100 pMC were matched directly to the atmospheric ^{14}C record. In most cases, this yielded 2 solutions, one either side of the peak in bomb ^{14}C. To determine which of the 2 solutions was more likely, we considered the ^{14}C results for samples from adjacent

Table 1 Details of ^{14}C analyses for Site A.

Publication code	Depth (cm)	Material	^{14}C enrichment (pMC ± 1 σ)	^{14}C age BP ± 1 σ (if applicable)	$\delta^{13}C_{PDB}$ ± 0.1‰
AA-49834	3–4	*Calluna/Erica* leaves/stems	126.83 ± 0.71	—	–27.7
AA-42454	5–6	*Calluna/Erica* fragments	136.16 ± 0.51	—	–28.2
AA-49835	6–7(a)	*Calluna/Erica* leaves/stems	120.92 ± 0.86	—	–28.0
CAMS-91938	6–7(b)	Seeds (95%) and *Calluna/Erica* leaves	101.78 ± 0.35	—	–26.8
AA-42455	7–8	*Calluna/Erica* fragments	135.87 ± 0.55	—	–30.9
AA-42456	9–10	*Calluna/Erica* fragments	112.28 ± 0.48	—	–29.4
AA-42457	11–12	*Calluna/Erica* fragments	96.50 ± 0.44	286 ± 37	–29.1
AA-42458	13–14	*Calluna/Erica* fragments	97.96 ± 0.46	165 ± 38	–28.5

Table 2 Details of ^{14}C analyses for Site B.

Publication code	Depth (cm)	Material	^{14}C enrichment (pMC ± 1 σ)	^{14}C age BP ± 1 σ (if applicable)	$\delta^{13}C_{PDB}$ ± 0.1‰
AA-48953	3–4	Moss leaves	112.33 ± 0.55	—	–28.5
AA-48954	5–6	*Calluna*/*Sphagnum* leaves	136.12 ± 0.58	—	–29.2
CAMS-91936	6–7	Moss leaves and *Calluna*/*Erica* leaves	131.50 ± 0.58	—	–28.7
AA-48955	7–8	*Calluna* leaves and flower heads	130.91 ± 0.57	—	–28.2
AA-48956	9–10	*Sphagnum* leaves/stems	119.76 ± 0.54	—	–27.7
CAMS-91937	10–11	*Sphagnum* leaves	99.40 ± 0.46	50 ± 40	–26.7
AA-48957	11–12	*Sphagnum* leaves	90.95 ± 0.50	762 ± 44	–27.5

depths, and in most cases, could eliminate one of the solutions by assuming that samples from deeper in the peat profile would be older.

Calibration of the 2 samples located nearest the bomb ^{14}C peak was less straightforward. These samples had calibration solutions which fell either side of the bomb peak, and it was not possible to discount one of the solutions simply using the ^{14}C results. In such instances, we considered the rate of peat accumulation which would need to have occurred to result in the alternative calibration solutions. For both sites, only the calibration of these samples shown in Figures 4 and 5 resulted in realistic peat accumulation rates. For example, depths 5–6 cm and 7–8 cm at Site A could be interpreted to be the same age, however, this would imply unrealistic peat accumulation rates of 2 cm yr^{-1}; the only realistic interpretation resulted when the calibrated ages were split either side of the bomb peak.

Three ^{14}C results could not be calibrated against the atmospheric curve when considered with the other samples from the same profile. For Site A, 2 samples of different materials from the same slice of peat (6–7 cm depth) had very different ^{14}C concentrations, both of which were lower than the results for adjacent depths. Calibration of these samples could be performed by independently matching their ^{14}C concentrations to the atmospheric record, giving ages of AD 1960/1984 for the heath fragments and AD 1956 for the seeds. An age of AD 1984 is considered very unlikely for the heath fragments at 6–7 cm since it would make this depth layer younger than layers nearer the surface. Given typical peat accumulation rates of ~10 yr cm^{-1} (Clymo 1991), it is conceivable that different types of macrofossils selected from a 1-cm layer of peat could be at least 4 yr different in age, as in the 6–7 cm layer at Site A. However, when considered in conjunction with the ^{14}C results for the adjacent depths at this site, neither of the samples from depth 6–7 cm could be fitted to the atmospheric record, and, therefore, neither were used in the chronology that we have interpreted for this site.

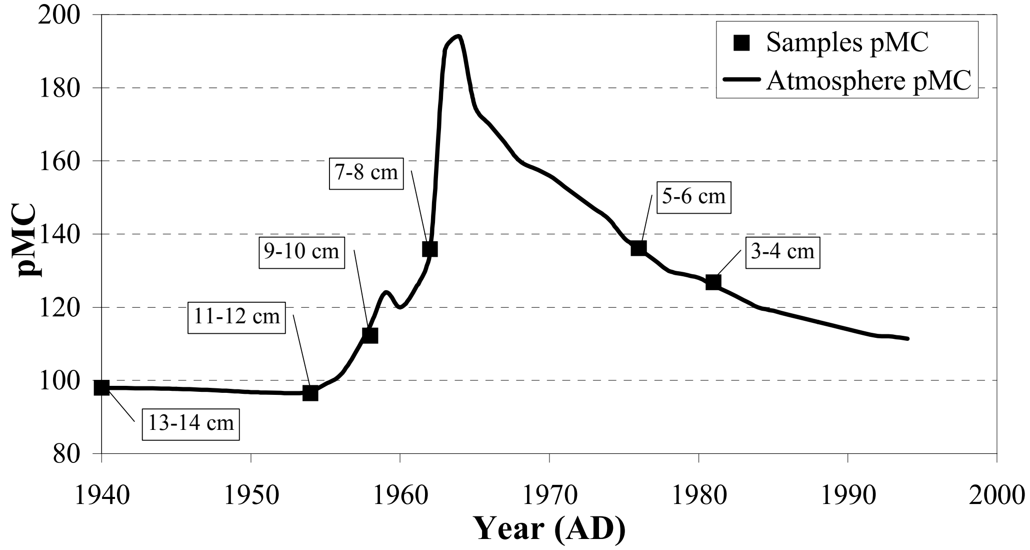

Figure 4 Calibration of ^{14}C AMS results for Site A. The chart shows our best interpretation of the results when matched to the atmospheric ^{14}C record. The symbols are larger than the 2-σ error of the ^{14}C measurements.

For Site B, the samples at depths 7–8 cm and 6–7 cm had very similar ^{14}C concentrations, both of which were lower than the sample at 5–6 cm. To calibrate these results, we again considered peat accumulation rates and chose the interpretation that resulted in more consistent rates of accumulation, rather than an alternative solution which implied very large variations in accumulation rate. Thus, we interpreted the sample at 7–8 cm to be AD 1962, and did not use the result for 6–7 cm in our final chronology (Figure 5). If we had used the result for depth 6–7 cm instead, this would have required much greater changes in peat accumulation rate over the depths between 6–10 cm; we have no stratigraphic evidence to support rapid changes in peat accumulation for this section of the profile.

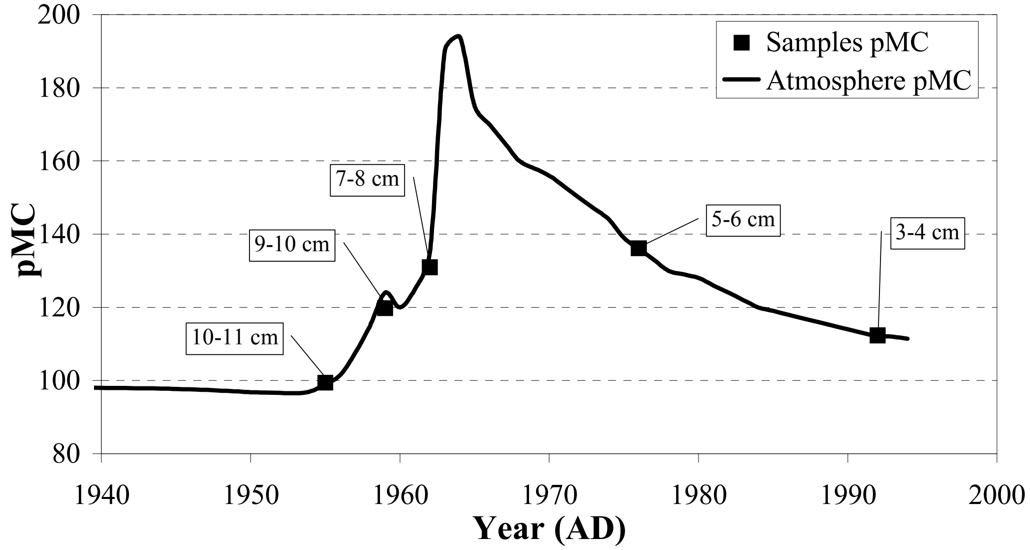

Figure 5 Calibration of ^{14}C AMS results for Site B. The chart shows our best interpretation of the results when matched to the atmospheric ^{14}C record. The symbols are larger than the 2-σ error of the ^{14}C measurements.

We matched samples with ^{14}C concentrations slightly less than 100 pMC to our atmospheric ^{14}C record, but because variations in pre-bomb ^{14}C were small, these calibrations have greater uncertainty. For Site A, the ^{14}C content of the sample from 11–12 cm (96.50 ± 0.44 pMC) best matched with a date of AD 1953 in our ^{14}C database, but was also calibrated using INTCAL98 (Stuiver et al. 1998) to cal AD 1520–1660 (1 σ). Since the ^{14}C concentration of the deeper sample at 13–14 cm [97.96 ± 0.46 pMC; cal AD 1660–1950 (1 σ)] was greater than at 11–12 cm, we consider that the AD 1953 date was the best interpretation for the 11–12 cm layer. Therefore, we consider that the 11–12 cm depth represents the period when the Suess effect had caused greatest depletion of atmospheric ^{14}C, immediately prior to the rapid ^{14}C increases caused by bomb testing. Although we suggest in Figure 4 that the sample at 13–14 cm represents AD 1940 (since this is the best match on our database of atmospheric ^{14}C), we have no evidence to determine whether this date or the INTCAL98 calibrated date is better. The deepest sample from Site B had a much lower ^{14}C concentration than the other samples, and was calibrated using INTCAL98 to cal AD 1220–1290 (1 σ).

Our interpretations of the ^{14}C results are shown in Figures 4 and 5. Although we acknowledge that other interpretations are possible, we consider our interpretations are best when based solely on the ^{14}C results.

DISCUSSION

It is difficult to test new methods for dating surface peats because many of the existing dating techniques which could be used to validate a new technique have themselves been shown to be unreliable. In the present study, the Hard Hill site presented a rare opportunity because it contained suitable independent dating evidence which we consider to be reliable; the large size and distinct peaks in concentration strongly suggests the charcoal is not mobile.

Figure 6 shows the age-depth relationship derived using the bomb ^{14}C chronology for Sites A and B. The independent charcoal-dated layers are also shown to allow comparison of the dating evidence. Our interpretation of the ^{14}C results produced a chronology that closely matched the independent chronology derived from the charcoal record; of the 5 charcoal layers, three were dated to within 1 yr of the known burning event using the bomb ^{14}C-derived chronology (Figure 6). The bomb ^{14}C-derived ages differed from the remaining 2 charcoal-derived ages by only 5 yr. These results show that bomb ^{14}C can be useful for dating the surface layers of blanket peat.

However, there were a number of problems encountered which introduced uncertainty to the results. No sample had a ^{14}C concentration >140 pMC, although atmospheric ^{14}C exceeded 190 pMC (Levin and Hesshaimer 2000). Macrofossils for ^{14}C analysis were picked from 1-cm-thick slices and would contain an average ^{14}C content for the number of years it took for 1 cm of peat to accumulate; Figure 6 indicates that peat growth rates were ~3–5 yr cm^{-1}. Therefore, we expected a greater peak in ^{14}C concentration of the macrofossils. Other causes of a "damped" ^{14}C signal in the peat include possible recycling of "old" carbon from decomposing peat (Tolonen et al. 1992) and contamination with SCP; these particles adhere strongly to macrofossils (Punning and Aliksaar 1997), are fossil fuel derived (would dilute the ^{14}C signal), and were abundant in levels where bomb ^{14}C should have been highest (Figures 2 and 3). ^{14}C analyses of macrofossils by Goodsite et al. (2001) approached 180 pMC; however, the raised mires in their study were more remote from large industrial areas (and therefore SCP sources) and accumulation rates were greater (~2.5 yr cm^{-1}).

Two samples of different macrofossil material were analyzed from depth 6–7 cm at Site A, and neither could be matched to the atmospheric ^{14}C record when considered with the other samples.

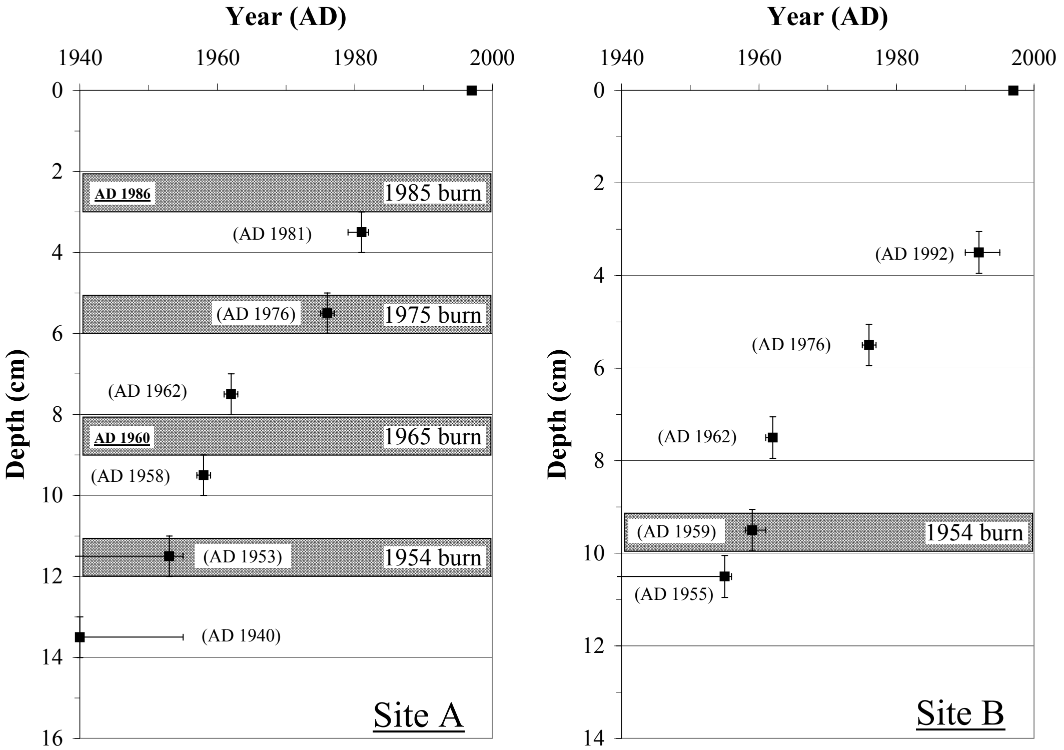

Figure 6 Age-depth relationship for Sites A and B based on the calibration of the ^{14}C results shown in Figures 4 and 5. Shading represents the layers with greatest charcoal concentration which have been dated by reference to the known record of burning. The calibrated ages for the ^{14}C samples are given in brackets. Horizontal error bars are 2-σ age ranges of the calibrated ^{14}C results and vertical error bars represent the sampling resolution (i.e. 1-cm slices). Linear interpolation of the ^{14}C results was used to calculate ages for two of the charcoal-rich layers, which had not been analyzed for ^{14}C (underlined).

Despite being from the same slice of peat, the samples had very different ^{14}C concentrations (~121 and 102 pMC). The ^{14}C differences could have been due to differences in the way the plant materials were incorporated into the accumulating peat at a time when atmospheric ^{14}C concentrations were changing rapidly, or may simply represent plant materials that grew over slightly different years but were ultimately compacted into the same 1-cm layer of peat. Alternatively, there may have been different levels of SCP contamination in the samples since Punning and Aliksaar (1997) found sorption of SCP to *Sphagnum* was (slightly) species dependent; the relative sorption of particles to the entirely different plant materials used in the present study is unknown but could well be greater than the differences between *Sphagnum* species. Also, the other dating results imply this depth relates to the 1960s to the early 1970s, a time when scientific activity at the site was intense; therefore, site disturbance may have been a factor. It is possible that some of the plant macrofossils used for ^{14}C analysis could have been blown in from an upwind disturbed site. However, unless they were from eroding peat, these macrofossils would have a similar ^{14}C concentration to the contemporary vegetation; there were no eroding peat surfaces close to the sampling sites when the cores were collected.

Sphagnum macrofossils were preferentially selected for ^{14}C analysis as recommended by Kilian et al. (1995) but also because *Sphagnum* leaves were considered likely to have a smaller in-built age compared to heath fragments. However, an additional source of uncertainty arose because in some depths the peat was highly decayed and *Sphagnum* macrofossils were scarce, meaning that alternative materials had to be used for ^{14}C analysis. Where only heath macrofossils were available, we selected fragments which would have the least in-built age. Heath species (e.g. *Calluna vulgaris*) can survive at least 25–30 yr (Hobbs and Gimmingham 1987). Yet, due to the rapid changes in ^{14}C associated with the bomb pulse, it would only require a few years of in-built age for the sample to have a ^{14}C content unrepresentative of the age of the peat layer. Despite taking precautions to avoid analyzing materials with in-built ages, the paucity of suitable dating material in some levels meant that heath fragments were the best material for analysis. The in-built age of these samples may explain some of the difficulties encountered when calibrating the ^{14}C results. However, for the 2 samples from depth 6–7 cm at Site A, it would be expected that the heath leaves/stems (6–7a) would have a greater in-built age than the seeds sample (6–7b), and, therefore, that the leaves/stems would have a ^{14}C content representative of a few years earlier than the seeds. In fact, when these samples were calibrated independently of the others, the results suggested that the seeds were older than the leaves/stems.

The burnt plot adjacent to Site A has been burned on 4 occasions following 1954 (i.e. 1965, 1975, 1985, 1994); however, there are only 3 charcoal peaks (in addition to the 1954 layer) in the charcoal record (Figure 2). Linear interpolation of the ^{14}C-derived chronology for Site A suggests that the charcoal produced in the 1994 burn should be located in the top 1 cm of the profile, but there is no peak in charcoal concentration for this layer (Figure 2). An explanation may be that the surface layer of peat has not yet undergone the same amount of decomposition as deeper layers. Also, whereas the peat decays, the charcoal does not. Therefore, with time, the relative concentration of charcoal will increase in a given weight of peat. Since as much as 90% of the organic matter entering the surface of a peat may be lost through decomposition (Clymo 1984), the effect would be to multiply the charcoal concentration up to a factor of 10. Therefore, as the peat which formed the surface 1-cm layer of the mire in 1997 is buried by subsequent peat growth and progressively decays, a charcoal peak representing the 1994 burn may become evident.

Peat accumulation rates and preservation of macrofossils can be much lower in blanket peats compared to raised mires (e.g. Goodsite et al. 2001). These conditions make blanket peats less suitable for dating using the bomb ^{14}C approach since lower accumulation rates dampen the ^{14}C signal and poor preservation means less suitable macrofossils are available for ^{14}C analysis. Despite these disadvantages, the results of the present study show that the bomb ^{14}C approach can be useful for dating the surface layers of blanket peats.

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