Quaternary Research 55, 223–234 (2001)
doi:10.1006/qres.2000.2190, available online at http://www.idealibrary.com on IDEAL®

Paleohydrological Records from Peat Profiles and Speleothems in Sutherland, Northwest Scotland

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Received December 22, 1998

Paleohydrological changes during the late Holocene are inferred from humification, testate amoebae, and pollen evidence from three blanket peat profiles in northwest Scotland. Replicate peat humification records from the Traligill basin share the same patterns of change for a 600-yr period of overlap between 1800 and 2400 cal yr B.P. The shared patterns, inferred from samples with a resolution of 5–13 yr, represent basinwide hydrological changes. In a nearby, but hydrologically separate, area with caves beneath peat, the luminescence emission wavelength measured in two speleothem samples correlated with the humification record in the overlying peat. This correlation implies that speleothem luminescence emission wavelength depends primarily on decay rates in the soils from which drip waters are derived, as long as there is no major change in soil or vegetation. The peat and speleothem records from the cave site further correlate with the peat records from the Traligill basin. Taken together, the records thus represent a regional climatic signal. Peaks in surface wetness replicated in two or more records occur at ca. 2300, 2090, 2030, 1820, 1600, and 1440 cal yr B.P. Further peaks occur at 800, 570, and 115 cal yr B.P. in the humification and stalagmite records that extend to the present day. Correlative changes have been observed, not only in other peat records from Scotland but also in ice accumulation at GISP2. These further correlations imply that precipitation regimes in Scotland and Greenland were in phase during the late Holocene.

INTRODUCTION

Inferred changes in the hydrological status of peatlands have been used as a proxy indicator of paleoclimatic change in the middle and late Holocene for many years. Early reconstructions sought to identify major shifts in past climate, but more recent work has provided continuous records of surface wetness changes through time in northwest Europe (e.g., Aaby, 1976; Barber, 1981; Blackford and Chambers, 1991; 1995; Barber *et al*., 1994; Tallis, 1995; Chambers *et al*., 1997). However, there have been no direct comparisons between the peat paleohydrology and other terrestrial proxies of paleoclimatic change.

One potential proxy for comparison with peat records is speleothem luminescence, because western Europe has a number of regions with caves as well as peat. It has been hypothesized that speleothem luminescence intensity and wavelength variations provide indices of paleoclimatic change by acting as a

0033-5894/01 $35.00

measure of dissolved organic matter derived from overlying soils (Shopov *et al.*, 1994; Baker *et al.*, 1996). Changes in the amount and composition of organic acids deposited on the speleothems from drip waters are reflected in the luminescence intensity and wavelength signals, respectively, of the speleothem (Baker *et al.*, 1997, 1998). A strong link between humification changes of overlying peat and speleothem luminescence has been shown for the Uamh an Tartair cave in Assynt, northwest Scotland (Baker *et al.*, 1999). However, the speleothem luminescence and peat humification records may still only represent changes over a limited area, which could result from local hydrological and vegetation changes rather than a regional paleoclimatic record.

This paper provides independent paleohydrological data from widely spaced replicate profiles from a Scottish peatland and compares these with the paleoenvironmental records of a nearby cave and its overlying peat. The main aim is to test the hypothesis that the records represent a regional paleoclimate record.

STUDY AREA

The Traligill basin (Fig. 1, National Grid Reference NC2720, 58°08′ N, 4°55′ W) is a peatland-dominated basin in the upper catchment of the River Traligill in Sutherland, northwest Scotland. Based on 1961–1990 averages, the climate is oceanic with >1900 mm rainfall, 250–270 rain days (>0.2 mm in a 24-h period), 4–6 snow days (snow lying at 0900 h), and an average 77% cloud cover annually. The peatland occurs on the flat area of the basin and covers approximately 5 ha and is bounded by mineral soils on sloping ground. The peatland area is a blanket mire dominated by dwarf shrubs (*Calluna vulgaris, Erica tetralix*), Cyperaceae (principally *Scirpus cespitosus* and *Eriophorum angustifolium*), and *Molinia caerulea*. *Sphagnum* cover is discontinuous and the dominant species is *S. capillifolium*, although a number of other species occur, particularly in localized wetter areas. The peatland has formed over a thin cover of glacial till that overlies the Cambro-Ordovician dolomite. An intermittent stream bisects the peatland into two separate areas. However, due to the high permeability of both the till and the bedrock, the stream flows only during wetter periods of the year. The surface of the peatland is ombrotrophic (dependent only on precipitation for its water supply), and the runoff from the peatland feeds the intermittent stream. About 300 m to the north and downslope from the Traligill basin, the dolomite is exposed and there are several cave entrances, including the Uamh An Tartair cave, which are overlain by mineral soils and by localized shallower peats in small pockets (generally less than 10 × 10 m).

The area was chosen for the study as it provides an opportunity to compare paleoclimate records from peat and speleothems. The speleothems and the overlying peat provide a record of hydrological change in and around the cave, and it can be shown that there is a strong relationship between speleothem luminescence wavelength and the degree of humification of the peat (Baker *et al.*, 1999). Because the peatland in the Traligill basin is hydrologically separate from the cave environment, it should provide an independent record of paleohydrological change with which to test the hypothesis that this is also a regional paleoclimatic record.

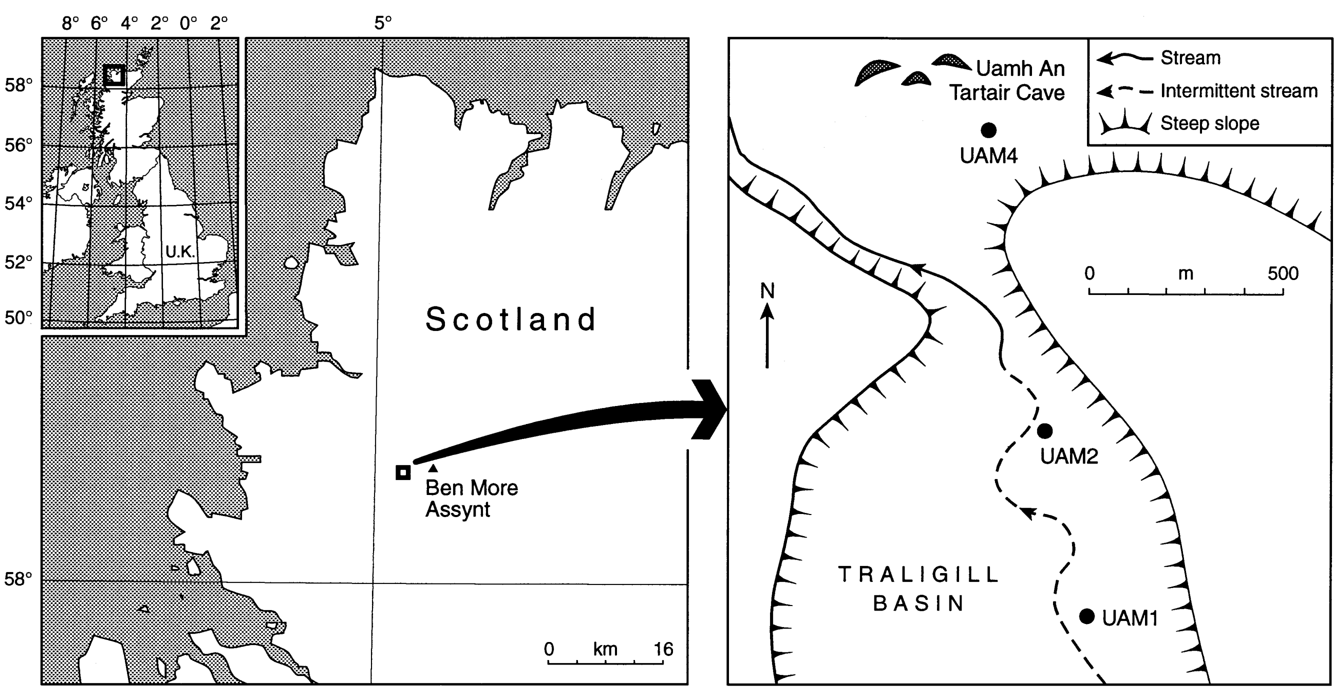

FIG. 1. Traligill basin and the location of the peatland samples and the cave from which speleothem records were obtained.

METHODS

Field Sampling

Two profiles (UAM1, UAM2), approximately 400 m apart, were sampled from exposures in the blanket peatland in the Traligill basin (Fig. 1). The faces were cleaned and sampled in $30 \times 10 \times 5$ cm monolith tins overlapping by 5 cm vertically. Both of these profiles were approximately 180 cm deep with a basal transition to the mineral substrate below. There were no clear stratigraphic changes in the profiles except in the top 20 cm, where surface roots and less decayed plant material were evident, and in the lower 20 cm, where mineral inclusions were present and the peat was blacker and had a more greasy texture. Where recognizable remains occur, they indicate that the peat is formed of *Sphagnum* and *Eriophorum* with occasional fragments of ericaceous wood. One profile from shallow peat immediately above the cave entrance was sampled from an excavated pit using similar techniques (UAM4). This profile extended to 84 cm, with the transition to mineral soil occurring at 76 cm depth. There were no identifiable plant remains in this profile except monocotyledonous roots in the top 10 cm, and the peat was black and highly decayed.

Laboratory Analyses

A variety of techniques are available for reconstructing past hydrological changes on ombrotrophic peatlands, including humification, plant macrofossil, and testate amoebae analyses, with pollen providing additional information on vegetation changes. Plant macrofossil analysis is most useful in raised peats where there is an established relationship between taxa and hydrology and where preservation is good (Barber, 1981). Thus far, the application of testate amoebae analysis has been limited mainly to raised mires (Aaby, 1976; Warner and Charman, 1994; Woodland *et al*., 1998) and intermediate raised/blanket mires (Hendon, 1998). In this study, while the main data are provided by humification, supplementary data are provided by pollen and testate amoebae analyses.

Because testate amoebae analysis is a relatively new technique, it is worth explaining the basis for the method in a little more detail. Testate amoebae inhabit a wide variety of wet soils and aquatic habitats. In peatlands the main control on species distribution is soil moisture, as the amoebae live within water films on the leaves and stems of bryophytes and vascular plants growing on the surface. Studies that relate environmental parameters to testate amoebae distribution often measure water table rather than soil moisture because water table is a more easily repeated measurement for which mean annual values can be produced (Woodland *et al*., 1998). The cell is contained within a shell (the test), which is preserved after death and can be used to identify the organism. A large range of taxa occurs in peatlands, and the main ones found in this study are illustrated in Figure 2, as examples.

Because initial results of TIMS (Thermal Ionization Mass Spectrometry) U–Th series analyses on the speleothem samples suggested that the record fell approximately within the period 1000–2500 cal yr B.P, analyses of the peat samples were focused principally on this time period. Based on a range-finding radiocarbon age of 2980 ± 60 ^{14}C yr B.P. (Beta-82198) for 120 cm depth in a profile from the same section as UAM2, analyses concentrated on the depth range 40–100 cm in UAM1 and UAM2. This decision had the advantage of avoiding problems associated with the incompletely decayed plant material in the upper peat layer (the acrotelm), where it is difficult to compare humification results. Within these sections, humification was measured in contiguous 0.5-cm-thick samples and testate amoebae were counted in contiguous 1-cm-thick samples. In addition, pollen and macrofossil analyses were carried out on contigous 1-cm-thick samples from UAM1. For UAM4, the potential age was unknown and humification was measured on 0.5-cm contiguous samples down to 63 cm depth, where significant amounts of mineral matter were evident. Pollen and testate amoebae analyses were also undertaken at 4-cm intervals on UAM4.

Humification measurements were carried out using a standard technique (Blackford and Chambers, 1993), where the degree of decay is determined colorimetrically in a spectrophotometer. Our results are expressed as a percentage of transmission through the sample so that high values represent low decay. Pollen preparations followed Moore *et al*. (1991), and all samples were counted to 500 total land pollen (TLP). Results are expressed as a percentage of TLP including mire taxa.

Testate amoebae preparations followed Hendon and Charman (1997), with counts continued until either 150 tests or 1000 *Lycopodium* spores had been reached. The hydrological indicator values of the main peatland taxa are now well known and these can be used to calculate inferred water table depths. The transfer function of Woodland *et al*. (1998) was used here as this training set is based on samples from throughout the mainland Britain and yields values for mean annual water table. Error estimates for predicted water table depths were calculated using WACALIB (Line *et al*., 1994) using 1000 bootstrap cycles.

The macrofossil analyses were undertaken following difficulties obtaining countable numbers of testate amoebae (see below) to assess the relationship between peat composition and testate amoebae concentration. Consequently, only small (2–3 cm^3) samples were analyzed using an ordinal five-point scale to assess the abundance of components. Luminescence variations in the speleothems were measured using an Elmer–Perkin LS-50B Luminescence Spectrophotometer with fiber optic extension (1 mm beam width), at 2 nm resolution in excitation wavelength and 0.5 nm resolution in emission wavelength. The maximum luminescence was recorded in terms of its emission and excitation wavelengths.

CHRONOLOGY

Identifiable above-ground plant material such as *Sphagnum* fragments were too infrequent to use for radiocarbon dating, so 14 bulk 1-cm-thick samples for radiocarbon analyses were submitted to the NERC Radiocarbon Laboratory for AMS analyses.

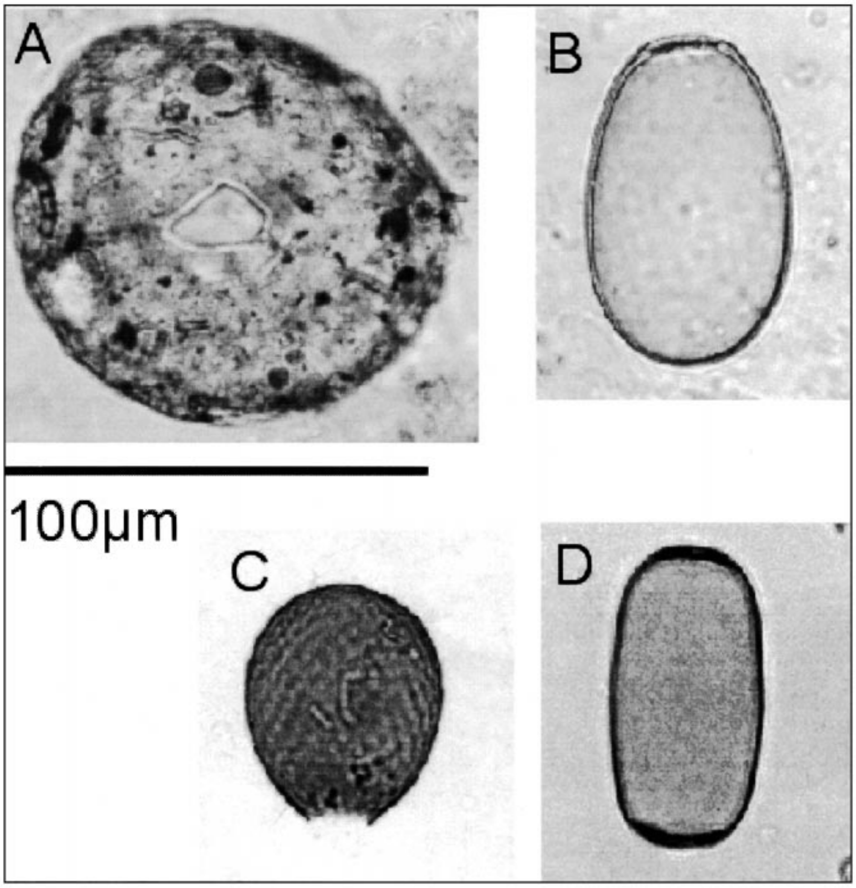

FIG. 2. Examples of testate amoebae found in Traligill basin peat. (a) *Trigonopyxis arcula*, an indicator of dry conditions. (b) *Hyalosphenia subflava*, a dominant taxon in the assemblages indicating very dry conditions. (c) *Assulina muscorum*, a cosmopolitan species. (d) *Amphitrema flavum*, indicative of moderately wet conditions.

Radiocarbon ages of all three profiles are given in Table 1. Radiocarbon ages were calibrated to the calendar time scale using CALIB Rev.3.0.3 (Stuiver and Reimer, 1993) using the decadal tree-ring calibration data set (Stuiver and Becker, 1993). Age–depth relationships were calculated using the median age of the 95% calibrated age range. UAM1 and UAM2 show linear age–depth relationships ($r^2 = 0.993$ and 0.997, respectively), and a second-order polynomial function was fitted to give the relationship for UAM4 ($r^2 = 0.998$). All dates in the text are quoted in cal yr B.P., rounded to the nearest 10 yr as recommended by Stuiver and Reimer (1993) unless otherwise stated.

Despite the potential problems of using bulk material for dating, the age estimates form coherent series in all the profiles. There are no age reversals or other indications of problems even where there is close vertical spacing of samples. Some of the 2σ calibrated age ranges do overlap. However, because the sample material is not ideal, in the comparison between records we emphasize the comparability of patterns of change rather than precise timing. The stalagmite chronology for stalagmite SU-2 was derived from five TIMS U–Th analyses using standard techniques (Edwards *et al.*, 1986). Annual lamination counting from the top of the sample (A.D. 1996) provided the chronology for SU-96-7.

Although we provide estimates for events in both peat and stalagmite records rounded to the nearest decade, we recognize that potential errors on these estimates are of the order of 100–200 years. This level of uncertainty must be kept in mind for the interpretations below.

HYDROLOGICAL CHANGE IN THE TRALIGILL BASIN

UAM1

The radiocarbon dates show that the 40- to 100-cm section of UAM1 dates to between ca. 1400 and 3000 cal yr B.P., giving an average accumulation rate of 26.7 cal yr cm^{-1}. The majority of pollen taxa did not display significant variability within the sampled section (Fig. 3). Humification values show a series of peaks (reflecting a wet surface) and troughs (reflecting a dry surface) with peaks at 2810, 2540, 2280, 2090, 2010, 1840, and 1470 cal yr B.P. Additional minor peaks are present as a group of

TABLE 1
Radiocarbon Dates from the Peat Samples, with Calibrated Age Ranges Calculated Using CALIB3.03 of Stuiver and Reimer (1993) and the Decadal Tree-Ring Calibration Data of Stuiver and Becker (1993)

Lab. code	Depth (cm)	Age (^{14}C yr B.P. $\pm$ 1σ)	$\delta^{13}C_{PDB} \pm 0.1‰$	Calibrated age and its midpoint (2σ range, in cal yr B.P. $\pm$ 2σ)
UAM1				
AA-26310	44	1595 ± 45	–27. 8	1590 (1470) 1350
AA-26311	58	1940 ± 45	–27. 7	1990 (1860) 1730
AA-26312	74	2245 ± 55	–27. 3	2350 (2235) 2120
AA-26313	84	2570 ± 50	–27. 7	2760 (2570) 2380
AA-26314	95	2705 ± 45	–27. 3	2920 (2830) 2740
UAM2				
AA-26315	50	1955 ± 45	–27. 7	1990 (1865) 1740
AA-26316	64	2065 ± 45	–27. 9	2150 (2025) 1900
AA-26317	84	2290 ± 45	–27. 9	2350 (2250) 2150
AA-26318	92	2325 ± 50	–27. 4	2430 (2295) 2160
UAM4				
AA-26319	12	25 ± 50	–29. 4	
AA-26320	20	135 ± 50	–29. 3	290 (145) 0
AA-26321	34	630 ± 50	–29. 0	670 (600) 530
AA-26322	47	1210 ± 45	–28. 9	1260 (1115) 970
AA-26323	62	2165 ± 50	–29. 4	2310 (2130) 1950

Note. Calibrated ages are quoted as the maximum 2σ age ranges rounded to the nearest decade with the midpoint age used for calculation of the age–depth relationships in parentheses.

three (1550, 1610, 1670 cal yr B.P.) and at 1770 and 1890 cal yr B.P. The pollen data show that the particularly low transmission values between the first of these two peaks are associated with a large increase in *Empetrum* pollen, supporting the inference that this was a dry period. The curves for *Calluna vulgaris* and Cyperaceae show a series of reciprocal peaks and troughs, which to some extent coincide with the changes in humification. High Cyperaceae values are associated with the humification peaks at

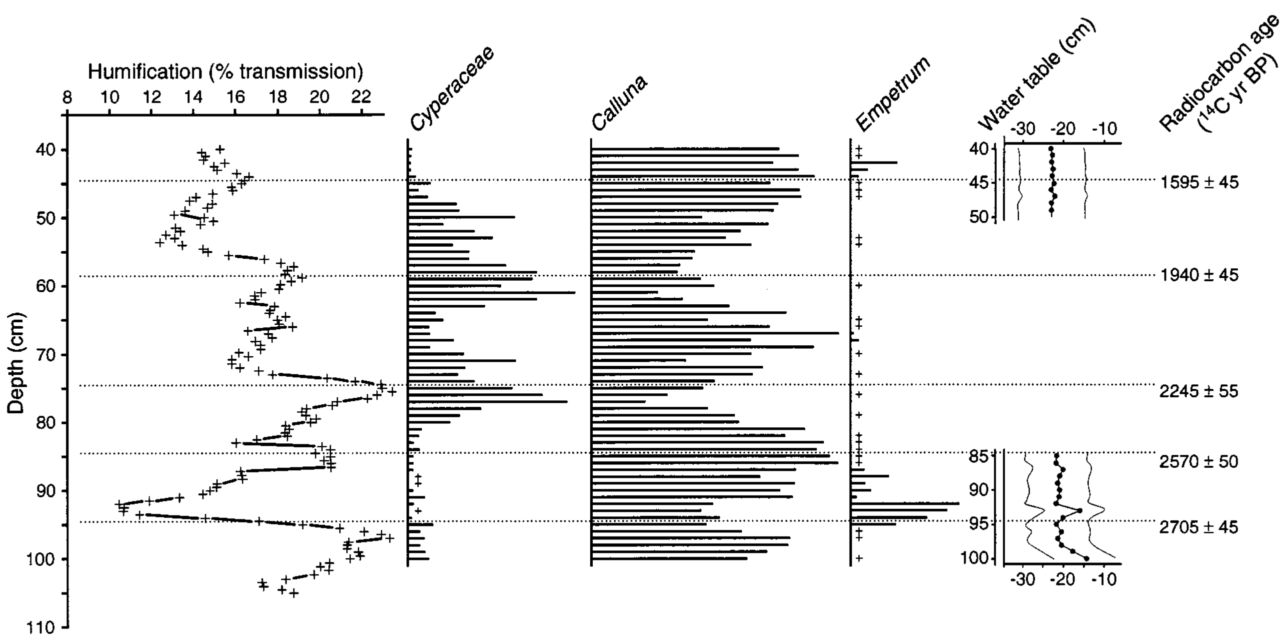

FIG. 3. Humification record from UAM1 with selected pollen curves (% TLP—Total Land Pollen) and reconstructed water table values from testate amoebae analysis (see text for details).

2280, 2010, and 1840 cal yr B.P., and high *Calluna vulgaris* values occur during the relatively low values after 1840 cal yr B.P. and between 2540 and 2810 cal yr B.P. However, Cyperaceae is not abundant at the humification peaks of 2540 and 2810 cal yr B.P. The pollen data thus support the humification data to some extent with Cyperaceae associated with high values in the upper part of the section.

The results from testate amoebae analysis (Fig. 4) show that conditions overall were relatively dry, compared with the ombrotrophic surfaces that have been sampled for modern analogues (e.g., Woodland *et al*., 1998), throughout the upper and lower parts of the profile. Assemblages are dominated by *Hyalosphenia subflava*, an indicator of extreme dryness (Charman and Warner, 1992; Tolonen *et al*., 1992), with another xerophilous taxon, *Trigonopyxis arcula*, present throughout. This dry surface could be due to the permeable substrate beneath the peat. An increase in *Amphitrema flavum* at the base of the profile suggests wetter conditions prior to 2810 cal yr B.P. The reconstructed water table values (Fig. 3) reflect this pattern. The relative complacency of the testate amoebae record in comparison to the humification changes is most likely related to the dry conditions, which are probably limiting for the existence of these organisms. Concentrations of testate amoebae were not countable to statistically reliable numbers between 51 and 82 cm depth, supporting the suggestion that conditions were unsuitable for their growth. A further factor could be poor preservation of amoebae tests, due to prolonged exposure at the surface prior to burial by peat growth. Changes in peat composition (Fig. 5) may also affect test preservation. Although the peat is dominated by monocotyledonous peat throughout the section, *Sphagnum* (principally Sect. Acutifolia) was more abundant at the base and top of the profile. No testate amoebae were found between 55 and 68 cm, where *Sphagnum* was almost completely absent.

UAM2

The section of dated peat at UAM2 covers a shorter time than the equivalent depths at UAM1. The period covered is only approximately 600 yr from ca. 1800 to 2400 cal yr B.P. The estimated peat accumulation rate (10.5 cal yr cm^{-1}) is more than twice that of UAM1, although the measured humification values do not differ markedly from UAM1 (Fig. 6). The humification record for UAM2 shows a series of peaks and troughs with peaks dated to 2310, 2240, 2090, 2020, and 1870 cal yr B.P., with additional minor peaks at 1800 and 1900 cal yr B.P. The magnitude of the fluctuations is relatively small except for the decrease after 2240 cal yr B.P., which is about three times larger than the other changes.

The pattern of peaks matches that found in the corresponding section of UAM1 (Fig. 6), within uncertainties in dating. UAM2 has higher resolution due to the more rapid accumulation rate and, as a result, the differentiation of peaks is often much better,

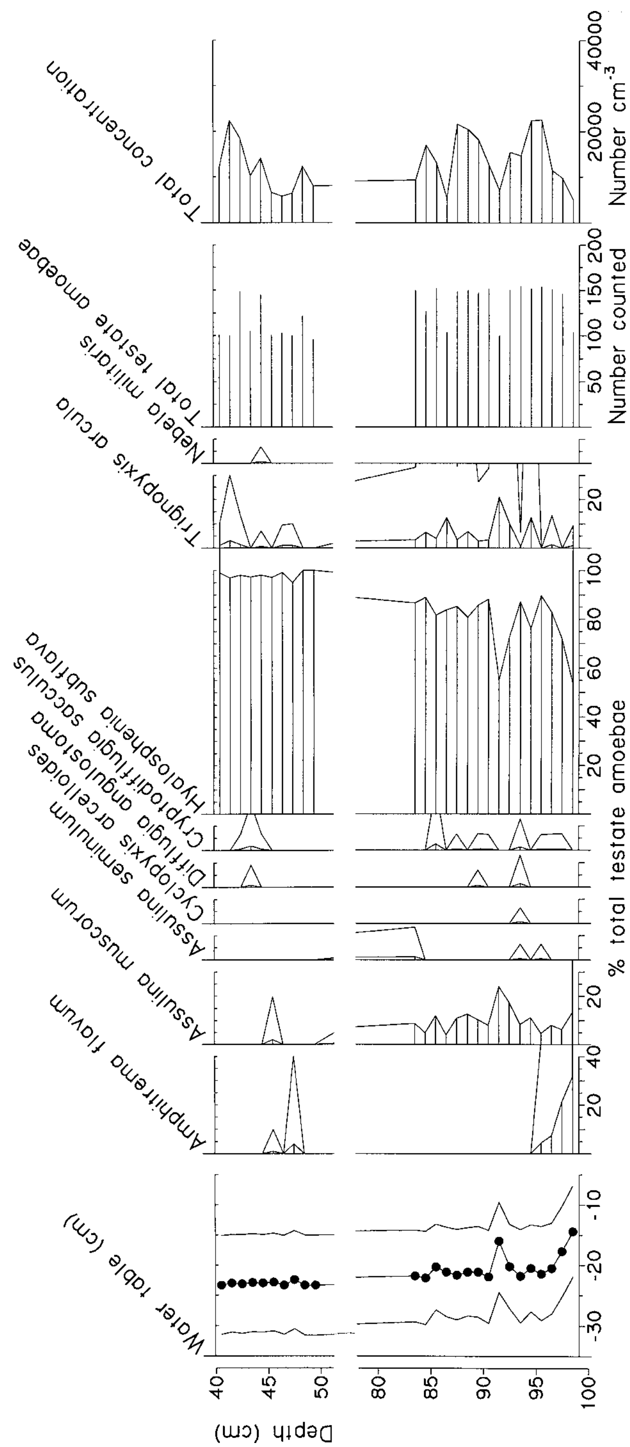

FIG. 4. Testate amoebae diagram for UAM1.

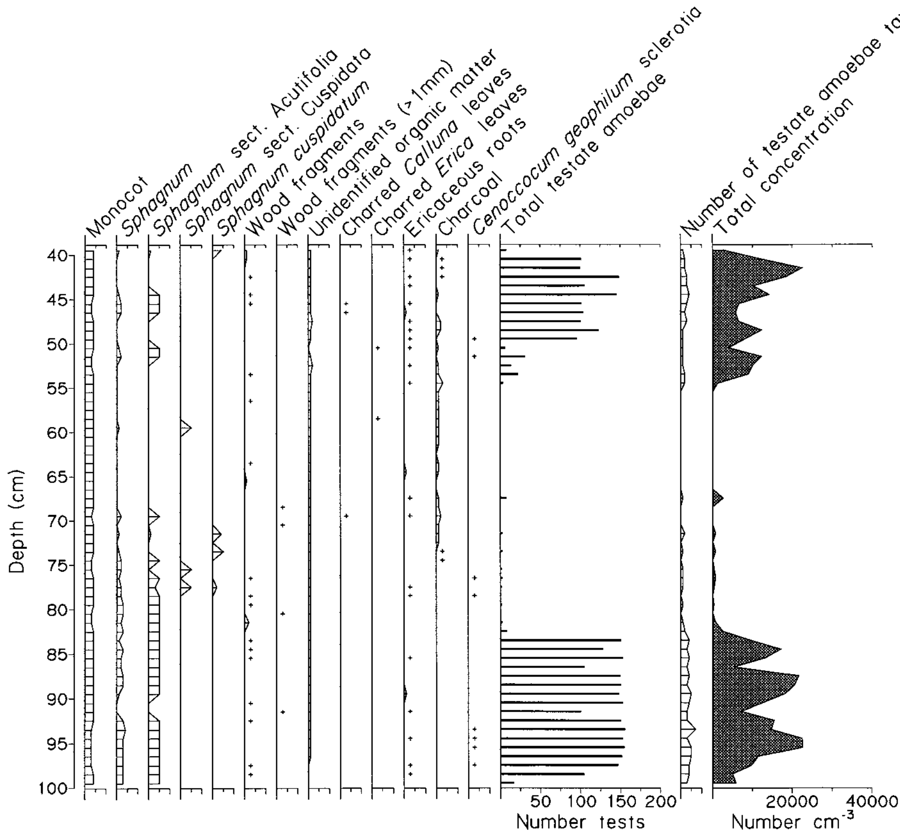

FIG. 5. Plant macrofossil diagram and testate amoebae summary data for UAM1.

for example the three peaks between 1770 and 1900 cal yr B.P. Nevertheless, there is a good match between even fine-scale changes. Only the peak at 2280 cal yr B.P. in UAM1 is difficult to match clearly in UAM2. Although values are generally high at this time in UAM2, the record is more complex and there are two distinct peaks. All other suggested correlations are within ±30 cal yr of each other, despite the likely errors in the chronologies.

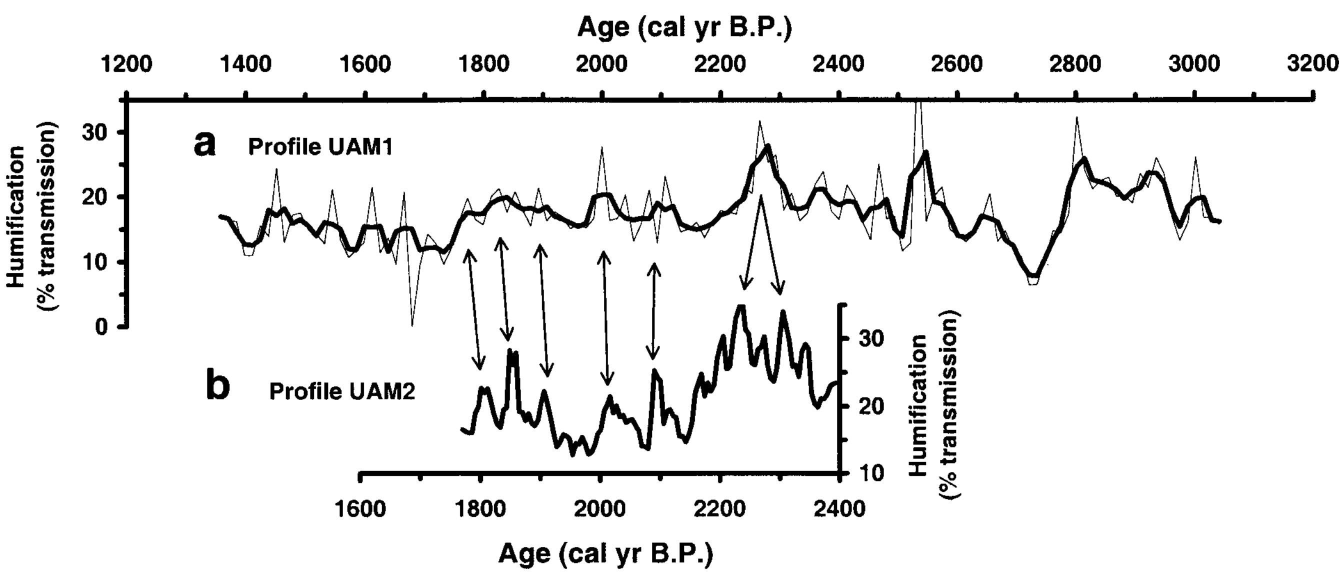

FIG. 6. Humification record for UAM2 and UAM1. Thick lines are three-point moving averages and the thin line for UAM1 represents raw data. Arrows show suggested correlations between the peaks in the records. For clarity, the raw data for UAM2 are not shown.

The good correlation between the records at UAM2 and the equivalent age section of UAM1 suggests that the humification records are reflecting hydrological change taking place across the whole of the Traligill peatland. Although they differ in terms of location and in peat accumulation rate, the records show almost identical patterns of change. Consequently, very local hydrological change plays a minor role in determining the relative changes in the humification characteristics of the peat profiles. Because the peatland is ombrotrophic, the most likely cause of the recorded changes is climatic, although it is conceivable that internal mesoscale factors such as mire expansion and development could also play a role.

HYDROLOGICAL CHANGE AT THE UAMH AN TARTAIR CAVE SITE

UAM4

The humification record from UAM4 (Fig. 7) shows peaks in wetness at 580, 820, 1120, 1600, 1740, and 2060 cal yr B.P. A further peak occurs at 130 cal yr B.P. although this is less certain due to the problems associated with interpretation of the humification record in the acrotelm. The overall pollen record (Fig. 8) shows relatively little correspondence with the humification and is dominated by changes that reflect off-site vegetation. *Betula* decreases at ca.1000 cal yr B.P. and almost disappears in the last 200 yr. Associated with these changes is an increase in Cyperaceae and *Calluna vulgaris*, suggesting the soils might have been getting wetter at the same time the vegetation became more open. Conditions were unsuitable for the growth and preservation of testate amoebae for the majority of the profile, although counts were also difficult purely because of the abundance of fine organic material in the preparations. As at UAM1 and UAM2, the testate amoebae assemblages (Fig. 9) reflect very dry conditions in the topmost portion of the profile, and the fauna also contains several taxa that are more common in mineral soils, such as *Centropyxis arcelloides* type.

The Speleothem Records

The speleothem records have been presented and discussed in detail elsewhere (Baker *et al*., 1999), and only a summary diagram of the luminescence emission wavelength record from stalagmites SU-2 and SU-96-7 is presented here for comparison with other records (Fig. 7). The speleothem records show peaks in emission wavelength at 2360, 2010, 1730, 1630, 1540, 1220, 1030, 780, 560, and 100 cal yr B.P.

The speleothem record thus shows a high degree of correspondence with the humification record from the overlying peat at UAM4 (Fig. 7). Peaks in both records occur at ca. 2035, 1735, 800, 570, and 115 cal yr B.P. (these are the averages of the estimated ages of corresponding peaks). The humification

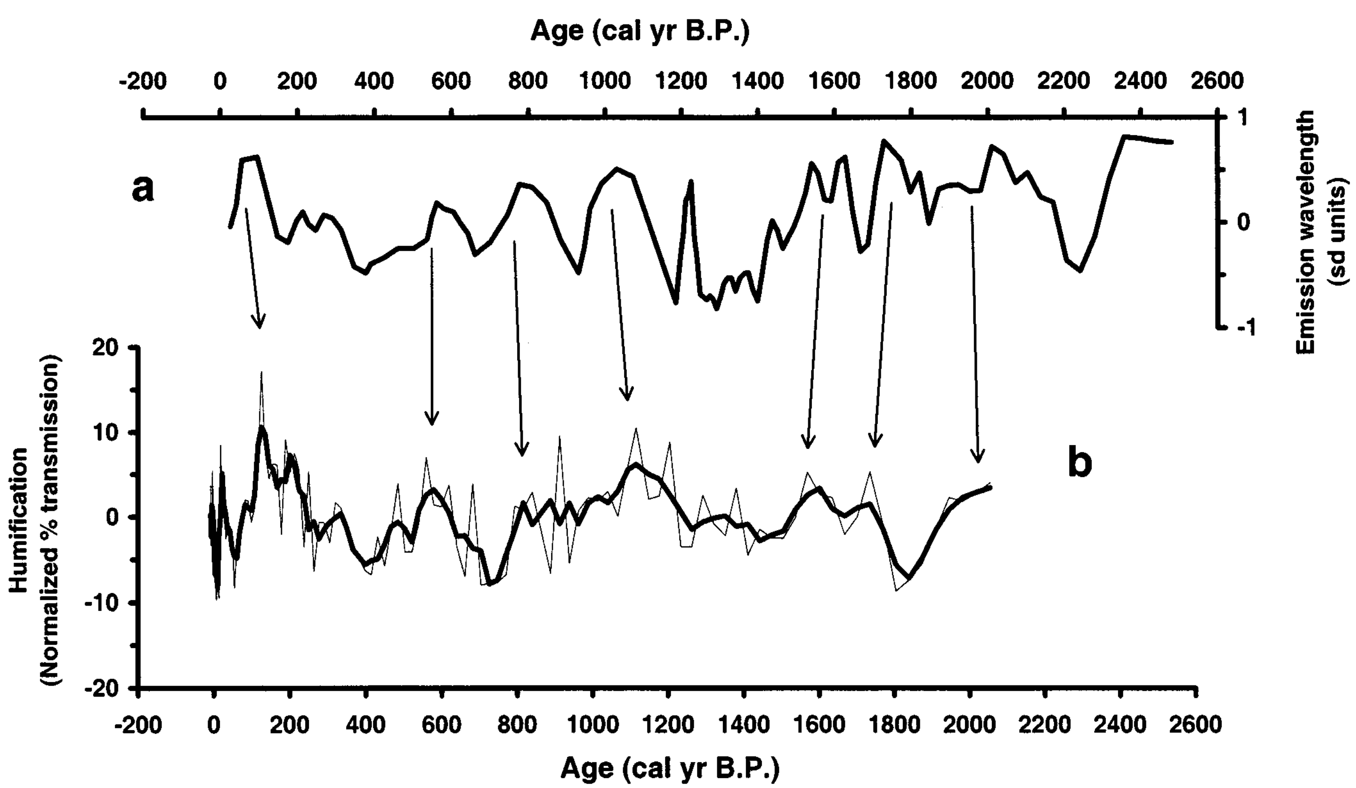

FIG. 7. (a) Normalized humification record for UAM4 shown with (b) the speleothem luminescence emission wavelength record from stalagmites SU-2 and SU-96-7 (Baker *et al*., 1999). Arrows show hypothesized correlations between peaks in humification and the luminescence emission wavelength.

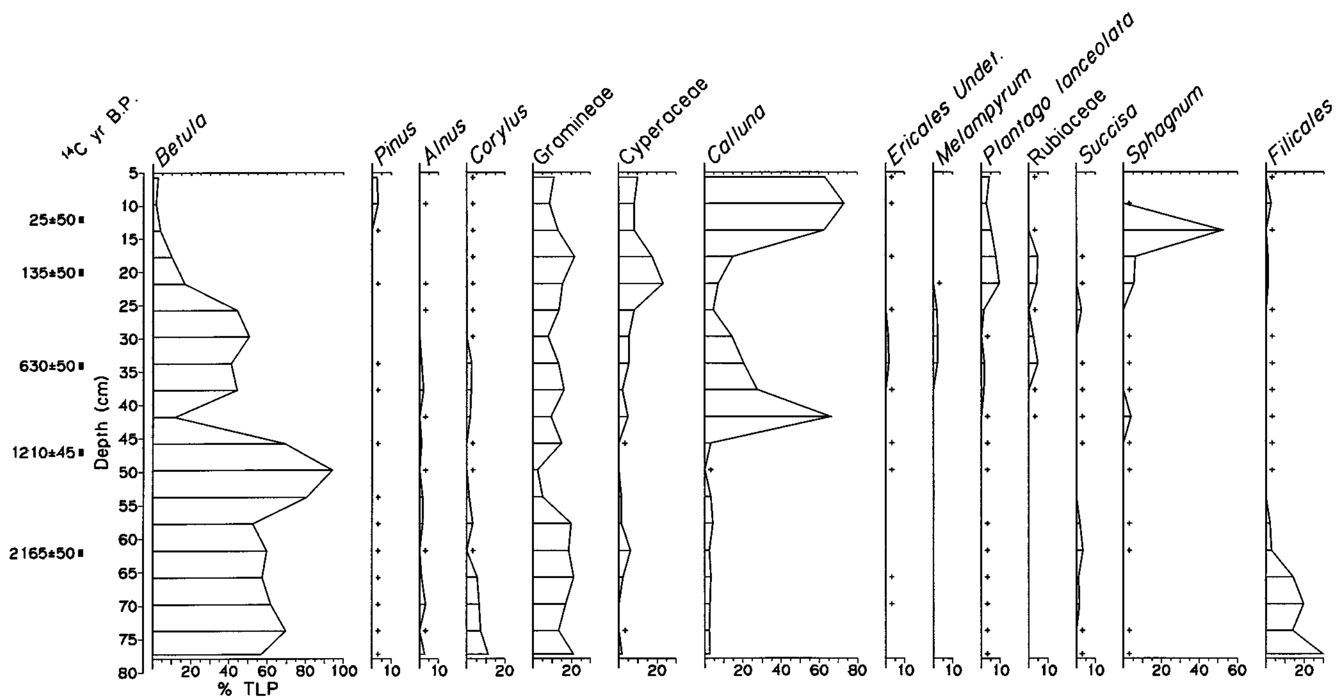

FIG. 8. Summary pollen diagram from UAM4 (% TLP). All taxa occurring at <1% TLP throughout the profile are excluded. Plus signs indicate values <1%.

peak at 1120 cal yr B.P. may match either of two separate peaks (1030, 1220 cal yr B.P.) in the speleothem record. In addition, the double peak in SU-2 (1630/1540 cal yr B.P.) coincides with the single peak at 1600 cal yr B.P. in UAM4, which may be a result of the poorer resolution in the peat record. The match between the overlapping sections of the speleothems and UAM4 supports the idea of a clear link between speleothem luminescence wavelength and decay in the overlying soils and suggests this is a robust record of local paleohydrological change.

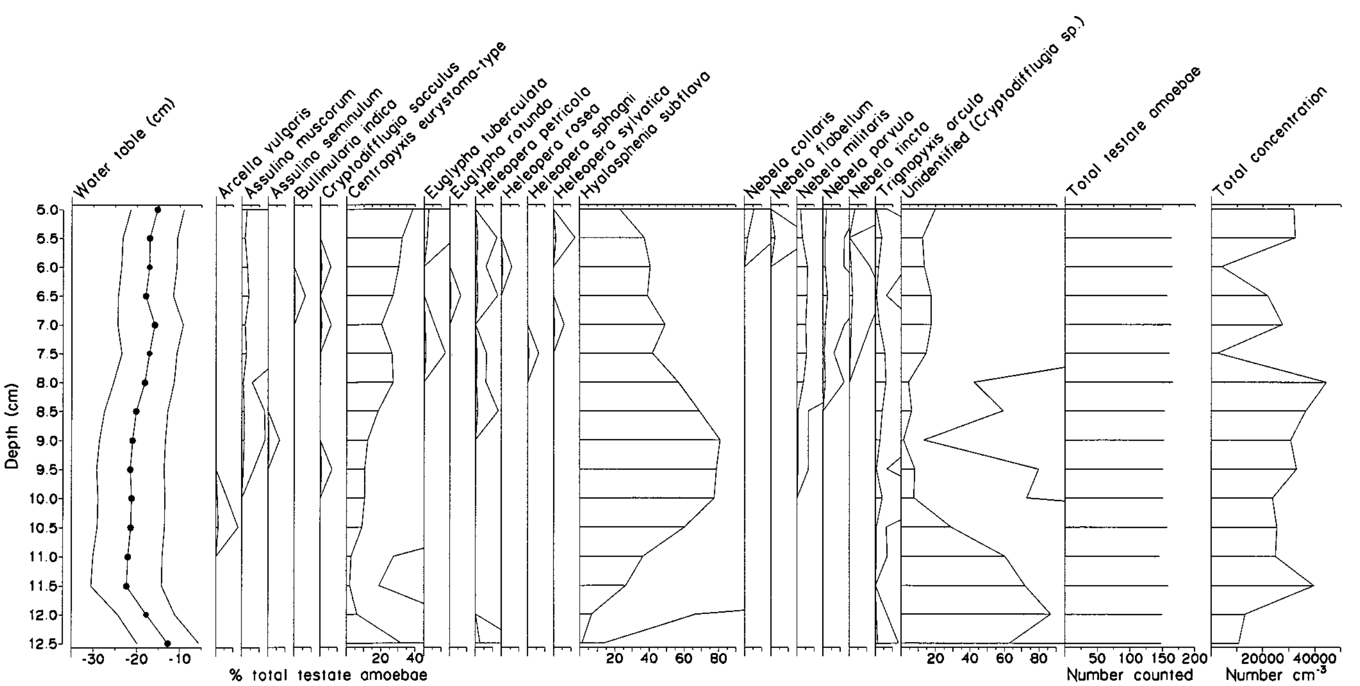

FIG. 9. Testate amoebae diagram from UAM4.

PALAEOHYDROLOGICAL CHANGES IN THE TRALIGILL AREA

The overlap between all three peat records and the stalagmite is relatively short but the main changes are replicated quite well for this period, with mean ages for the two peaks of 2025 and 1760 cal yr B.P (Fig. 10, Table 2). The peaks in the records show surprisingly good correspondence, with maximum differences between age estimates for these peaks of 50 and 70 cal yr, respectively, compared to possible dating errors of 100–200 yr. The 1760 cal yr B.P. estimate refers to the mean age of the final peak before the subsequent fall in values. It is preceded by two other small linked peaks in UAM1 and UAM2 that are poorly resolved or not present in UAM4 and the speleothem record.

Prior to ca. 2050 cal yr B.P., only the speleothem and the Traligill basin records overlap. All show high values prior to ca. 2200 cal yr B.P., but because this is the last part of the speleothem record, it is hard to assess exact correspondence between peaks. Following the period of maximum overlap (after 1750 cal yr B.P.), UAM1 has a peak corresponding with the speleothem record and UAM4 at a mean age of 1600 cal yr B.P. This period is resolved as three separate peaks in UAM1, two in the speleothem and one in UAM4 (Fig. 10, Table 2).

TABLE 2

Estimated Ages, in cal yr B. P., of Main Peaks in Records from the Speleothem Record and Peat Profiles UAM1, UAM2, and UAM4, Based on Maximum Values of Three-Point Smoothed Data

UAM1	UAM2	UAM4	Speleothem	Mean	Mean (multiple)
		130	100	115	
		580	560	570	
		820	780	800	
		1120	1030	1075	
			1220	1170	
1470		*1410*	*1440*	1440	
1550		—	1540	1545	
1610		1600	1630	1613	1600
1670		—	—	1670	
1770	*1800*	1740	1730	1760	
1840	1870	—	—	1855	1818
1890	*1900*	—	—	1895	
2010	2020	2060	2010	2025	
2090	2090		*2100*	2093	
2280	2240		2360	2298	
	2310				
2540					
2810					

Note. All ages rounded to nearest 10 yr. The mean value is the average age of each peak that occurs in two or more profiles. Mean (multiple) is the mean value for multiple peaks that may correspond to a single peak in other records. Figures in italics are relatively minor peaks (see Fig. 10). Long dashes indicate peaks not clearly recorded. Blanks are periods not covered by the records. The speleothem record is based on two individual records (SU-2, SU-96-7) joined together (Baker *et al*., 1999).

Because of these similarities among all five records, the predominant signal is regional climatic change rather than shifts in local site conditions.

REGIONAL PALEOCLIMATES

It is difficult to compare the data presented here with similar published data because the temporal resolution of most plots is much lower due to slower peat growth rates and because there could be significant regional differences in past rainfall regimes. However, the data appear to compare well with the nearest humification records from further south in Scotland (Anderson *et al*., 1998), where a humification record from a summit blanket mire 70 km to the south shows prominent peaks in surface wetness at ca. 2200–2300, 2000, 1400–1600, and 600 cal yr B.P., coinciding with three of the peaks recorded here (Table 2). In southwest Scotland, humification data in Chambers *et al*. (1997) show peaks in surface wetness estimated at 2300, 2000, 1700, 950, and 500 cal yr B.P. All except the 950 cal yr B.P. peak occur within 100 cal yr of the estimated ages of peaks in Table 2. Such agreement among the published peat records from Scotland suggests that a number of the peaks in surface wetness have a wider regional significance. However, because annual fluctuations in precipitation are not closely correlated even over relatively short distances in Scotland (e.g., Harrison and Clark, 1998) a correspondence among paleoclimate records is not necessarily expected. Perhaps longer term, higher magnitude changes in precipitation show greater regional coherence than annual and subannual fluctuations.

As a paleoclimatic proxy, surface wetness of ombrotrophic mires is ambiguous because it depends on both temperature and precipitation. Data from historical times suggest that the extreme cold periods of the Little Ice Age period (LIA) coincide with increased surface wetness on many mires in Britain (Blackford and Chambers, 1995; Chambers *et al*., 1997), but this could equally be caused by enhanced storminess (cf. Vitafinzi, 1995) and rainfall as well as by reduced temperatures. Reconstructions of European and Northern Hemisphere summer temperatures for recent historical times (Bradley and Jones, 1993; Overpeck *et al*., 1997; Mann *et al*., 1998) suggest no clear correlation between temperature and peatland records apart from some correspondence during the 17th century. Even the peak of surface wetness in UAM4 and the high luminescence wavelength in the speleothem at ca. 580 cal yr B.P. do not occur during the coldest temperatures in the late 17th century (Bradley and Jones, 1993), but immediately precedes them.

The records from Sutherland show some correspondence with the GISP2 record of ice accumulation in Greenland. The strongest links are with the peat record since 1000 cal yr B.P. in UAM4 and with the speleothem record (Fig. 10). If correct, this correspondence would suggest that precipitation changes are the more dominant control on mire surface wetness changes in western Europe over 10^2 to 10^3 yr time scales. The ice accumulation record is normally taken to be a proxy for temperature,

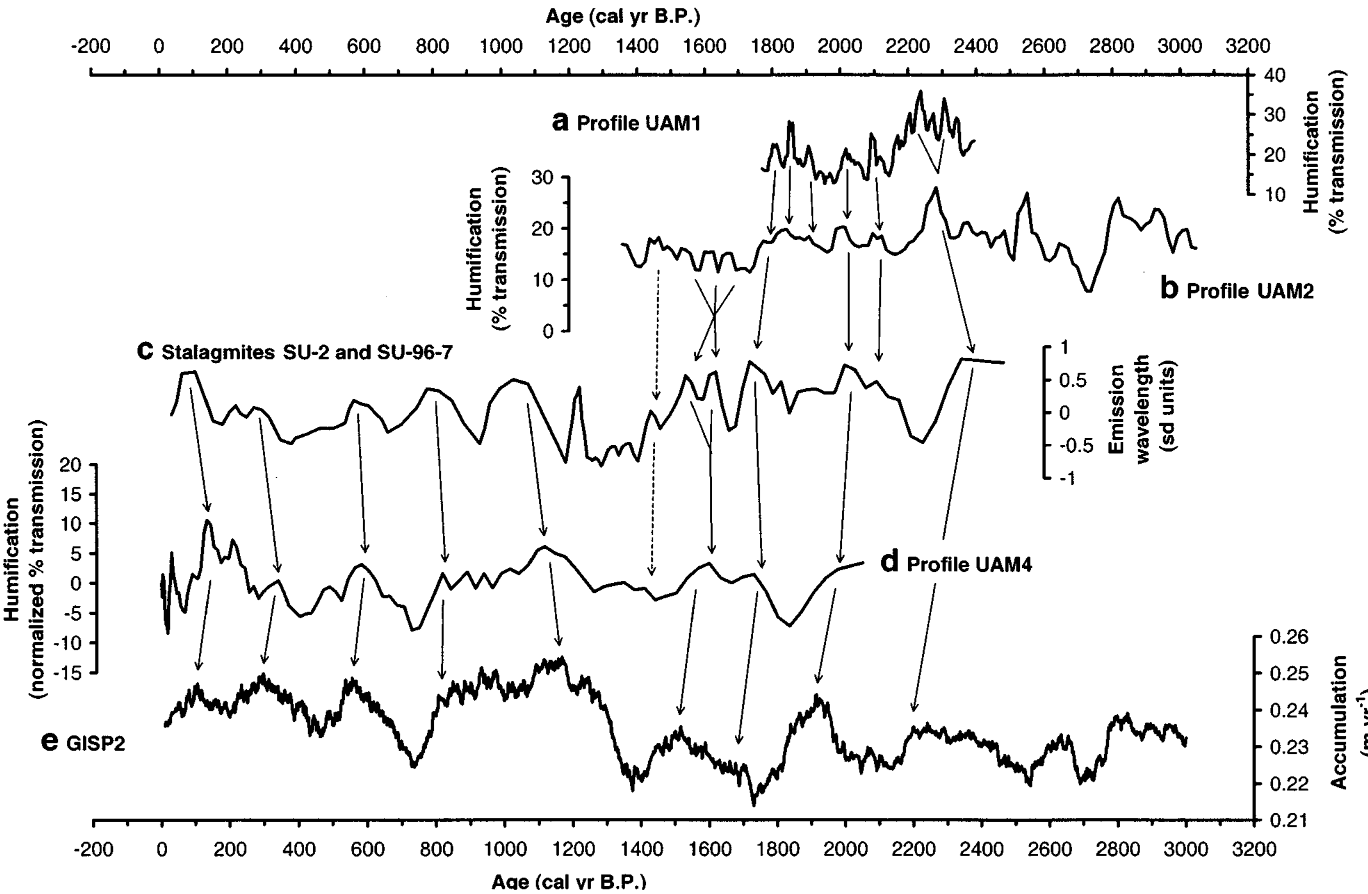

FIG. 10. Summary of humification and speleothem records. Humification records from the Traligill basin peats at (a) UAM1 and (b) UAM2. (c) Luminescence emission wavelength for composite stalagmite record from stalagmites SU-2 and SU-96-7 (Baker *et al*., 1999). (d) Humification record from the Uamh an Tartair cave site (UAM4). (e) The 100-year smoothed GISP2 ice accumulation record. The UAM4 humification has been normalized as it extends to the incompletely decayed material in the surface peat. Solid arrows show major suggested correlations between the records, and dashed lines show less certain matched peaks. GISP2 data is as inferred from the 200-km retreat model by Cuffey and Clow (1997) and Cuffey *et al*. (1995). GISP2 data is provided by the National Snow and Ice Center University of Colorado at Boulder, and the World Data Center-A for Paleoclimatology, National Geophysical Data Center, Boulder, Colorado.

principally based on correlations with δ^{18} O records from long records, but smaller variations such as those during the middle and late Holocene do not show such a clear relationship (Meese *et al*., 1994). Alternatively, increased precipitation in Greenland during the late Holocene is related to the strength and intensity of storm tracks in the North Atlantic rather than temperature per se (Kapsner *et al*., 1995; Cuffey and Clow, 1997). Peatland water table changes in northern England over the past 900 yr have been shown to be closely related to historical climatic changes and also to the GISP2 ice accumulation record over the past 4500 yr (Charman and Hendon, 2000). Such relationships cannot be explained by a simple strengthening of modern storm track positions; a southward movement of their position would also be necessary.

CONCLUSIONS

The correspondence between the two peat records from the Traligill basin shows that these represent surface wetness changes over the entire peatland basin. Although accumulation rates in UAM2 were more than double those in UAM1, the pattern and timing of change are almost identical for the period of overlap. The peat humification (UAM4) and speleothem luminescence records from the Uamh an Tartair cave site also show close correspondence with one another, supporting the hypothesis that the speleothem record is primarily determined by the amount of decay in the overlying soils (Baker *et al*., 1996). Although the Traligill basin peatland and the cave site are hydrologically separate, the records also correlate well between these two sites within dating errors of ^{14}C, TIMS U–Th, and counting of annual laminae. Taken together, the records thus represent a proxy paleoclimatic record for 0–2700 cal yr B.P. for this area of northwest Scotland. The lack of a clear correlation between instrumental and proxy temperature records for this and other peat surface wetness reconstructions suggests that the record is more strongly influenced by precipitation changes than by temperature. Comparison with the 100-year smoothed ice accumulation record from the GISP2 core supports this hypothesis and suggests that surface wetness changes may be closely linked to processes affecting a large part of the North Atlantic.

ACKNOWLEDGMENTS

The work was funded by NERC grants GR9/02051 and GR3/10744, and the Royal Society. The radiocarbon dating was funded by NERC Radiocarbon Laboratory, allocation number 684/1296. John Birks and two anonymous referees provided helpful comments on an earlier version of the manuscript.

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