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Rapid Communication

A Cromerian Complex stalagmite from the Mendip Hills, England

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ABSTRACT: In order to provide a better chronological constraint on a British Middle Pleistocene interglacial, a large stalagmite boss from the Mendip Hills was selected for palaeoclimate data using pollen analysis. Dating analyses by thermal ionisation mass spectrometry (TIMS) of uranium–thorium ratios and by magnetostratigraphy constrain the age of the sample to 450–780 ka. The isotopic consistency of the TIMS analyses, plus the presence of luminescence laminations, suggest that the sample has been preserved under closed-system conditions. Pollen assemblages have been recovered from the speleothems, despite the fact that the pH of calcite deposition is usually greater than 7. Furthermore the evidence presented here indicates that the pollen was probably transported by the speleothem feedwater, rather than entering the cave aerially. The pollen record contained within the stalagmite is interpreted as early–mid-interglacial but does not have clear Cromerian affinity. © 1997 by John Wiley & Sons, Ltd.

KEYWORDS: stalagmite; pollen; Cromerian Complex; uranium series; palaeomagnetism.

Introduction

The British Quaternary sequence is characterised by its lack of continuous record. Palynological studies have succeeded in differentiating interglacial periods by their distinctive flora, and recent developments in faunal identification and their ecological ranges have helped improve our understanding of Quaternary environmental change at several sites. However, the majority of sites suffer from a lack of chronological constraint, especially once outside the limits of ^{14}C, U–Th and amino-acid techniques. A good example is the 'Cromerian Complex', which is assigned to Oxygen Isotope Stages 13–21 on the grounds that the Anglian glaciation is Oxygen Isotope Stage 12, and that Cromerian Complex sites underlie these glacial deposits. A series of glacial–interglacial cycles is known from this period in The Netherlands (Zagwijn, 1996a; de Jong, 1988), and Cromerian sites from the British Isles include the Sugworth Channel Deposits of the Thames (Bridgland, 1994), West Runton (West, 1980a,b), and Little Oakley (Gibbard and Peglar, 1990). Considerable debate surrounds the correlation and completeness of these records from the British Isles (see discussion in Bridgland (1994) and, particularly, Turner (1996), for example), and it is likely that the Dutch 'Cromerian Complex' comprises more interglacials than so far recognised in the British sequence (Zagwijn, 1996b). Thus, there is a need to provide dated type sites that can better constrain the British Quaternary stratigraphy, for example, Proctor (1994) successfully uses alpha-spectrometric U–Th analyses on speleothems to differentiate faunal deposits of Oxygen Isotope Stages 7, 9, and 11 in Devon cave systems. Another possible solution would be to use pollen that is contained in speleothem samples, which can be dated reliably by U–Th analyses back to 450 ka using TIMS techniques, and thus be used for correlation with other terrestrial sites.

With the advent of the TIMS U–Th technique (Edwards *et al.*, 1986), there is a potential to constrain the pollen records derived from cave speleothem deposits back to 450 ka. Pollen trapped in speleothems may provide proxy palaeoclimatic data. Although the validity of such records has been questioned (Turner, 1985), Bastin (1978, 1990) has demonstrated a good agreement between stalagmite pollen and surface pollen records for the Holocene period, and Burney and Burney (1994) have monitored pollen transport mechanisms in contemporary caves to demonstrate that speleo-

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thems could be a good repository of pollen with little taphonomic bias. Although high pollen concentrations have been reported from speleothems near the entrances of African cave sites (Brook *et al.*, 1990), there have been few published studies of pollen input through groundwater seepage into deep caves (Brook and Nickmann, 1996) where there were no major openings to the outside atmosphere. A short pollen record in a British stalagmite from the East Mendip Hills, together with U–Th and palaeomagnetic dating, is presented here as a pilot study.

Methods

Stalagmite HQ-91-1 was sampled from a small cave intersected by quarrying operations on the East Mendip Hills, England (51°15′N, 2°25′W, National Grid Reference ST7040). The boss, of about 10 cm in diameter and 7 cm in height, was collected from a depth of > 20 m from the surface, the cave thus being significantly distant from any entrances to the surface prior to quarrying. The stalagmite was sectioned and polished for luminescence analysis according to the method of Baker *et al.* (1993), and subsampled for mass spectrometric uranium series dating, pollen analysis and palaeomagnetic determinations. A section through the sample, including subsampling locations, is presented in Fig. 1. The three subsamples (top, middle and base) of 1–2 g were used for TIMS uranium series analysis using techiques based on Edwards *et al.* (1986). Five 1 cm^3 subsamples for palaeomagnetic determinations (P1 to P5) were sawn along the growth axis (Latham *et al.*, 1986). The sample was also sectioned into three bulk sections for pollen analysis (pollen top, middle and base), of respectively 256 g, 192 g and 182 g. Samples were dissolved in 10% HCl, and then processed by standard procedures (Moore *et al.*, 1991) with double treatments of boiling in HF and acetolysis. Spikes of *Lycopodium* spores were added to allow determination of pollen concentration per gram of calcite.

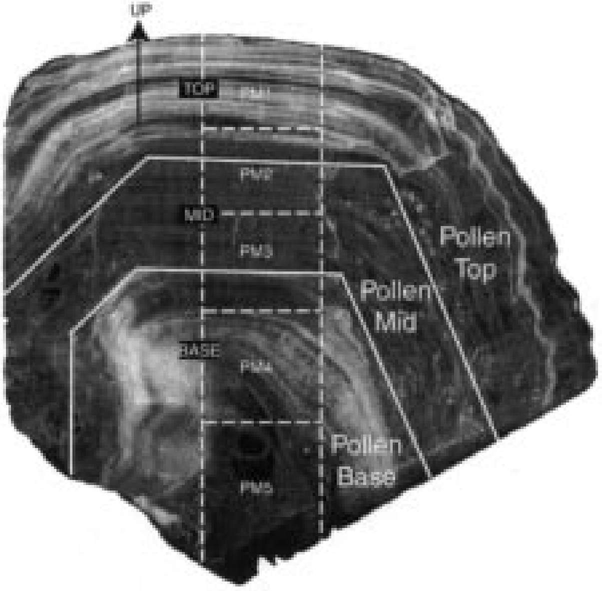

Figure 1 Stalagmite HQ-91-1, showing the five palaeomagnetism subsamples (PM1 to PM5) in relation to the vertical orientation of the sample. The TIMS uranium–thorium sample locations and pollen subsamples are also shown (TIMS and PO1 to PO3 respectively).

Results

The results of the TIMS uranium–thorium and palaeomagnetic determinations are presented in Table 1. The TIMS results demonstrate that the sample is free from detrital thorium, the constant uranium concentration and systematic decrease in $^{234}\text{U}/^{238}\text{U}$ activity ratio from base to top suggests that the sample has remained isotopically closed, and with $^{230}\text{Th}/^{234}\text{U}$ at secular equilibrium the stalagmite yields an age beyond the limits of the technique (> 450 ka). All five palaeomagnetic directions are positive downwards, indicating that the speleothem was probably deposited during the Brunhes magnetochron, and is therefore younger than 780 ka, the Brunhes–Matuyama boundary (Baksi, 1993).

Luminescence laminations are discontinuously preserved throughout the sample, with the biggest concentration between 5 and 18 mm from the base and 45–50 mm from the base (Fig. 2). In the 23 mm of sample for which laminations can be observed, 106 laminations have an average ($\pm 1\sigma$) width of 0.026 ± 0.010 mm.

The pollen results are presented in Table 2, and demonstrate interglacial affinity. The arboreal pollen (AP) and shrub counts comprise a consistent variety of taxa, including *Betula, Pinus, Quercus, Alnus* and *Corylus*, with lower values for *Ulmus, Fraxinus, Acer, Salix, Ilex* and *Buxus*. The non-arboreal pollen (NAP) assemblage is dominated by Poaceae but with a variety of herbs, particularly *Bellis perennis* and Lactuceae type (*Taraxacum*), with the following referable to species level: *Anagallis arvensis, Plantago lanceolata, Chelidonium majus* and *Mercurialis perennis*. Ericales pollen was found in all samples, but at very low counts. Although counts for unidentified pollen varied between 20 and 35% TLP + unidentified, this was due mainly to mechanical damage, with little chemical breakdown, and such figures are not unusual in speleothem data. Resistant taxa such as *Bellis* and *Taraxacum* may be overrepresented, but the range of taxa found suggests that the assemblage is a reasonable representation of the flora of the time of deposition.

Interpretation and conclusion

The three TIMS uranium–thorium analyses give ages greater than 450 ka. The values of the $^{234}\text{U}/^{238}\text{U}$ ratios of 1.12 to 1.26, however, show that insufficient time has elapsed for equilibrium to have been attained and this implies that the sample is still substantially less than 1.5 Ma old. This is supported by the palaeomagnetic directions, which indicate that the sample was deposited during a period of normal Earth polarity – which is most likely to be the early part of the Brunhes chron; i.e., between 780 and 450 ka. Correlation with the earlier Jaramillo subchron (910 to 970 ka) remains a possibility. No interglacial floral evidence is yet established for the British Isles for this period, although in The Netherlands deposits of the Bavel interglacial of the Bavelian Stage show partial positive polarity (Zagwijn, 1975, 1996b). Correlation would have to be with the later part of this interglacial, which retains Tertiary relicts such as *Tsuga* and *Eucommia*, as well as including *Picnea* and *Abies* (Zagwijn, 1992). The speleothem pollen has none of these taxa. Thus, considering that the $^{234}\text{U}/^{238}\text{U}$ ratios in the stalagmite are significantly distant from secular equilibrium, such an early age is unlikely.

The luminescence laminations contained within the stalag-

Table 1 Summary of three TIMS uranium–thorium results and palaeomagnetic directions of the five subsamples for HQ-91-1
(a) *TIMS uranium–thorium results*

Sample ID	^{238}U (ppm)	^{234}U/^{238}U act	^{232}Th (ppb)	^{230}Th/^{232}Th act	^{230}Th/^{234}U act	Age (2σ)
TIMS-top	0.50477 ± 0.00090	1.12006 ± 0.00316	16.08367 ± 0.01925	114.90 ± 0.28	1.06959 ± 0.00381	>450 ka
TIMS-mid	0.47897 ± 0.00078	1.19182 ± 0.00396	13.37448 ± 0.01414	138.59 ± 0.32	1.06253 ± 0.00414	>450 ka
TIMS-base	0.40849 ± 0.00034	1.25714 ± 0.00204	8.23587 ± 0.01300	208.16 ± 0.71	1.09243 ± 0.00377	>450 ka
(blank)	0.00002 ± 578E-8	0.01728 ± 0.00008				

(b) *Palaeomagnetic results*

Relative declination (°E)[a]		Inclination (degrees down from horizontal)[b]	Angular moment dispersion (AMD)[c]
PM-1	315	71	15
PM-2	294	58	10
PM-3	282	69	14
PM-4	297	63	8
PM-5	325	80	11

[a] Declination is relative as the stalagmite was not oriented upon sampling

[b] The inclinations are reckoned to be within about 5°. The inclinations demonstrate unequivocally that the stalagmite layers formed in a Normal Earth's field

[c] The AMD is the cone of 95% confidence based on the last five demagnetization steps. Samples were demagnetized in steps of 100 mT to 500 mT

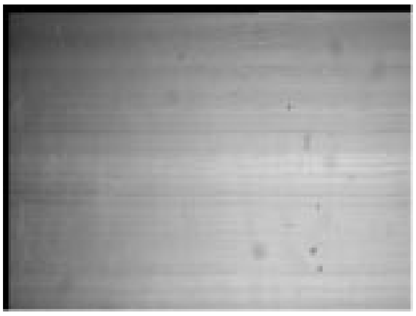

Figure 2 Luminescence laminations at a distance 17 mm from the base of the stalagmite, image captured using ×10 magnification using a Zeiss Axiotech© microscope and enhanced using Image Pro Plus©. Younging is to the top of the image and each lamina has a width of ca. 30 μm.

mite are probably annual. Demonstration of this is limited by the non-finite U–Th results, but using analogues with other laminated samples growing in the region and elsewhere in the current interglacial, annual luminescence variability is suggested (Baker *et al.*, 1996; Genty *et al.*, 1997). If so, the stalagmite grew at a rate of 0.026 ± 0.010 mm yr^{-1}, and when extrapolated over the rest of the sample stalagmite deposition occurred for ca. 2–4 ka. The discontinuous nature of the laminations may be caused by changes in the seasonality or groundwater residence time of the drip waters feeding the samples; these may be caused by climatic variations, but as individual stalagmites have different responses to climate (Baker *et al.*, 1997), a climatic interpretation is not possible without calibration against other high-resolution proxies (Smart *et al.*, 1996). However, one important observation from the growth rate of the sample as determined from the annual laminations is that the growth rate of ~0.01–0.03 mm yr^{-1} is at the lowest extreme of values observed in the region today (0.02 to 0.2 mm yr^{-1}; Baker and Smart, 1995; Baker *et al.*, 1996). Growth rate theory dictates that this is caused by a very low calcium concentration in the drip waters (Dreybrodt, 1988; Baker *et al.*, 1996), possibly determined by a poor surface soil development or unfavourable conditions for microbial respiration, and thus conditions may have been comparatively worse than at interglacial maxima.

Given the depth of the cave and thus distance from any openings at the time of deposition, all the pollen must have entered via drip waters from the overlying soil. Concentrations of pollen in the calcite of 5.9–14.7 ($\mu = 9.2$) grains g^{-1} are in the range found in a stalagmite from Han-sur-Lesse cave in Belgium (1.5 to 13.0 grains g^{-1}; Genty, 1993), which from its depth in the cave may also have had a drip source. The broad range of the pollen assemblage in this sample and in others (Bastin, 1978; and Brook and Nickmann (1996), for example) suggests that there has been little or no taphonomic bias when compared with surface concentrations, although, in a more comprehensive study, this would need to be tested further.

There is some variation in the presence/absence of pollen taxa across the speleothem, but the overall assemblage is remarkably consistent, especially the ratio of AP + shrubs:NAP. Given the range of NAP taxa, and the variety of trees and shrubs represented it is likely that there was an open scrubby vegetation immediately over the site, dominated by birch and alder, but with relatively thermophilous (i.e. interglacial) woodland contributing a longer distance component. Given the groundwater source for the pollen, the herb flora probably represented by local groundstorey of the scrub, dominantly grasses and typical open-ground species such as *Taraxacum, Bellis* and *Plantago*, but also with tall herbs such as *Filipendula* and herbs more characteristic of the scrub, e.g. *Mercurialis perennis*. Of particular interest is the presence of *Bruxus*, which suggests conditions close to maximum warmth experienced in interglacials (i.e. minimum July temperature of 17°C; Zagwijn, 1996a), and which may have been important in the local woodland.

From the dating constraints, no later than 450 k BP, the assemblages should correlate with Cromerian assemblages elsewhere in the British Isles. Although a composite of several interglacial stages these assemblages are well documented (West, 1980a,b), with sites such as West Runton (West, 1980a), Ardleigh (Bridgland *et al.*, 1988) and Little Oakley (Gibbard and Peglar, 1990) in East Anglia and the Thames Basin. The absence of any relict Tertiary taxa would

Table 2 Pollen results from the three sub-samples of stalagmite HQ-91-1

	Top	Middle	Base
Betula	11 (8.1:6.5)	2 (1.7:1.1)	4 (8.9:5.8)
Pinus sylvestris	18 (13.2:10.6)	14 (11.8:7.9)	6 (13.3:8.7)
Ulmus	–	–	1 (2.2:1.4)
Quercus	5 (3.7:2.9)	8 (6.7:4.5)	1 (2.2:1.4)
Alnus glutinosa	12 (8.8:7.1)	13 (10.9:7.3)	2 (4.4:2.9)
Fraxinus excelsior	–	2 (1.7:1.1)	–
Acer campestre	1 (0.7:0.6)	2 (1.7:1.1)	–
Percentage arboreal pollen	34.5	34.5	31.0
Corylus avellana type	2 (1.5:1.2)	5 (4.2:2.8)	2 (4.4:2.9)
Salix	1 (0.7:0.6)	1 (0.8:0.6)	1 (2.2:1.4)
Buxus sempervirens	2 (1.5 (1.2)	–	–
Ilex aquifolium	1 (0.7:0.6)	–	–
Percentage shrubs	4.4	5.0	6.6
Poaceae undifferentiated	48 (35.3:28.2)	59 (49.6:33.3)	18 (40.0:26.1)
Ericales	1 (0.7:0.6)	3 (2.5:1.7)	1 (2.2:1.4)
Bellis perennis	14 (10.3:8.2)	1 (0.8:0.6)	–
Chelidonium majus	3 (2.2:1.7)	–	4 (8.9:5.8)
Lactuceae (*Taraxacum*)	8 (5.9:4.7)	7 (5.9:3.9)	–
Anagallis arvensis	4 (2.9:2.3)	–	1 (2.2:1.4)
Chenopodiaceae	1 (0.7:0.6)	–	–
Filipendula	1 (0.7:0.6)	1 (0.8:0.6)	–
Hypericum performatum t.	1 (0.7:0.6)	–	–
Plantago lanceolata	1 (0.7:0.6)	–	1 (2.2:1.4)
Mercurialis perennis	–	–	1 (2.2:1.4)
Ranunculaceae	–	–	1 (2.2:1.4)
Rubiaceae	–	–	1 (2.2:1.4)
Urticaceae	–	–	
Percentage non-arboreal pollen	60.8	60.4	62.1
Unidentified	34 (20.0)	58 (32.8)	24 (34.8)
Total pollen	170	177	69
Pre-Quaternary spores	17	34	11

Figures in brackets represent (%TLP:%TLP + unidentified pollen). Nomenclature follows Bennett (1994)

suggest later Cromerian age, but with absence of *Picea* from this site is a major problem. *Picea* is characteristic of Cromerian assemblages, especially once relatively warm conditions are found, as indicated here by *Buxus* (the pollen of which is generally lacking from Cromerian assemblages). It is unlikely that *Picea* was preferentially lost in pollen deposition considering the high levels for *Pinus*, much of it as broken fragments. Comparison is better with some early Hoxnian assemblages, such as at Nechells in Zone IIN (Kelly, 1964), in which macrofossils, but not pollen, of *Buxus* are recorded with a similar AP assemblage, and in which, although present, levels for *Picea* are very low. Hoxnian deposits themselves probably represent two interglacial episodes, but are also usually characterised by the presence of Type X pollen. This was not found here, although one unidentified grain had a number of features characteristic of this pollen type (Phillips, 1976).

It is difficult to be certain as to how close a correlation can be made between pollen assemblages from a speleothem with those from other depositional environments, especially when the main records are from much more eastern locations. Nevertheless, assuming that the pollen assemblage is a valid representation of the overlying vegetation in its range of taxa within the time period defined by the radiometric and palaeomagnetic dating, the results do raise a number of problems. Either the date of deposition is not within the Cromerian and the dating is wrong, or the site is Cromerian and reflects a vegetation particularly characteristic of local conditions as a ‘western’ site. A further possibility is that sites previously defined as Hoxnian, but not suitable for radiometric dating, represent interglacials older than 450 ka BP.

The data presented above, especially the geochronological data, suggest that this stalagmite was deposited in interglacial conditions, and that this interglacial was one of those in the Cromerian Complex. The analyses may not have improved understanding of the chronology of this event, but it has demonstrated the presence of adequate numbers of pollen grains for analysis from speleothems of Middle Quaternary age. Furthermore, this sample from a deep and enclosed cave site is unlikely to have airborne pollen transported on to it, and thus a drip-water source is likely. Further studies are necessary to investigate this flow routing and any taphonomic biases it may create; but the presence of pollen assemblages that faithfully reflect vegetation communities, albeit mainly from calcareous areas, together with the large number of alpha-spectrometrically dated British stalagmites in University rock collections, could significantly improve our understanding of the British Middle and Early Quaternary.

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References

BAKER, A. and SMART, P. L. 1995. Recent flowstone growth rates: field measurements in comparison to theoretical predictions. *Chemical Geology*, **122**, 121–128.

BAKER, A., GENTY, D. and BARNES, W. L. 1996. Recent stalagmite growth rates: cave measurements, theoretical predictions and the environmental record. *Proceedings of the Conference 'Climatic Change – The Karst Record'*, Bergen, August, pp. 7–9.

BAKER, A., SMART, P. L., EDWARDS, R. L. and RICHARDS, D. A. 1993. Annual growth banding in a cave stalagmite. *Nature*, **364**, 518–520.

BAKER, A., BARNES, W. L. and SMART, P. L. 1997. Stalagmite drip discharge and organic matter fluxes in Lower Cave, Bristol. *Hydrological Processes*, **11**, 1541–1555.

BAKSI, A. K. 1993. A geomagnetic polarity time-scale for the period 0–17 Ma, based on Ar-40/Ar-39 plateau ages for selected field. *Geophysical Research Letters*, **20**, 1607–1610.

BASTIN, B. 1978, L'analyse pollinique des stalagmites: une nouvelle possibilite d'approche des fluctuations climatiques du Quaternaire. *Annales de la Societe Geologique de Belgique*, **101**, 13–19.

BASTIN, B. 1990. L'analyse pollinique des concretions stalagmitiques. *Karstologia*, **2**, 3–10.

BENNETT, K. D. 1994. *Annotated catalogue of pollen and pteridophyte spore types of the British Isles.* Department of Plant Sciences, University of Cambridge, unpublished, 37 pp.

BRIDGLAND, D. R. 1988. The Pleistocene fluvial stratigraphy and palaeogeography of Essex. *Procs. Geol. Assoc.,* **99**, 291–314.

BRIDGLAND, D. R. 1994. *Quaternary of the Thames Geological Conservation.* Review Series No. 7, Chapman and Hall, London, 441 pp.

BROOK, G. A. and NICKMANN, R. J. 1996. Evidence of Late Quaternary environments in Northwestern Georgia from sediments preserved in Red Spider Cave. *Physical Geography*, **17**, 465–484.

BROOK, G. A., BURNEY, D. A. and COWART, J. B. 1990. Desert palaeoenvironmental data from cave speleothems with examples from the Chihuahuan, Somali-Chalabi, and Kalahari deserts. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **76**, 311–329.

BURNEY, D. A. and BURNEY, L. P. Modern pollen deposition in cave sites: experimental results from New York State. *New Phytologist*, **124**, 523–535.

DE JONG, J. 1988. Climatic variability during the past three million years, as indicated by vegetational evolution in northwest Europe and with emphasis on data from the Netherlands. *Philosophical Transactions of the Royal Society of London, Series B*, **318**, 603–617.

DREYBRODT, W. 1988. *Processes in Karst Systems.* Springer-Verlag, Berlin.

EDWARDS, R. L., CHEN, J. H. and WASSERBURG, G. J. 1986. 238U–234U–230Th–232Th systematics and the precise measurement of time over the past 500,000 years. *Earth and Planetary Science Letters*, **81**, 175–192.

GENTY, D. 1993. *Interet des speleothemes comme enrigistreurs des environnements anciens et recents.* Unpublished Post-doctoral Report, Faculte Polytechnique de Mons, Belgique, 146 pp.

GENTY, D., BAKER, A. and BARNES, W. L. 1997. Comparison entre les lamines luminescentes et les lamines visibles annuelles de stalagmites. *Comptes Rendus Hebdomedaires des Sciences de l'Academie Sciences Paris, Science de la terre et des planetes*, **325**, 193–200.

GIBBARD, P. L. and PEGLER, S. M. 1990. Palynology of the interglacial deposits at Little-Oakley, Essex and their correlation. *Philosophical Transactions of the Royal Society of London, Series B*, **328**, 341–357.

KELLY, M.R. 1964. The Middle Pleistocene of North Birmingham. *Philosophical Transactions of the Royal Society of London, Series B*, **247**, 533–592.

LATHAM, A. G., SCHWARCZ, H. P. and FORD, D. C. 1986. The palaeomagnetism and U–Th dating of Mexican stalagmite DAS2. *Earth and Planetary Interiors*, **79**, 195–207.

MOORE, P. D., WEBB, J. A. and COLLINSON, M. E. 1991. Pollen Analysis, 2nd Edition. Blackwell Scientific Publications, Oxford.

PHILLIPS, L. 1976. Pleistocene vegetation history and geology in Norfolk. *Philosophical Transactions of the Royal Society of London, Series B*, **275**, 215–286.

PROCTOR, C. J. 1994. *A British Pleistocene chronology based on uranium series and electron spin resonance dating of speleotherm.* Unpublished PhD thesis, University of Bristol.

SMART, P. L., ROBERTS, M. S., BAKER, A. and RICHARDS, D. A. 1996. Palaeoclimate determinations from speleotherms – a critical appraisal of the state of the art. *Proceedings of the Conference 'Climatic Change – The Karst Record'*, Bergen, August, pp. 157–159.

TURNER, C. 1996. A brief survey of the early Middle Pleistocene in Europe. *IN:* Turner, C. (ed.), *The Early Middle Pleistocene in Europe*, 295–317. Balkema, Rotterdam.

TURNER, C. 1985. Problems and pitfalls in the application of palynology to Pleistocene archaeological sites in western Europe. *IN:* Renault-Miskovsky, J., Bui-Thi-Mai and Girard, M. (eds), *Palynologie Archeologique*, 347–373. Actes des Journees du 25-26-27 janvier 1984, Editions du Centre National de la Recherche Scientifique, Paris.

WEST, R. G. 1980a. *The Pre-Glacial Pleistocene of the Norfolk and Suffolk Coasts*. Cambridge University Press, Cambridge.

WEST, R. G. 1980b. Pleistocene forest history in East Anglia. *New Phytologist*, **85**, 571–622.

ZAGWIJN, W. H. 1975. Variations in the climate as shown by pollen analysis, especially in the Lower Pleistocene of Europe. *IN:* Wright, A. E. and Moseley, F. (eds), *Ice Ages Ancient and Modern*, 137–152. Geological Journal Special Issue Number 6, Searle House Press, Liverpool.

ZAGWIJN, W. H. 1992. The beginning of the Ice Age in Europe and its major subdivisions. *Quaternary Science Reviews*, **11**, 583–591.

ZAGWIJN, W. H. 1996a. An analysis of Eemian climate in Western and Central Europe. *Quaternary Science Reviews*, **15**, 451–470.

ZAGWIJN, W. H. 1996b. The Cromerian Complex Stage of the Netherlands and correlation with other areas in Europe. *IN:* Turner, C. (ed.), *The Early Middle Pleistocene in Europe*, 145–172. Balkema, Rotterdam.