11. Dating

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This chapter falls into two parts. The first is focused primarily on dating the Middle Pleistocene occupation and deals with the application of thermoluminescence (TL) and Uranium series dating to stalagmites, and so to chronostratigraphy. It also considers the application of TL to burnt flints and explores, with some success, the use of electron spin resonance (ESR) for bone dating. The second part deals with the radiocarbon dating of the Devensian fauna. The overall aim was to establish evidence for temporal patterning in the taxonomically diverse faunal record from the Upper Breccia in order to relate these to taphonomic, ecological and climatic factors that could have influenced the biomass, faunal composition and animal biodiversity of the surrounding environs to the site.

Thermoluminescence dating of flint, stalagmite and sediment from Pontnewydd Cave

Nicholas C. Debenham

Introduction

Thermoluminescence (TL) has been applied to the dating of flints, stone, stalagmites and sediment from Pontnewydd Cave. While details of the date measurements differ between these four types of material, the same general principles underlie all these methods. In fact, the date measurement involves two distinct procedures. The first is the TL examination of the sample, in which it is used as a dosimeter to measure the quantity of ionising radiation that it has received since the event to be dated. The second set of measurements allows an assessment of the rate at which the radiation dose was received, which, combined with the TL data, produces the elapsed time. The general principles of TL date measurement are explained below. Separate sections describe the TL examination and the dose rate assessment procedures. The last section discusses the TL dates obtained for the various materials excavated from Pontnewydd Cave.

General principles of TL dating

Many crystalline materials share the potential for being used as dosimeters, capable of recording the doses of ionising radiation to which they have been exposed. Ionising radiation is present in varying intensities in all environments. Alpha, beta and gamma radiation originates from naturally occurring radioactive nuclides, such as uranium, thorium and potassium, while cosmic radiation is generated when high-energy particles are incident on the Earth's atmosphere. When crystals are exposed to the energy of these radiations, their electronic structures are re-arranged in a variety of ways. Most of these re-arrangements are temporary. However, some of the alterations persist for very long periods, and effectively form a long-term memory of the quantity of radiation which the crystal has absorbed. The radiation dose thus recorded is termed the palaeodose.

Thermoluminescence is one means of obtaining a read-out of the crystalline dosimeter. As the crystal is progressively heated, a luminescence is produced. This emission of light results from the release of radiation energy which has been absorbed, and subsequently retained, by the crystal. The intensity of the luminescence is thus related to the palaeodose, and a measurement of this dose can be obtained from observations of the material's present-day TL intensity (or natural TL), and of its response to known doses of radiation. These measurements can determine the palaeodose with a precision which is typically between ±4% and ±8%.

For the TL observations to be useful as a measurement of age, the following two requirements must be satisfied; (i) the event to be dated must cause the removal of all (or nearly all) of the pre-existing TL, and (ii) it must be possible to make an assessment of the rate at which the material absorbed radiation energy since the initial event

Sample	*Find no.*	*Lab ref.*	*Layer*	*Square*	*Height*	*Dated by*
Main Cave Areas B, C, D, F, and G						
Stal (i/s)[1]	B409	226g1	LSG 3	K17		OxTL
Stal (i/s)[1]	B556	PND42	LSG	Deep Sounding	97.48	BMTL
Stal (i/s)	D188	226a1	LT	H5		OxTL
Stal[2]	D471	226e6	On LB	G9	99.45	OxTL
Stal (i/s)	D604	226e14	On LB	J9	99.67	OxTL
Stal (i/s)	D1693	226h3	On LB	G10		OxTL
Stal (i/s)	D1711	226h21	On LB	J7		OxTL
Stal (i/s)	F2264	PND37	On Pond	G2 NE	99.73	BMTL
Stal (i/s)	G75	PND47	Site G[3]	GA0997SE	99.8	BMTL
Stal (d)	B111	226a8	Int/Br	K21	99.07	OxTL
Stal (d)	B396	226e4	Base of Br	K20	99.07	OxTL
Stal (d)	B0b:1	226f2	Base of Br	K21		OxTL
Stal (d)	B0b:2	226f1	Base of Br	K21		OxTL
Stal (d)	D292	226e13	UB	K10	99.69	OxTL
Stal (d)	D446	226e9	UB	H8	99.78	OxTL
Flint (d)	D4367	PND25	Top of LB	K8 NE	99.49	BMTL
New Entrance Area H						
Sediment (i/s)	H196	PND23	Scree 12		103.03	BMTL
Flint (d)	H598	PND33	26	AB994 NE	99.03	BMTL
Flint (d)	H1036	PND32	28	AB994 NW	98.80–98.70	BMTL
Stal (i/s)	H1713/2	PND41	31	AA994 SE	98.22–98.14	BMTL
Stal (d)	H1724	PND43	Scree; 50	AC991 SW/NW		BMTL
Stal (d)	H1725	PND44	Scree; 50	AC991 SW/NW		BMTL
Stone (d)	H2312	PND62	26	AB993S/AC993N	99.15–99.00	QTLS
Stal (d)	H3150	PND66	39	AC994 NW	97.09	QTLS

Abbreviations: (i/s) = *in situ*; (d) = derived; LSG = Lower Sands and Gravels; LT = Laminated Travertine; UB = Upper Breccia; LB = Lower Breccia; Br = Breccia; Int = Intermediate; OxTL = Research Laboratory for Archaeology, Oxford; BMTL = British Museum, Department of Scientific Research; QTLS = Quaternary TL Surveys, Nottingham.

Notes: 1 Interstitial calcite; 2 Probably *in situ*; 3 Stalagmitic floor between 2 and 3.

Table 11.1. Locations and descriptions of samples dated by TL.

occurred. The first requirement is fulfilled when, for instance, flint or stone is heated, stalagmite crystallizes, or sediment is deposited and exposed to light. Because the TL is zeroed (or greatly reduced) by these occurrences, the palaeodose evaluated from the present-day TL intensity can be interpreted as the quantity of radiation absorbed since the date of the event. Provided that the mean rate at which the radiation dose was received can also be evaluated, the date may be calculated.

For an assessment of the mean dose rate to be possible, the sample should ideally have lain undisturbed during its history. Furthermore, enough of the burial environment should be preserved to allow the contribution it has made to the sample's dose rate to be measured. This last condition is particularly important for flint and stalagmite samples, because the radiation dose received from the environment is often greater than that which the sample administers to itself.

In addition to the above conditions, it is required that the stored TL be adequately stable and that it does not saturate. The long-term stability of the TL has already been mentioned as a basic necessity, ensuring that there is no significant loss of the TL signal before it is measured in the laboratory. Saturation of the TL refers to the situation whereby, after a high dose of radiation, the TL capacity of the material is reached, and further doses produce no increase of TL intensity. Clearly, both instability and saturation prevent an accurate evaluation of the palaeodose, and therefore limit the age range over which the TL method may be applied.

None of the samples from Pontnewydd Cave, whether flint, stalagmite or sediment, have been limited by TL saturation. This is evident from the fact that further doses of artificial radiation, added to the palaeodose, have in all samples produced TL intensities well in excess of the natural TL. The loss of TL through decay cannot be so directly observed; it can only be deduced from wider studies comparing TL dates obtained from different materials, from comparisons with dates measured by other methods, or from correlations of date frequency distributions with known climatic fluctuations. In the case of flint, the evidence suggests that no significant loss of TL through decay has occurred since Marine Isotope Stage (MIS) 7. For stalagmites of this age, if an instability is present its effect is not larger than the typical TL date error limit, or 15%. In contrast, the TL dating of sediments is severely limited by instability to the last 150,000 years.

Palaeodose evaluations

Table 11.1 lists the stratigraphic details and find locations of twenty-four samples of stalagmite, sediment, flint and

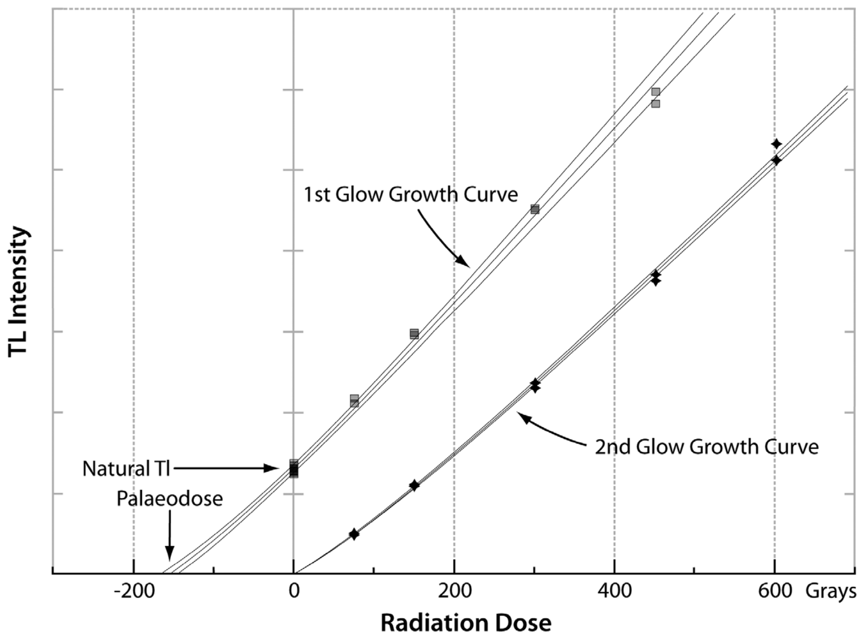

Figure 11.1. TL measurements of stalagmite, H3150 (PND66)

stone which have been dated by TL. While procedures for measuring palaeodoses are similar for flint, stone and stalagmite, they are to some extent different for sediment. To prepare the former materials, the outer 2 mm of each piece are cut away to remove those parts that have been exposed to light and to the alpha and beta activity of the burial soil. The interior piece is then crushed, and two different grain sizes are selected for TL examination. Large grains, of size 75–125 μm, are sprinkled onto stainless steel discs. Fine grains (approximately 2–10 μm) are deposited from suspension in acetone onto aluminium discs.

The set of large grain discs is used for the main palaeodose evaluation. About half of the discs are irradiated with varying doses from a beta radiation source, while the rest are left un-irradiated. The TL intensities of the un-irradiated discs yield the natural TL level. Together with the emissions of the irradiated discs, these measurements are referred to as the first glows, and they demonstrate the growth of TL intensity as increasing radiation doses are added to the palaeodose. The palaeodose is evaluated by extrapolating the growth of the TL backward to zero intensity.

For both flint and stalagmite, palaeodose evaluation is complicated by the fact that the growth of TL vs. radiation dose follows a non-linear curve. Clearly, it is necessary to know how the TL accumulated while the sample was buried, and this is discovered by a further set of TL measurements, known as the second glows. Following the first glow measurements, sample discs are re-irradiated with various doses to induce new TL signals in them. The growth of TL vs. dose in the subsequent second glows then provides the template for extrapolating the first glow data. This method of palaeodose evaluation is illustrated in Figure 11.1, which compares the first and second glow growth curves of the stalagmite, H3150 (PND66).

Alpha radiation produces TL in a manner different from that in which beta and gamma radiations act. In particular, the TL producing efficiency of alphas relative to other rays varies between different samples of flint or stalagmite. This relative efficiency is expressed as a b-value, which is measured by comparing the intensities of TL induced by known doses of alpha and beta radiations. Because alpha rays have very low penetration, thinly deposited fine grain discs must be used for this measurement. Table 11.2 lists the b-values obtained.

For sediment dating, a slightly different procedure is used for the palaeodose evaluation. The date of deposition is measurable because one of the TL signals present in sediments is greatly reduced, or bleached, by the exposure to daylight which accompanies the event. Care must be taken when collecting sediments for TL dating to avoid light exposure, and outer parts of the sample, which may have been exposed, are subsequently removed. Fine grains are selected and deposited onto a set of aluminium discs for TL examination.

About half of these discs are used for natural and first glow TL measurements, as described for flint and stalagmite. The rest of the discs are exposed to daylight for a few days to remove the bleachable part of the TL signal, and are then irradiated with various beta or alpha doses to regenerate their TL signals. After measurement of these TL emissions, it is possible to evaluate the dose which regenerates a TL intensity equal to that of the natural material. This quantity of radiation, which is termed the natural regeneration dose, can be identified with the palaeodose by virtue of the observation that bleaching does not alter the efficiency of TL production. The palaeodose shown in Table 11.2 for the sediment H196 (PND23) is the natural regeneration dose of beta radiation, while the b-value shows its relationship to the alpha dose which had the same effect.

Sample	*Find no. (Lab ref.)*	*Lab ref.*	*Palaeodose (Grays)*	*b-Value (Gy.μm^2)*	*Internal dose rate (Gy/ka)*	*External dose rate (Gy/ka)*	*TL Age (ka BP)*
Main Cave Areas B, C, D, F and G							
Stal	B409	226g1	243 ± 17	3.80	0.43	0.88	210 ± 70
Stal	B556	PND42	146 ± 7	2.30	0.489	0.88	115 ± 46
Stal	D118	226a1	22 ± 11	3.77	0.38	0.62	27 ± 14
Stal	D471	226e6	227 ± 27	3.65	0.59	0.77	188 ± 35
Stal	D604	226e14	207 ± 20	2.57	0.14	0.82	222 ± 42
Stal	D1693	226h3	174 ± 12	2.81	0.41	0.68	177 ± 30
Stal	D1711	226h21	172 ± 14	2.37	0.20	0.86	173 ± 23
Stal	F2264	PND37	121 ± 9	2.48	0.253	0.595	141 ± 29
Stal	G75	PND47	88 ± 5	1.29	0.122	0.988	87 ± 14
Stal	B111	226a8	160 ± 19	4.36	0.84	0.96	115 ± 21
Stal	B396	226e4	200 ± 15	6.51	1.61	1.09	107 ± 15
Stal	B0b:1	226f2	162 ± 17	7.11	1.02	1.05	108 ± 18
Stal	B0b:2	226f1	143 ± 17	4.62	0.59	1.05	113 ± 19
Stal	D292	226e13	134 ± 19	3.17	0.41	0.73	139 ± 29
Stal	D446	226e9	134 ± 34	2.83	0.14	0.61	196 ± 54
Flint	D4367	PND25	298 ± 30	1.33	0.225	0.884	269 ± 37
New Entrance Area H							
Sediment	H196	PND23	155 ± 26	0.99	2.956	0.940	32 ± 6
Flint	H598	PND33	173 ± 15	2.35	0.205	0.761	179 ± 22
Flint	H1036	PND32	247 ± 17	1.89	0.631	0.794	173 ± 20
Stal	H1713/2	PND41	178 ± 11	4.02	0.868	1.105	101 ± 25
Stal	H1724	PND43	103 ± 5	3.43	0.154	0.534	154 ± 36
Stal	H1725	PND44	86 ± 5	3.53	0.276	0.432	130 ± 29
Stone	H2312	PND62	452 ± 17	2.70	1.300	0.783	214 ± 21
Stal	H3150	PND66	155 ± 8	3.98	0.228	0.518	226 ± 21

Notes. Uncertainties in the b-value lie mostly in the range from ±8% to ±24%; those for the internal dose rate, from ±10% to ±23%; and those for the external dose rate, from ±7% to ±22% (excepting samples B409 and B556, whose external dose rates have uncertainties of approximately ±35%). The internal dose rate gives the present-day effective dose rate due to alpha and beta radiations; the external dose rate is that due to gamma and cosmic radiations.

Table 11.2. TL date measurements of samples from Pontnewydd Cave.

Dose rate assessments

The radiation dose absorbed by a TL sample during its period of burial is composed of two parts. The internal dose is that imparted by the short-ranged alpha and beta rays originating within the sample. The external, or environmental, dose is mainly due to gamma rays which are emitted by the surrounding soil, and which can penetrate up to 30 cm before losing energy in the TL sample. The external dose also includes a small contribution from cosmic rays. Flint and stalagmite generally have a low content of radioactivity, and in consequence, the absorbed palaeodose is often dominated by the external gamma dose. Therefore, the confidence with which the external dose rate can be assessed is the principal factor in determining the precision of the date measurement.

The typical cave environment is extremely inhomogeneous in its radioactive content. The recovery of the TL sample inevitably results in some destruction of its burial environment, and it is sometimes difficult to assess accurately the external dose rate to which the sample was exposed. Where possible, use is made of surviving sections of the burial soils which can, with varying degrees of confidence, be taken as representative of the destroyed deposit. The error limits of the date measurements listed in Table 11.2 mainly reflect the uncertainty of the external dose rate assessment. Most notably, the very low dating precision for the interstitial calcites from the Lower Sands and Gravels is due to the large variability of gamma dose rate within this deposit.

Most of the external dose rate assessments in this study were performed by means of capsules containing a sensitive TL dosimeter (calcium fluoride). The capsules were buried for approximately one year in the burial soils, and at the end of this time the dose absorbed by the calcium fluoride was measured. Alternatively, external dose rates were measured using a portable gamma spectrometer. This method not only avoids the delay inherent in the use of capsules, but also identifies the sources of the gamma rays. Internal dose rates were measured in the laboratory by observing the alpha activities of the TL samples, and by analysis of their potassium contents. Assessments of the present-day internal and external dose rates are shown in Table 11.2.

TL Dates

The TL measurements, described above, yield the present natural TL intensity of the examined material, and the manner in which the TL increased with radiation exposure.

The dose rate assessments allow us to calculate how the radiation dose accumulated with time. By combining these measurements, the age of the material can be obtained as the length of time required for the different forms of radiation to induce TL levels which sum to the observed natural intensity. In the case of stalagmitic material, allowance must be made for the changing internal dose rate which results from the increasing presence of thorium-230 and its decay products. (This phenomenon provides the basis of the uranium series disequilibrium dating method.) The external dose rate may also vary with time, mainly as a consequence of varying water content in the burial deposits. The water acts as a radiation shield, absorbing gamma energy which might otherwise be received by the TL sample. It is therefore necessary to estimate a range of values within which the average past water content of the deposits is likely to have lain. The uncertainty associated with this range is incorporated in the error limits of the TL date measurement.

The calculated TL dates are listed in Table 11.2. The quoted error limits include all sources of error, both random and systematic, and represent the 68% confidence level. Four TL dates refer to the heating of flint or stone. If this heating did not coincide with the human occupation itself, it must certainly have occurred while the material remained at ground surface. The TL date of the flint, D4367, lies separate from an otherwise tight grouping formed by the other three (H598, H1036 and H2312). However, taking its error limits into account, there is insufficient evidence from TL dates for proposing more than a single period of occupation. The weighted mean of the four dates yields a best estimate of 196,000±19,000 BP for the heating of the flint and stone pieces. This is in good agreement with the TL date of 200,000±25,000 BP obtained for the flint D687 (OxTL 226d1) by Huxtable (1984).

The dated stalagmitic material falls mainly into two categories; that formed *in situ*, which provides a chronological marker in the stratigraphy, and derived material, whose formation must pre-date the deposit within which it occurs. A third category comprises the interstitial calcites, B409 and B556, which must have formed after the deposition of the Lower Sands and Gravels. Together with the uranium series disequilibrium dates on stalagmite from the cave, the TL dates serve to constrain the chronology of the various emplacements, and to relate the stratigraphic units uncovered in the Main Cave with those in the New Entrance.

Among the *in situ* stalagmites, samples D471, D604, D1693 and D1711 all formed on top of the Lower Breccia in the Main Cave. Their TL dates are mutually consistent and indicate an age of formation between 170,000 and 200,000 BP. This is earlier than the formation of the derived stalagmite from Layer 31 in the New Entrance, H1713, whose TL date places it in the Last Interglacial (this stalagmite had been erroneously interpreted as *in situ* in Aldhouse-Green 1995). The derived pieces of stalagmitic floor (B111, B396, B0b:1 and B0b:2) form a clearly defined set of samples. Their TL dates are closely grouped, suggesting that all pieces derived from the same formation, and indicate a Last Interglacial age for the floor. They were published in Schwarcz (1984) as having been found at the base of the Breccia in the Main Cave or at its boundary with the Intermediate unit. But this was commented on by Green (1984, 30) where he suggests that these stalagmites can only be referred to somewhere in the Upper Breccia/Intermediate sequence as a whole.

The TL date of sediment, H196, relates to the scree deposition which covered the New Entrance.

Speleothem U-Series dating: University of East Anglia alpha spectrometry results

Peter Rowe, Tim Atkinson and Nick Hebden

Sampling

Most speleothem samples were collected by the archaeological team during the course of excavation, although a few were collected by the authors under the supervision of Stephen Aldhouse-Green.

Sample selection and treatment

Typically 20–60 g of calcite were used for dating. Selected layers of interest were cut from the main calcite body using diamond-edged circular or diamond wire saws, avoiding dirt bands (hiatuses) and vuggy areas as far as possible, and crushed to a powder in a tungsten mill.

Chemical procedures

The calcite powder was slowly added to 1–2 litres of constantly stirred dilute (1M) nitric acid solution to which had been added a weighed amount of spike solution which was in secular equilibrium ($^{228}Th/^{232}U = 1.027$). Following dissolution and subsequent filtering to remove insoluble detritus (generally <1%), the solution was boiled to reduce volume and remove dissolved CO_2. A few milligrams of $FeCl_3$ was added and the pH of the solution raised to ~9 to co-precipitate uranium and thorium with $Fe(OH)_3$. The bulk of the supernate was decanted and the precipitate centrifuged down before being dissolved in a few millilitres of 9M HCl and passed through a pre-washed anion exchange column (Bio-Rad AG 1-X8 100–200 mesh) to separate uranium and thorium isotopes. These were then further purified from interfering elements on additional exchange columns in 7M HNO_3 and the final eluate evaporated and electroplated in ammonium sulphate solution onto stainless steel discs for counting.

Alpha spectrometry

The isotopes were counted on EG and G Ortec 576A alpha spectrometers with efficiencies of ~36% and resolution of 10MeV (FWHM). Several thousand counts were accumulated under the main isotopic peaks of interest to minimize age errors. The raw spectrometric data were background corrected and input to a computer programme to iteritively solve the ^{230}Th/^{234}U age equation.

Results

Table 11.3 summarizes the results for the 9 samples analysed.

Discussion

The speleothem growth phases recorded by these samples correspond, within the dating errors, to interglacial or interstadial periods (table 11.3). F5084a is beyond the range of the dating method (>300,000 years ago) and no conclusion can be reached regarding this sample. A517 is heavily contaminated with detritus and the corrected age of 81,500 (MIS 5a) is an estimated age based on assumptions about the thorium isotopic composition of the detritus (see Table 11.3). It is possible that its true age is younger and that it grew during an interstadial phase in MIS 3. Although the ages of D5901 and H2217 do not precisely correspond with warm phases, the dating errors easily allow the former to be correlated with MIS 5e and the latter with MIS 7.3 or 7.5. H2216 has an apparent age of 269,400 BP, placing it in MIS 8. Whilst this may be the case since it is not known to have been a period of extensive lowland glaciation in the British Isles, the dating errors allow correlation with MIS 9 but suggest it is unlikely to date from MIS 7.5.

Electron Spin Resonance dating of tooth enamel from Pontnewydd Cave

E. J. Rhodes, R. Grün and L. P. Zhou

Introduction

Electron Spin Resonance (ESR) age estimates have been derived for several mammal teeth or tooth fragments collected from excavations within Pontnewydd Cave (Table 11.4). ESR dating was undertaken in two campaigns. One series of tooth samples was prepared and measured by Rainer Grün (RG series samples), while the second series was prepared and measured jointly by Ed Rhodes and Li Ping Zhou (EJR-LPZ series). A similar approach for sample preparation and analysis was adopted in both campaigns, and determinations were made using similar ESR measurement parameters. The results form an internally coherent group of age estimates, despite significant variations in internal uranium content between several samples.

Although hydroxyapatite from teeth contains a strong ESR signal from which precise values of equivalent dose can be measured, teeth absorb uranium during burial from ground water (Grün and Invernati 1985). Uncertainty in the pattern of uranium uptake, besides its spatial distribution within each of the different tooth materials (enamel, dentine, cement), leads to uncertainty in the final ESR age estimates. Uranium uptake can be modelled (Grün *et al*. 1988), though such models may not accurately reflect the reality of uranium migration, particularly in cave environments (Grün 2009b). Additionally, recent research casts some doubt on the validity of conventional ESR equivalent dose determinations and suggests that ESR age underestimates may be encountered (Joannes-Boyau and Grün 2011). Notwithstanding these caveats, we present the ESR age determinations made for samples from Pontnewydd Cave.

Sample preparation and measurement

Samples were prepared by cutting one or more panels of enamel from each tooth, recording the initial thickness, then grinding the outer layers to remove the surface (see Table 11.4 for details). The remaining enamel was ground using an agate pestle and mortar, and sieved. A subsample was removed for U content analysis. For the single enamel samples removed from teeth E80 and E81 (EJR-LPZ series), the remaining enamel was divided into 4 different grain size fractions, to assess whether there were any systematic variations in accumulated dose value. Each sample was weighed out into 10 equal aliquots to within ±0.5%, and these were administered a range of different gamma dose values.

Room temperature X-band ESR measurements (9.16 GHz) were made using a microwave power of 2mW, modulation frequency of 100kHz and modulation amplitude of 0.5mTpp. For the RG sample series, measurements were made using a Bruker 100 ER spectrometer at McMaster University, Canada (sample D2312 only) or a JEOL RE1X at Cambridge, UK, while for the EJR-LPZ series samples, determinations were performed using a small bench-top Bruker spectrometer at Royal Holloway, University of London.

Age estimation

For both measurement series, equivalent dose values were determined using a conventional multiple aliquot additive dose procedure (Grün 1989). Additive dose curves were constructed for each group of aliquots by fitting an exponential function and extrapolating to zero ESR signal intensity in order to derive an equivalent dose estimate. Age calculations were performed using the DATA program of Grün (2009) using the parameters shown in Table 11.4, and incorporating the most recent values for beta attenuation, uncertainty propagation, energy conversion and other factors. Internal uranium concentrations for enamel and dentine were measured by delayed neutron counting at XRAL, Ontario, Canada. Sediment U, Th and K concentrations were measured by instrumental neutron activation analysis (INAA), also performed at XRAL. Gamma dose rates were not measured directly, but were calculated based on U, Th and K concentrations of sediment from appropriate locations within the cave. Sediment beta dose rates were based on sediment collected with each tooth, or from values measured from the appropriate horizon.

Sample lab. ref.	*Site ref.*	*Yield U %*	*Yield Th %*	*U ppm*	$\frac{^{234}U}{^{238}U}$	*Error*	$\frac{^{230}Th}{^{234}U}$	*Error*	$\frac{^{230}Th}{^{232}Th}$	*Error*	*Age (ky) uncorrected*	*Age (ky) corrected*	*Marine Isotope Stage*
UEA771	F773 Top*	71	74	0.69	1.0841	0.0153	0.6844	0.0141	267.0	39.0	122.4+5.2/-4.9	122.4+5.2/-4.9	5e
UEA772	A517	83	27	0.32	1.0358	0.0221	0.6186	0.0180	2.6	0.1	103.8+5.7/-5.3	81.5+-6.4/-6.1**	5a
UEA773	F5084a	79	30	0.48	1.1148	0.0240	1.0761	0.0311	6.3	0.2	>350	>350***	---
UEA774	F4894	77	55	0.31	1.1326	0.0158	0.9154	0.0183	74.0	8.2	237.3+20.3/-16.9	237.3+20.3/-16.9	7.5
UEA775	D5901 Base	55	47	0.76	1.0489	0.0184	0.7240	0.0198	90.5	10.3	137.4+8.6/-7.9	137.4+8.6/-7.9	5e
UEA644	D4698	46	71	0.90	1.0713	0.0231	0.6657	0.0326	100.3	10.4	116.8+10.6/-9.7	116.8+10.6/-9.7	5e
UEA646	F2996	47	55	0.49	1.1151	0.0219	0.8581	0.0362	215.9	37.1	197.5+25.1/-20.6	197.5+25.1/-20.6	7.1
UEA683	H2216	52	30	0.39	1.1006	0.0120	0.9408	0.0184	18.2	0.8	269.4+24.0/-19.9	265.3+28.5/-22.4	9?
UEA684	H2217	51	5	1.16	1.0662	0.0147	0.8880	0.0256	88.9	8.4	224.8+23.2/-19.2	224.8+23.2/-19.2	7.3/7.5

Errors are 1 s.d. based on counting statistics. Samples with ^{230}Th/^{232}Th ratios <20 are detritally contaminated and calculated uncorrected ages therefore are maximum possible ages. Corrected ages for these samples are calculated assuming that the initial (^{230}Th/^{232}Th) value of the contaminanating detritus was 0.8, representing an average crustal value assuming equilibrium in the ^{238}U decay chain. * F773: the dated sample is one of several stalagmite bosses on the upper surface of this flowstone; the base of F773 has not been dated because its internal structure is quite complex, it is generally vuggy, and it contains several broken pieces of older stalagmite that have fallen and been incorporated within the younger calcite. ** A517: this sample is heavily contaminated with detritus and a corrected age is very sensitive to choice of (^{230}Th/^{232}Th)$_{\text{initial}}$ value and although the Marine Isotope Stage 5a corrected age is plausible, the true age could be younger and lie within MIS 3. *** F5084a: This sample is heavily thorium contaminated and correction using a (^{230}Th/^{232}Th)$_{\text{initial}}$ ratio $\leq$4 does not produce a finite age.

Table 11.3. U-series dating results.

Lab. code	*Find no.*	*Layer*	*Grid square*	*X*	*Y*	*Depth below S.D.*	*Description*
EJR-LPZ series samples							
E75a	F2853	LBc	I1NE			99.32–99.22	*Stephanorhinus* sp. tooth fragment
E78a	D2909	LB	H9NE	45	78	99.24	*Stephanorhinus* sp. tooth fragment
E80a, b, c, d	C286	LB	L13NW	44	49	99.01	*Stephanorhinus kirchbergensis* tooth fragment
E81a, b, c, d	C189	LB	M13NE	47	68	99.37	*Stephanorhinus* sp. tooth fragment
E82a, b	B440		K22SW	65	6	99.44	*Stephanorhinus* sp. tooth fragment
RG series samples							
394	D2312	LB	J7SW			99.05–98.95	Unidentified tooth
570	H428	24	AB994NW	37	12	99.25	? Bovid tooth
589	D358	LB	H9SW/SE				*Stephanorhinus* sp. tooth
590	C119	LB	M13NW			99.13	*Stephanorhinus* sp. tooth fragment
591	D2121	LB	I7NW			99.10–99.00	*Cervus elaphus* M_3

Table 11.4. ESR sample locations and descriptions.

Dating results

ESR age estimates, and the parameters used in their calculation are presented in Table 11.5, integrating samples from both sample series and listing the results in approximate stratigraphic order within the cave. Following the usual format adopted for ESR, age estimates are presented based on different models of uranium migration into the teeth, specifically on early uptake (EU) and linear uptake (LU) models. Additionally, age estimates assuming a recent uptake (RU) model are presented. It should be noted that these uptake models implicitly assume that all uranium in a given tooth sub-sample was acquired from ground water in a uniform fashion, a condition not likely to pertain in reality.

The age estimates mostly lie in the range of 100–300 ka. No single uptake model provides ages that are entirely consistent, though the recent uptake (RU) ages have the smallest fractional variation between results.

Discussion and conclusions

A striking features of the ESR age estimates is the consistency between the two sample series, measured at different times using different equipment. However, variation exists for the age estimates of teeth nominally from the same horizon. For the samples from the Lower Breccia (layer LB in Table 11.5), the variation between samples represented by one standard deviation is around twice the mean uncertainty value for the recent uptake model age estimates.

Several caveats to these conventional ESR age estimates have been mentioned above. These include differences in uranium uptake pattern experienced by different teeth and within single teeth, leading to apparent age variation, and also recently described problems associated with differential response of tooth enamel ESR centers to beta and gamma radiation (Joannes-Boyau and Grün 2011). This latter effect may lead to age underestimates of up to 30%; variations in magnitude may exist between species and the effect may possibly also be dependent on age and tooth type. The complexities of cave stratigraphy should also be borne in mind when considering these results.

In summary, ESR age estimates for 11 teeth or tooth fragments provide ages between 90±6 ka and 232±14 ka (EU), 108±8 ka to 274±19 ka (LU) or 132±12 ka to 322±29 ka (RU). Problems associated with the conventional ESR dating approach used here that have only recently been identified, besides better understood issues of complex uranium uptake and migration within teeth, render these age estimates difficult to interpret in a more detailed manner. However, future ESR dating application, for example incorporating laser ablation ICP-MS uranium determinations and investigation of the relative contributions of different CO_2– radicals responsible for the ESR signal, may be able to overcome these current limitations.

A summary of the chronological evidence from Pontnewydd Cave

Nicholas C. Debenham

Introduction

The programme of absolute age measurements on materials excavated from Pontnewydd Cave has had two principal objectives. These are (i) to date the human occupation of the site, and (ii) to date the emplacement of the remains of that occupation within the cave. Regarding the date of occupation, the most direct evidence is provided by thermoluminescence (TL) date measurements on five heated archaeological flints which derived from the cave deposits. For the second objective, the clearest indications are provided by measurements on *in situ* stalagmitic formations, especially those which mark the interval between the Lower Breccia and Upper Breccia emplacements. A total of thirty-one samples of *in situ* stalagmite were dated using the uranium series disequilibrium technique, of which nine were also dated by TL. In addition, date measurements were performed on forty-three samples of derived materials, including stalagmitic fragments, bone and teeth, by means of U-series, TL and electron spin resonance (ESR) procedures.

Tables 11.6 and 11.7 list details of the available dating evidence for *in situ* and derived samples, respectively. The data are sub-divided according to the stratigraphic unit to which they relate, and then ordered by find number of the dated sample. Summaries of the data are presented graphically in Figures 11.2 and 11.3. Uncertainties attached to the date measurements are expressed by the error limits which accompany the central date values. In the present data sets, error limits refer to the 68% confidence level. When comparing dating evidence from a variety of measurement techniques, it is useful to distinguish three categories of uncertainty. The first source of uncertainty is directly related to the measurement procedures in the laboratory and field. These measurement errors, whether random or systematic, are quantifiable by normal scientific methods and should always be included in the calculation of the date error limits.

The second category includes estimated corrections that are applied to the date calculations. Examples of these adjustments are the detrital thorium correction in the U-series method, and the correction of the dose-rate assessment in TL dating to allow for possible long-term variations in environmental factors. Where such corrections are applied, the additional uncertainty that they introduce should also be included in the date error limits. The third category of uncertainty arises from the possible invalidity of assumptions which form the basis of the dating method. In TL dating of stalagmites, it is assumed that the speleothem has not partly or wholly re-crystallized since its original formation. In U-series dating, the stalagmite is assumed to be a perfect time capsule, and that no uranium or thorium has passed into or out of the sample during its history. The effects on measured dates caused by failures of these assumptions are unquantifiable, and are therefore

														ESR age estimates								
Find no.	***Lab. code***	***De (Gy)***		***De error (Gy)***	***U-EN (ppm)***	***U-DE (ppm)***	***U-SED (ppm)***	***Th-SED (ppm)***	***K-SED (%)***	***Gamma dose rate (µGy/a)***	***Water in sediment (%)***	***Enamel thickness (µm)***	***Removed either side (µm)***	***EU (ka)***		***EU error (ka)***	***LU (ka)***		***LU error (ka)***	***RU (ka)***		***RU error (ka)***
H428	570A	254	±	7	1.17	54.3	5.81	13.0	2.25	1370	20	1230	20	102	±	7	124	±	9	153	±	14
	570B	219	±	7	1.11	54.3	5.81	13.0	2.25	1370	20	1350	20	90	±	6	108	±	8	132	±	12
H359	E83A1	207	±	7	0.30	51.2	6.23	7.2	1.22	630	15	2335	115	186	±	14	227	±	18	280	±	26
F2853	E75A	445	±	13	0.40	91.1	13.2	11.5	2.13	1370	15	1500	100	177	±	13	217	±	17	269	±	25
D2909	E78A	276	±	9	0.30	45.8	14.2	12.3	2.13	1050	15	1680	100	155	±	11	179	±	14	206	±	18
D2312	394	227	±	6	0.17	8.96	9.47	16.0	2.93	880	20	800	20	140	±	9	149	±	11	163	±	13
	394A	312	±	9	0.13	29.1	9.47	16.0	2.93	880	20	900	20	170	±	11	196	±	14	224	±	18
	394B	306	±	11	0.53	15.1	9.47	16.0	2.93	880	20	700	20	160	±	16	181	±	15	204	±	18
D358	589A	447	±	6	0.10	31.2	9.47	16.0	2.93	880	10	850	25	232	±	14	271	±	18	316	±	26
	589B	452	±	14	0.43	31.6	9.47	16.0	2.93	880	10	740	20	210	±	14	253	±	17	306	±	25
	589C	431	±	14	0.30	32.5	9.47	16.0	2.93	880	10	1050	25	232	±	15	274	±	19	322	±	29
D2121	591A	258	±	7	0.09	3.73	9.47	16.0	2.93	880	10	1900	50	215	±	17	222	±	18	227	±	19
	591C	267	±	6	0.01	3.73	9.47	16.0	2.93	880	10	1900	50	228	±	18	232	±	19	235	±	20
C286	E80A1	290	±	10	0.20	20.8	19.6	11.3	1.90	880	15	1900	120	214	±	17	234	±	19	253	±	22
	E80A2	291	±	11	0.20	20.8	19.6	11.3	1.90	880	15	1900	120	214	±	17	234	±	20	254	±	23
	E80A3	290	±	11	0.20	20.8	19.6	11.3	1.90	880	15	1900	120	214	±	17	234	±	19	253	±	23
	E80A4	293	±	12	0.20	20.8	19.6	11.3	1.90	880	15	1900	120	216	±	18	236	±	20	255	±	23
C189	E81A1	230	±	6	1.40	42.7	19.6	11.3	1.90	880	15	2000	120	127	±	9	159	±	11	202	±	18
	E81A2	226	±	7	1.40	42.7	19.6	11.3	1.90	880	15	2000	120	126	±	9	157	±	12	199	±	18
	E81A3	229	±	7	1.40	42.7	19.6	11.3	1.90	880	15	2000	120	127	±	9	159	±	12	202	±	18
	E81A4	225	±	7	1.40	42.7	19.6	11.3	1.90	880	15	2000	120	125	±	9	156	±	11	198	±	18
C119	590A	254	±	7	0.36	63.5	19.6	11.3	1.90	880	10	1500	50	140	±	9	171	±	12	213	±	18
	590B	247	±	6	0.68	49.3	19.6	11.3	1.90	880	10	1600	50	140	±	9	170	±	12	210	±	18
B440	E82A1	298	±	8	1.00	134	19.6	11.3	1.90	880	15	2320	115	143	±	10	190	±	14	262	±	23
	E82A2	293	±	10	0.80	111	19.6	11.3	1.90	880	15	2010	110	145	±	11	188	±	14	257	±	23

Table 11.5. ESR age estimates and parameters used in age calculations..

Find no. (Sample no.)	***Layer***	***Square***	***Depth S.D.***	***Age ka***	***Method***	***Dated by***	***Notes***
A517 (UEA772)	---	F37	99.78	103.8 +5.7/-5.3	U u	UEA	Stalagmite on north wall of the Entrance outside the Guard Chamber
				81.5 +6.4/-6.1*	U c		* Sensitive to (230Th/232Th)init value
D188 (226a1)	LT	H6	---	13 +7/-6	U c	RLA	Laminated travertine
				32 +12/-11	U c		
				15 ± 7	U c		Mean of 3 U-series dates: 17 ± 5 ka
				27 ± 14	TL	RLA	
D4698 (UEA644)	---	G10NE	100.50	116.8 +10.6/-9.7	U c	UEA	High level wall stalagmite (North Passage)
D5901:base (UEA775)	---	K7NE	100.50	137.4 +8.6/-7.9	U c	UEA	High level wall stalagmite (South East Fissure)
G75 (PND47)	On LB	GAO997SE	99.8	87 ± 14	TL	BM	Stalagmitic floor above Lower Breccia
F2264 (PND37)	On Sb	G2NE	99.73	141 ± 29	TL	BM	Stalagmite
B274	On LB	J22NW	99.85	230 +21/-20	U u	MCM	Flowstone over Lower Breccia
				217 +24/-20	U c		
C0 (MCM-78852)	On LB	M13SE	99.33	189 ± 12	U u	MCM	Stalagmite Boss
				177 ± 12	U c		
C133 (Root of C0)	On LB	M13SE	99.33	> 350	U u	MCM	Interstitial calcite crust
D312 : top	On LB	K9NW	99.54-99.64	89.3 ± 2.7	U u	MCM	Base of stalagmitic pillar and part of apron
D312 : base				95.7 ± 4.3	U u		Mean of 2 dates: 91.1 ± 2.9 ka
D471 (226e6)	On LB	H7SE	99.45	174 +35/-27	U c	RLA	Stalagmite
				188 ± 35	TL	RLA	
D534 : 2	On LB	H11NE	99.50	227 ± 13	U u	MCM	Stalagmitic pillar
D534 : 3				300 +54/-37	U u		Mean of 2 dates: 232 ± 19 ka
D604 (226e14)	On LB	J9	99.67	161 ± 11	U u	MCM	Stalagmitic boss
				222 ± 42	TL	RLA	
D642	On LB	I7NW	99.44	95 ± 7	U u	MCM	Stalagmitic boss
				83 ± 9	U c		
D1288B:upper	On LB	J7NW	99.68	196 +27/-22	U u	MCM	Stalagmitic floor
D1288B:middle				257 +60/-40	U u		
D1288B:lower				193 +21/-18	U u		D1288B: mean of 3 dates: 215 ± 36 ka
D1288C:upper (HAR 2255)	On LB	J7NW	99.68	184 +26/-22	U	AEA	Stalagmitic floor
D1288C:upper (HAR 5612)				285 +71/-45	U	AEA	Upper: mean of 3 dates: 225 +44/-32 ka
D1288C:upper (HAR 5624)				205 +35/-27	U	AEA	
D1288C:middle (HAR 2256)				262 +69/-44	U	AEA	
D1288C:middle (HAR 5610)				238 +44/-33	U	AEA	Middle: mean of 4 dates: 218 +39/-29 ka
D1288C:middle (HAR				183 +20/-17	U	AEA	

5622)							
D1288C:middle (HAR 5623)				188 +25/-21	U	AEA	
D1288C:lower (HAR 2257)				239 +41/-31	U	AEA	Lower: mean of 2 dates: 229 +41/-32 ka
D1288C:lower (HAR 5621)				218 +42/-31	U	AEA	D1288C: mean of 9 dates: 223 +40/-31 ka
D1288D:base	On LB	J7SW	99.68	218 +33/-26	U	MCM	
D1693 (226h3)	On LB	G10		176 +29/-23	U c	RLA	Stalagmitic floor
				177 ± 30	TL	RLA	
D1711 (226h21)	On LB	J7		302 +inf/-74	U c	RLA	Stalagmitic floor
				173 ± 23	TL	RLA	
F1058	On LB	H1SW		100.4 +4.4/-4.2	U c	AEA	Stalagmite B. Cross Rift. Locally thin *in situ* floor on Lower Breccia (in East Passage)
F2996 (UEA646)		G2NW	99.73 (top)	197.5 +25.1 / -20.6	U c	UEA	Stalagmite A. East Passage. Wall stalagmite on north side of cave
F4894 (UEA774)	On LB	G2SE	99.54	237.3 +20.3 / -16.9	U c	UEA	Stalagmite B
F5383 (J5629)	On LB	I2NE	99.77-99.75	193 ± 12	U c	AEA	Stalagmitic pillar (top)
F5417 (J5632)	On LB	I2NE	99.65-99.60	134 ± 27	U c	AEA	Stalagmitic boss 220 x 190 x 50 mm thick
F5579:base (J5634)	On LB	G5NW	99.53	121 ± 9	U c	AEA	Stalagmitic pillar 130 mm high on small base (100x70mm)
F5579:base (J5628)				131 ± 5	U c		As above. Separate measurement on another aliquot from same final solution. Mean of 2 dates: 129±5 ka
F5579:top (J5979)	On LB	G5NW	99.53	88 ± 3	U c	AEA	As above
F6050 (J5631)	On LB	I2NE	99.80–99.68	86 ± 6	U c	AEA	Stalagmitic pillar (lower part)
B409 (226g1)	LSG 3	K17		243 +91/-48	U c	RLA	Interstitial calcite concretion
				210 ± 70	TL	RLA	
B556 (PND42)	LSG	Deep sounding	97.48	115 ± 46	TL	BM	Interstitial calcite concretion
H196 (PND23)	Scree; 12		103.03	32 ± 6	TL	BM	Sediment
H3202 (J5627)	(42)	AC993NW/AC994NE	96.50	91 ± 7	U	AEA	*In situ* floor below Mudstone Gravel (38); fragment 20-25 mm thick
H3221 (J5630)	(43)	AB994SE	96.95	85 ± 9	U	AEA	Fragment of flowstone on bedrock below Mudstone Gravel

Layers: LT = Laminated Travertine; Sb = Silt beds; LB = Lower Breccia; LSG = Lower Sands and Gravels.

Method: U u = Uranium series disequilibrium - uncorrected for detrital Th; U c = Uranium series disequilibrium - corrected for detrital Th; TL = Thermoluminescence.

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Table 11.6. Pontnewydd Cave in situ samples.

Find no. (Sample no.)	*Layer*	*Square*	*Depth S.D.*	*Age ka*	*Method*	*Dated by*	*Notes*
B260	RCE	K20	99.73	307 +44/-55	U u	MCM	Porous flowstone
B262	RCE	K20	99.74	179 ± 12	U u	MCM	Stalactite
B275	Interface of RCE /UB	K20	99.69	132 ± 4	U u	MCM	Stalagmite clast
Boa (MCM-78850)	UB1	K20		149 ±9	U u	MCM	Flowstone clast
BOb : 1 (MCM-78851) (226f2)	UB1	K21		236 +80/-46	U c	RLA	Flowstone
				130 ±7	U u	MCM	
				108 ± 18	TL	RLA	
BOb : 2 (226f1)	UB1	K21		244 +88/-46	U c	RLA	Flowstone
				204 ± 20	U u	MCM	
				113 ± 19	TL	RLA	
B111: 1-2 (226a8)	UB/Ic	K21	99.07	104 +14/-13	U c	RLA	Stalagmite block
				143 +20/-17	U c	RLA	Mean of 2 U-series dates: 118 +14/-13 ka
				115 ± 21	TL	RLA	
B148	UB	L21	99.28	209 ± 16	U u	MCM	Stalagmite clast
B279	UB	K20	99.62	227 +24/-20	U u	MCM	Stalagmite clast
B396 : 1-2 (226e4)	UB (base)	K20	99.07	118 +17/-15	U c	RLA	Stalagmite
				106 +15/-13	U c	RLA	Mean of 2 U-series dates: 111 +15/-13 ka
				107 ± 15	TL	RLA	
B440 (E82-A)	UB1	K22SW	99.44	143 ± 10	ESR e	LPZ/ER	*Stephanorhinus* sp. tooth fragment
				262 ± 23	ESR r		
				145 ± 11	ESR e	LPZ/ER	Mean e: 144 ± 9 ka
				257 ± 23	ESR r		Mean r: 260 ± 19 ka
D187	UB	I9NE	99.30	125 ± 6	U u	MCM	Stalactite
D292 : 1-2 (226e13)	UB	K10	99.69	160 +22/-18	U c	RLA	Stalagmite
				185 +45/-31	U c	RLA	Mean of 2 U-series dates: 165 +22/-18 ka
				139 ± 29	TL	RLA	
D303	UB	J8	99.87	t: 18.0±0.8 s: 33.0+4.6/-4.4	U	AEA	Bone: *Vulpes vulpes* (distal of end right femur)
D446 (226e9)	UB	H8	99.78	196 ± 54	TL	RLA	Stalagmite
D472	UB	I6	99.89	t (cancellous): 25.7 ± 5.9 t (cortical):	U	AEA	Bone: *Ursus* sp. ulna

				14.2 ± 0.8 s: 222.9 +115.4/-58.0			
F375/431: base	UB	H0NW		126 +8/-7	U c	AEA	Stalagmite boss
:top				99 +8/-7	U c		Additional determination from surface of boss. Mean of 2 dates: 113 ± 13 ka
F375/431: top	UB	H0NW	100.25	133 ± 7	U	MCM	Stalagmite boss, 42 cm thick. A core 34.9 cm deep was extracted by coring from upper surface of the boss
: middle				105 ± 5	U		Middle: between 10.0-15.7 cm deep
: base				131 ± 5	U		Mean of 3 dates: 121 ± 9 ka
F773: top (UEA771)	UB	G1SW/H1SW	99.16-99.76	122.4+5.2/-4.9	U	UEA	Rafted stalagmitic floor
D596	UB / LB Interface	H8	99.42	t: 16.0±6.9 s: 15.0±1.5	U	AEA	Bone: *Rangifer tarandus* phalange. (lacking prox. epiphysis).
D6058 (J5631)	sSb	H8NE	top 99.50 base 99.46	122 ± 2	U u	AEA	Inverted boss in base of Silt beds. Stalagmite boss and apron 70 x 70 x 33 mm (thick); incorporates soda straw stalactites
C119 (590a)	LB	M13NW	99.13	140 ± 9	ESR e	RG	*Stephanorhinus* sp. tooth fragment
				213 ± 18	ESR r		
(590b)				140 ± 9	ESR e	RG	Mean e: 140 ± 8 ka
				210 ± 18	ESR r		Mean r: 212 ± 16 ka
C189 (E81-A)	LB	M13NE	99.37	127 ± 9	ESR e	LPZ/ER	*Stephanorhinus* sp. tooth fragment
				202 ± 18	ESR r		
(E81-B)				126 ± 9	ESR e	LPZ/ER	
				199 ± 18	ESR r		
(E81-C)				127 ± 9	ESR e	LPZ/ER	
				202 ± 18	ESR r		
(E81-D)				125 ± 9	ESR e	LPZ/ER	Mean e: 126 ± 7 ka
				198 ± 18	ESR r		Mean r: 202 ± 14 ka
C286 (E80-A)	LB	L13NW	99.01	214 ± 17	ESR e	LPZ/ER	*Stephanorhinus kirchbergensis* tooth fragment
				253 ± 22	ESR r		
(E80-B)				214 ± 17	ESR e	LPZ/ER	
				254 ± 23	ESR r		
(E80-C)				214 ± 17	ESR e	LPZ/ER	
				253 ± 23	ESR r		
(E80-D)				216 ± 18	ESR e	LPZ/ER	Mean e: 214 ± 13 ka
				255 ± 23	ESR r		Mean r: 254 ± 15 ka
D358 (589a)	LB	H9SW/SE		232 ± 14	ESR e	RG	*Stephanorhinus* tooth
				316 ± 26	ESR r		
(589b)				210 ± 14	ESR e	RG	

				306 ± 25	ESR r		
(589c)				232 ± 15	ESR e	RG	Mean e: 224 ± 11 ka
				322 ± 29	ESR r		Mean r: 314 ± 22 ka
D809	LB	J8	99.27	t: 15.8 ± 0.9	U	AEA	Bone: *Ursus* sp. ulna
D1585	LB	H8SE	99.20-99.10	t: 147.1 +9.9 / -9.0	U	AEA	Bone: *Ursus* sp. metapodial
D2121 (591a)	LB	I7NW	99.10-99.00	215 ± 17	ESR e	RG	Tooth (M3) *Cervus elaphus*
				227 ± 19	ESR r		
(591b)				228 ± 18	ESR e	RG	Mean e: 221 ± 15 ka
				235 ± 20	ESR r		Mean r: 231 ± 17 ka
D2312 (394)	LB	J7SW	99.05-98.95	140 ± 9	ESR e	RG	Tooth
				163 ± 13	ESR r		
(394a)				170 ± 11	ESR e	RG	
				224 ± 18	ESR r		
(394b)				160 ± 16	ESR e	RG	Mean e: 153 ± 13 ka
				204 ± 18	ESR r		Mean r: 189 ± 19 ka
D2909 (E78)	LB	H9NE	99.24	155 ± 11	ESR e	LPZ/ER	*Stephanorhinus* sp. tooth fragment
				206 ± 18	ESR r		
D4367 (PND25)	Top of LB	K8NE	99.49	269 ± 37	TL	BM	Heated flint, pebble fragment
F2853 (E75)	LBc	I1NE	99.32-99.22	177 ± 13	ESR e	LPZ/ER	*Stephanorhinus* sp. tooth fragment
				269 ± 25	ESR r		
B162	Ic	L21	99.11	255 +89/-47	U u	MCM	Calcite coating on block
D584	LB/BI	J8	99.10	T: 24.6 ± 1.2	U	AEA	Bone: *Ursus* sp. phalange
D616	BI/OI	J9	99.01	T: 27.1 ± 3.8	U	AEA	Bone: *Ursus* sp. phalange
D687 (226d1)	BI	I9NE	98.97	200 ± 25	TL	RLA	Heated flint, discoidal core
H1724 (PND43)	50	AC991SW/NW		154 ± 36	TL	BM	Stalagmite
H1725 (PND44	50	AC991SW/NW		130 ± 29	TL	BM	Stalagmite
H3211:base [1] (J5634)	20	AE992NE	99.98	83 ± 3	U	AEA	Upper stalagmitic spread. Flowstone overlain by stalagmitic boss representing phase 2
:base 2 (J5978)				83 ± 6	U	AEA	As above: separate sample taken from different area of base
H359 (E83)	24	AA994SE	99.40	186 ± 14	ESR e	LPZ/ER	*Stephanorhinus* sp. tooth fragment
				280 ± 26	ESR r		
H428 (570a)	24	AB994NW	99.25	102 ± 7	ESR e	RG	? Bovid tooth
				153 ± 14	ESR r		
(570 b)				90 ± 6	ESR e	RG	Mean e: 95 ± 6 ka
				132 ± 12	ESR r		Mean r: 141 ± 12 ka
H598 (PND33)	26	AB994NE	99.03	179 ± 22	TL	BM	Heated flint, fragment of artefact

H2312 (PND62)	26	AB993S/AC993N	99.15-99.00	214 ± 21	TL	QTLS	Heated flint, retouched flake fragment
H1036 (PND32)	28	AB994 NW	98.80-98.70	173 ± 20	TL	BM	Heated flint, flake
H2216 (UEA683)	(b) of core=29	AB994SE	97.15-97.00	269.4 +24.0 / -19.9	U u	UEA	Stalagmite from the sediment core
				265.3 +28.5 / -22.4	U c		
H3096 (J5633)	31	AB994SE	97.16	94 ± 3	U	AEA	Derived stalagmitic floor in mudstone gravel. Fragment 40 mm thick
DUP (J5633)				113 ± 7	U	AEA	Mean of 2 dates: 97 ± 7 ka
H1713:top	31	AA994SE	98.22-98.14	132.0+8.2/-7.6	U	AEA	Derived stalagmite (previously identified as *in situ*)
:base				141.6+7.3/-6.8	U	AEA	Mean of 2 U-series dates: 137.3 +5.5/-5.1 ka
(PND41)				101 ± 25	TL	BM	
H2217 (UEA684)	(e) of core=38	AB994SE	95.90-95.80	224.8 +23.2 / -19.2	U c	UEA	Stalagmite from the sediment core
H3150 (PND66)	39	AC994NW	97.09	226 ± 21	TL	QTLS	Stalagmite

[1] These samples were recovered in cemented patches of Lower Breccia material which had been rafted within the Upper Breccia. See Green 1984, 96n.

Layer: RCE = Red Cave Earth; UB = Upper Breccia; Sb = Silt beds; LB = Lower Breccia; Ic = Intermediate complex; BI = Buff Intermediate; OI = Orange Intermediate.
Age: t = total bone sample; s = surface of bone. [N.B. ‘In general, Angela Rae regarded surface samples as the most reliable’.]
Method: U u = Uranium series disequilibrium - uncorrected for detrital Th; U c = Uranium series disequilibrium - corrected for detrital Th; TL = Thermoluminescence; ESR e = Electron Spin Resonance - assuming early uranium uptake; ESR r = Electron Spin Resonance - assuming recent uranium uptake.
Dated by: MCM = Henry Schwarz, Dept of Geology, McMaster University, Canada; AEA = Miro Ivanovich and Angela Rae, Atomic Energy Authority, Harwell, Oxford, UK; UEA = Peter Rowe and Timothy Atkinson, School of Environmental Sciences, UEA; RLA = Joan Huxtable, Nick Debenham and Mona Winter, Research Laboratory for Archaeology, Oxford University; BM = Nick Debenham, British Museum, London; QTLS = Nick Debenham, Quaternary TL Surveys, Nottingham; LPZ/ER = Li Ping Zhou, University of Cambridge, and Ed Rhodes, University of London, Egham; RG = Rainer Grun, Australian National University, Canberra.

Table 11.7. Pontnewydd Cave derived samples.

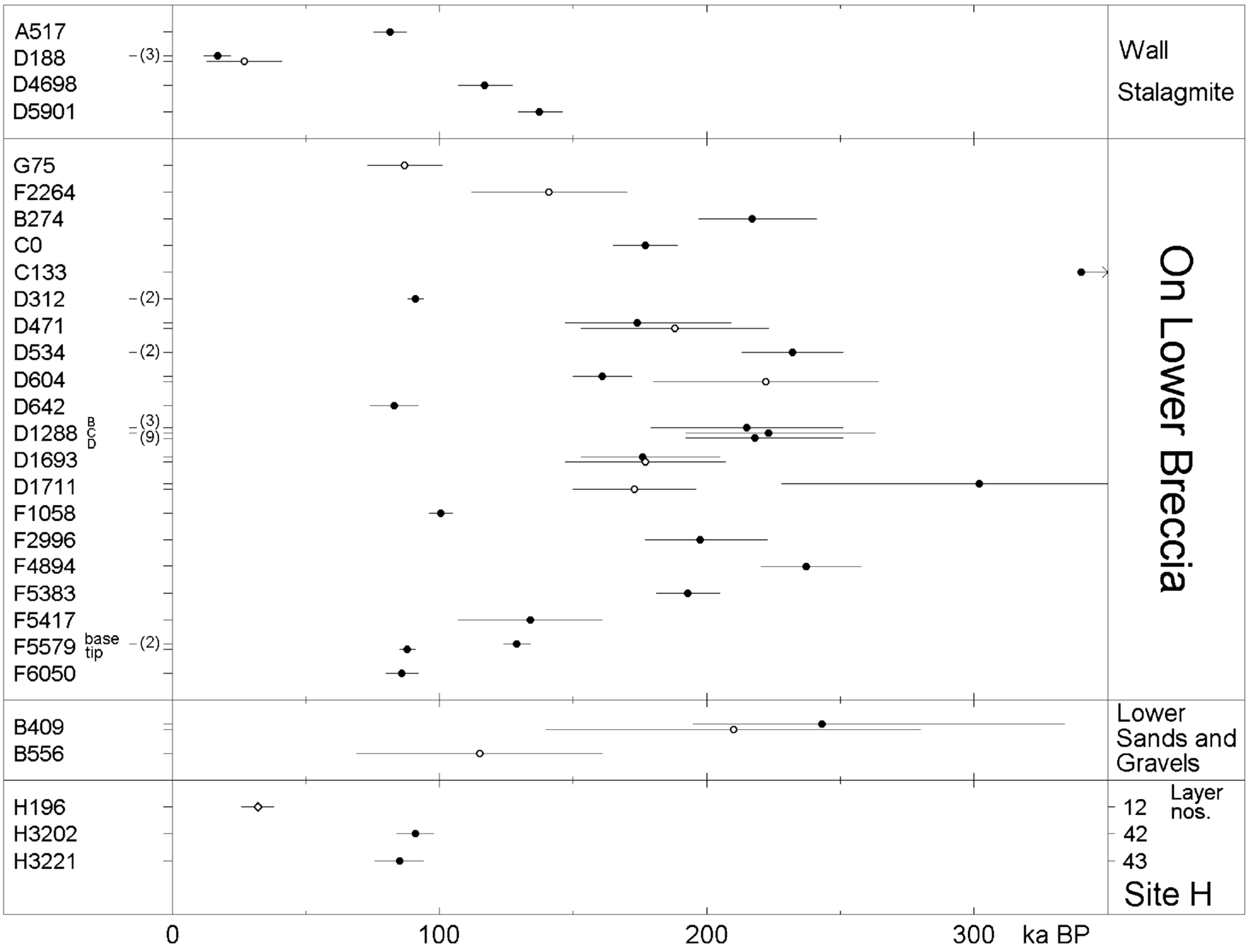

Figure 11.2. Date determinations on in situ samples from Pontnewydd Cave.

inexpressible in the quoted date error limits. However, since the effects generally differ from one dating technique to the next, an understanding of their scale may be gained by comparing the results from two or more methods.

Heated flint

Among the worked flints which were excavated from archaeological contexts, five pieces were found to be datable by TL. Two of these were found in the Main Cave; D687 in the Intermediate complex, and D4367 in the top of the Lower Breccia. The remaining three pieces were from Site H; H598 and H2312 from layer 26, and H1036 from layer 28. To be datable by TL, materials need to be exposed to temperatures in excess of 400°C, and it is clear that pieces must be on or very close to the ground surface for such heating to occur. It is not always certain whether the heating has resulted from human agency or natural fires. However, where heated materials are artefacts or closely associated with archaeological remains, the probability that the fire was of human origin is increased. With the possible exception of D4367, the dated flints from Pontnewydd Cave are worked pieces.

The five TL dates form a reasonably coherent data set which yields a weighted mean value of 197,000±17,000 BP. This is the best estimate for the date at which the archaeological material found in the Intermediate complex and Lower Breccia (Main Cave) and in Layers 26 and 28 (New Entrance) was heated on the surface. It is certain that the emplacement of the deposits from which the flints derived must post-date this event.

In situ *stalagmitic formations*

In the Main Cave, 29 samples of *in situ* travertine were dated by means of U-series and TL techniques. Twenty-three of these samples were taken from the stalagmitic floor which sealed the Lower Breccia, another four were attached to the cave walls at higher locations, and two were discovered in interstices within the Lower Sands and Gravels.

Stalagmite on the Lower Breccia Unit

The distribution of dates for the formation of the stalagmitic floor on the Lower Breccia is illustrated by the profile of date probabilities shown in Figure 11.4. The composition of the curve from U-series and TL data is also shown. It is clear that both methods support the interpretation that stalagmite formation occurred over an extended period of time. The precise form of the profile is not significant, depending

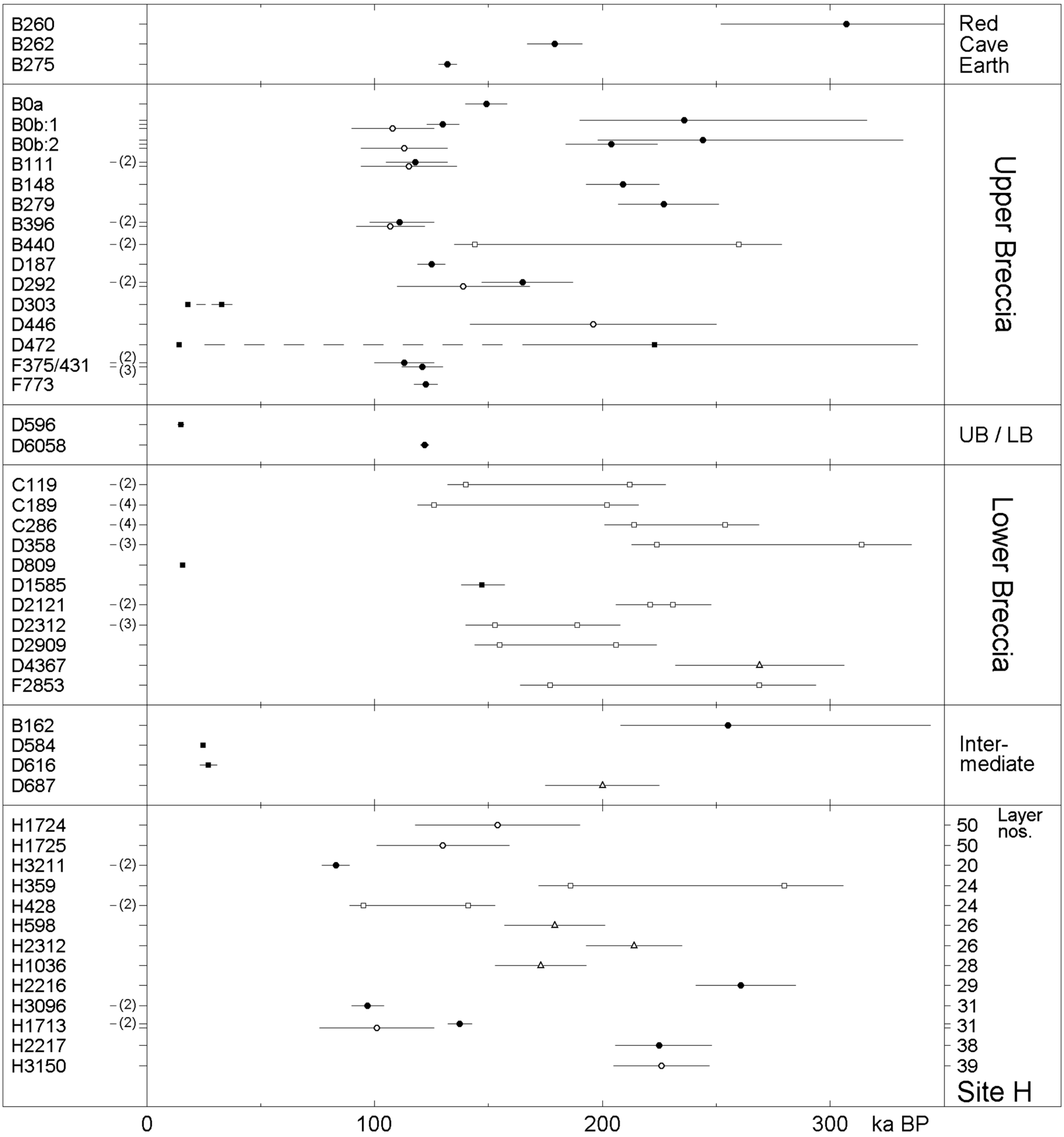

Figure 11.3. Date determinations on derived materials from Pontnewydd Cave.

as it does on a limited number of date determinations, but the curve appears to reveal episodes of enhanced stalagmite growth in MIS 7 and at the end of MIS 5. The low probability at the age of MIS 9 is expected given the presumption that Lower Breccia emplacement must post-date the heating of the flint artefacts (197,000±17,000 BP). However, there is a shoulder at approximately 225,000 BP on the profile of U-series dates which is inconsistent with this chronology.

Examining data from the Lower Breccia stalagmites more closely, it is found that only three out of the twenty-three samples (C133, D1711 and F4894) gave dates earlier than the heated flints to the extent that their error limits do not overlap, and that the discrepant dates are all from U-series measurements. The question therefore arises whether there are effects intrinsic to either U-series or TL methods that could account for this discrepancy. The uncertainties relevant to this question are those described in the introduction as of the third category, i.e. those which, resulting from failures of the basic assumptions, cannot be expressed in the date error limits. Comparisons between U-series and TL measurements on identical stalagmites present the best prospect for detecting such uncertainties.

Among the chronological data for Pontnewydd Cave, there are fourteen examples of U-series dates which can

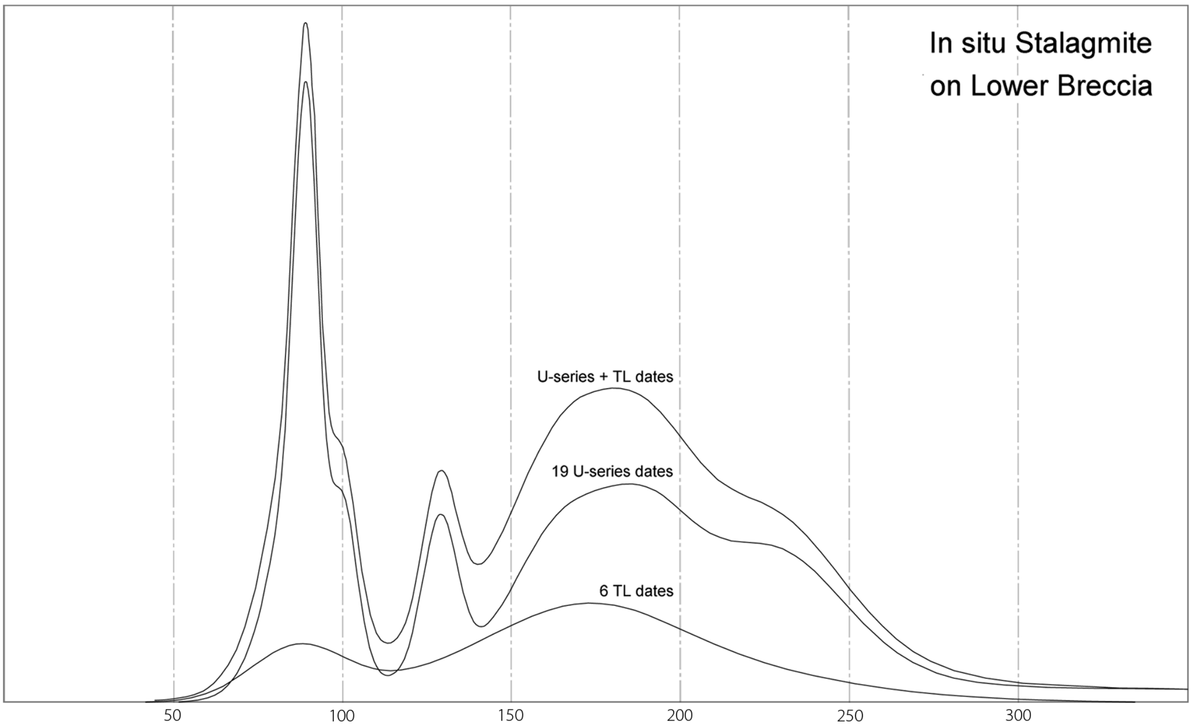

Figure 11.4. Distribution of date probabilities for in situ stalagmites on top of the Lower Breccia (Main Cave).

be directly compared with TL determinations. In six of the fourteen pairs, there is disagreement between the two measurements to the extent that their error limits do not overlap. This is a greater number than would be expected on statistical grounds. In all except one of the six discrepant pairs, the U-series ages are greater than the TL dates. This pattern accords with the view that TL measurements on stalagmites are prone to underestimate the true age while U-series dates tend to overestimation. In the case of TL, the explanation recognises that recrystallization of the calcite after its original formation can reduce the measured age. Similarly, recrystallization presents problems for U-series measurements. Discussing the dating of sample D534, Henry Schwarcz (1984) has referred to the possible leaching of radiogenic Th-230 from the surrounding limestone and its introduction into the stalagmite, thus causing the U-series date to over-estimate the true age. These effects are probably sufficient to account for both the observed pattern of TL and U-series comparisons, and the discrepancy between the alternative Lower Breccia emplacement dates as set, respectively, by the TL dates on heated flint, and by U-series measurements on *in situ* stalagmites. As a corollary, it should be inferred that a greater weight can be given to the eight cases in which the U-series dates and their TL counterparts are in agreement.

Wall attached speleothem

Four speleothems from *in situ* positions above the Lower Breccia were dated. Among them, two stalagmites attached to the cave wall (D4698 and D5901) produced U-series dates which are older than the youngest stalagmites on top of the Lower Breccia. At first sight, therefore, the dates appear to be conflicting. Both samples were located in Area D of the Main Cave (D4698 in the North Passage, and D5901 in the South-East Fissure) at an altitude approximately one metre above the stalagmitic floor on the Lower Breccia. Their U-series dates and error limits cover the range from 146,000 BP to 105,000 BP. It is interesting to note that no other *in situ* stalagmite from Area D has produced a date which encroaches upon this age range. Thus, D471, D534, D604, D1288, D1693 and D1711 all have lower age limits greater than 146,000 BP, while the date ranges of D312 and D642 are confined between 94,000 and 74,000 BP. It is not impossible, therefore, that in Area D a deposit temporarily covered the stalagmitic floor on the Lower Breccia to a depth of 1 m, and that D4698 and D5901 are the only remaining fragments of the stalagmites which formed on it.

Lower Sands and Gravels

Three date measurements were performed on calcite concretions in interstitial positions within the Lower Sands and Gravels. Assuming that the samples formed soon after the emplacement of the unit, they should not post-date by far the Intermediate and Lower Breccia emplacements. The TL date of sample B556 appears to conflict with this interpretation. However, two facts argue against the acceptance of this measurement as entirely reliable. Firstly, the technical difficulty in establishing a reliable environmental dose-rate introduced a large degree of imprecision which may not be fully reflected in the error limits; and secondly, its interstitial location meant that the calcite was especially prone to re-crystallization.

It is concluded, therefore, that the evidence provided by date measurements on *in situ* stalagmitic material within the Main Cave shows no major inconsistencies with the chronology given by the heated flints. It points to a finding that the emplacement of the archaeological remains within the cave took place during MIS 7, soon after the human occupation.

New Entrance

At the New Entrance, two *in situ* stalagmites produced date measurements; H3202 from layer 42, and H3221 from layer 43. The dates reveal that both samples are contemporaneous with the latest phase of stalagmitic growth on the Lower Breccia. This evidence, which forms the strongest link between the stratigraphies in the two entrances, is discussed below.

Derived materials

Date measurements were performed on 43 samples of various materials derived from deposits in the Main Cave and the New Entrance. They serve to test the proposed chronology of events at Pontnewydd Cave. The basis of the tests assumes that no material found within a unit can post-date the emplacement of the unit. This assumption is valid in the absence of bioturbation and mechanical disturbance.

Red Cave Earth and Upper Breccia Units

The emplacement of the Upper Breccia occurred as a debris flow which demolished parts of the stalagmitic floor on the Lower Breccia and incorporated fragments of it in the deposit. As expected, therefore, age determinations on 16 speleothems recovered from the Upper Breccia and Red Cave Earth show a date distribution similar to that of the source material. According to the measured dates, no parts of the stalagmitic floor sealing the Lower Breccia formed after approximately 85,000 BP. However, this growth terminus is possibly the result of a cooling climate rather than Upper Breccia emplacement. A much younger age for the Upper Breccia is suggested by the presence of one bone (D303) which is dated by U-series analysis to the range 18,000–33,000 BP.

Lower Breccia and Intermediate Units

A total of fifteen samples derived from units in the Main Cave which, prior to the Upper Breccia emplacement, had been sealed by the stalagmitic floor on top of the Lower Breccia. Therefore, these samples are expected to pre-date the emplacement of the Lower Breccia at approximately 200,000 BP. This chronology is also supported by faunal studies. According to Andy Currant (pers. comm.), the identification of rhinoceros tooth fragments as belonging to *Stephanorhinus kirchbergensis* places them at a date at or before late MIS 7. In fact, only four of the age determinations are inconsistent with this interpretation.

The four discrepant dates were all obtained by U-series analyses of bone samples (D809, D1585, D584, D616) which derived from the Lower Breccia and Intermediate deposits. If correct, their dates would imply that the emplacements of these units were late Devensian or Holocene events. It is impossible to reconcile these very recent dates with the U-series and TL measurements of *in situ* stalagmites formed on the Lower Breccia. Table 11.7 shows the results of U-series analyses performed on different components of the same bone. There is often inconsistency between the results of these repeated analyses, suggesting that the bone has not maintained its integrity as a closed system. A judgement in favour of the chronology based on stalagmites can be justified considering the degree of coherence between U-series and TL measurements on them, and the correlation of the date distribution with climatic events.

New Entrance

Out of a total of sixteen dated samples from the New Entrance excavations, thirteen were derived materials, including stalagmitic fragments, teeth and flint. The paucity of *in situ* samples and the limited extent of the excavation allow only a tentative interpretation of the data.

The three *in situ* samples comprise one sediment and two stalagmites. The sediment sample (H196) was collected from scree which covered the entrance, and provides a minimum age of approximately 32,000 BP for the underlying deposits. The two *in situ* stalagmites, H3202 and H3221, were found in layers 42 and 43, respectively, which places them stratigraphically beneath all other dated materials from Area H. They have produced U-series dates of approximately 85,000–91,000 BP, and therefore appear to be contemporaneous with the youngest stalagmitic formations on the Lower Breccia in the Main Cave. On this evidence, a case may be made for interpreting the overlying deposits as similar in age and nature to the Upper Breccia. The dates of samples derived from these layers can be viewed in the light of this suggestion.

Eight of the derived samples from Area H are stalagmitic fragments which have been dated by means of U-series and TL. The youngest stalagmite (H3211) is very similar in age to the youngest formation on the Lower Breccia. Likewise, the oldest stalagmitic fragment (H2216), dated by U-series analysis to approximately 260,000 BP, is similar in age to the oldest speleothem from the Upper Breccia. As noted above, three samples of heated flint from Area H (H598, H2312 and H1036) produced TL dates which are consistent with the dates of two flints from the Lower Breccia and Intermediate units. Finally, two measurements by ESR on teeth (H359 and H428) yielded results similar to those of corresponding material derived from the Lower Breccia.

Thus, the material types and dates obtained from Area H resemble a palimpsest of those found in the Upper and Lower Breccias and in the Intermediate complex. In the Main Cave, the debris flow which emplaced the Upper Breccia broke the stalagmitic floor sealing the Lower Breccia and channelled into the underlying unit. The Upper Breccia therefore incorporates not only parts of the floor but also a certain amount of material that had been sealed beneath it. In the New Entrance, it appears that a similar process has occurred, the only difference being that the original units have been mixed to a considerably greater extent than was the case in the Main Cave.

Last Glaciation faunas: the radiocarbon determinations

Paul Pettitt, Rupert Housley and Thomas Higham

Introduction

Pontnewydd is famous for being the earliest known humanly occupied site in Wales due to the presence of early Neanderthal cultural and anatomical remains from MIS 7, approximately one quarter of a million years ago. In the context of this part of the investigation programme, however, the early occupation is not the focus. Instead the radiocarbon dating programme relates to a later period, from ~41,000–21,000 BP (*i.e.* MIS 3 and early MIS 2), and is specifically concerned with the faunal history of the site rather than with the archaeology. Here, by examining the temporal patterning in the Upper Pleistocene fossil bone assemblages from the Upper Breccia, we seek to elucidate changing faunal composition, biodiversity and biomass within the Pontnewydd region over a period of ~20,000 years. The resulting trends are compared to similar data from other late Pleistocene localities in Wales and the adjoining western regions of the British 'peninsula' with the aim of answering a series of questions concerning the role of carnivore predation as an agent of bone accumulation in the cave, the identification of temporally-discrete faunal communities in the surrounding area, and the influence changing climate may have had on the faunal record in the Upper Breccia.

Over the past two decades the Oxford Radiocarbon Accelerator Unit (ORAU) has been responsible for making 57 AMS measurements on Middle Devensian Pleistocene fauna from Pontnewydd. Prior to 2001 Oxford had made a total of nine measurements on fauna from the cave, a single determination measurement (by John Gowlett) in 1986 on a femur of *Ursus* sp. (OxA–1025; Hedges *et al.* 1987) was followed by a further seven dates in 1993 (made by Rupert Housley) on a variety of taxa and faunal elements (OxA-4367 to -4373) and a single determination made by Paul Pettitt in 1996 on woolly rhinoceros (OxA-6267; Hedges *et al.* 1996). But in 2001 financial support from the Natural Environment Research Council permitted the dating of two large series of Upper Breccia specimens. It was found that many of the bones tested were so poorly preserved that a fair proportion of the first batch failed to yield adequate amounts of collagen (details below). Hence, a second series was sampled for processing and dating in 2003–2004. From this combined programme a further 48 dates were obtained. Given technological and methodological advancements in dating and sample pre-treatment methodologies between 1986 and 2004, it is not surprising that some potential for bias exists in this mixed data set, so in this report careful attention is given to this aspect of the research.

Aims of the study

The radiocarbon dating programme must be seen in the context of the wider aims of the Pontnewydd project as a whole. Thus, the Pontnewydd project forms part of the 'Palaeolithic Settlement of Wales Research Programme'. Its objectives have been to investigate, interpret and communicate:

- The nature and chronological patterning of Palaeolithic human presence at the periphery of the Pleistocene world;
- how evidence of this kind may be preserved in regions subjected to such a huge natural destructive process as glaciation;
- the social behaviour of hominins, including their relationship with the landscape, climate and changing faunas, mobility, and the exploitation of raw materials.

However, the specific ^{14}C sampling and analysis objectives that this programme aimed to investigate were as follows:

1. To identify changing patterns of faunal composition, biodiversity and biomass intensity over the period 40,000–20,000 BP.
2. To seek to identify from this, reasons for a scarce human presence (attested perhaps by a single cut-marked tooth) from the Upper Breccia context at Pontnewydd, which is composed of accumulations probably brought into the cave by the action of bears, wolves and foxes.
3. To compare Pontnewydd with relevant coeval assemblages – including those from the nearby sites of Ffynnon Beuno and Cae Gwyn – where there is evidence for both human and hyaena presence, both of which are lacking from Pontnewydd.
4. To examine whether the bear and wolf presences can be differentiated chronologically.
5. To establish whether the accumulations of herbivore remains primarily coincide with the pattern of wolf presence at the cave.
6. To examine whether original spatial and chronological configurations of animal bones in the cave can be retrieved.

The overall aim with the ^{14}C dating at Pontnewydd was thus to establish evidence for temporal patterning in the taxonomically diverse faunal record from the Upper Breccia in order to relate these to taphonomic, ecological and climatic factors that could have influenced the biomass, faunal composition and animal biodiversity of the surrounding environs to the site.

Methodology

Radiocarbon dating close to the background limit is challenging because it becomes increasingly difficult to distinguish autochthonous radiocarbon from exogenous or contaminant radiocarbon as the proportion of remaining ^{14}C significantly declines. Because of this all radiocarbon dates tend to cleave asymptotically towards 40,000–50,000, the so called 'radiocarbon barrier' (Chappell *et al.* 1996). Developments in sample chemistry at Oxford over the past 5–10 years have, however, led to increased confidence in dates for samples which approach background limits, or are within the overall time range of MIS 3 (Higham *et al*. 2006). The use of improved pre-treatment methods, including ultrafiltration, has enabled the extraction of better quality collagen from even poorly preserved bone (~1% wt collagen) (Higham *et al*. 2006). Ultrafiltration has been applied to all of the Pontnewydd dates produced since 2001 and the methodology is now described before comparing with the measurements made in the 1980s and 1990s.

Current Oxford ^{14}C methodology

Each of the bones dated from Pontnewydd 2001–2004 was sampled by Tom Higham using an NSK Electer GX drill with a tungsten carbide drill. Ideally, 500 mg was taken, but for some samples, the bones were too small to enable this amount to be taken and consequently some bones comprised a much smaller starting weight (Table 11.8). The bones were all pre-treated manually, initially with decalcification using 0.5M HCl, removal of humates using 0.1 M NaOH, then re-acidification using 0.5M HCl. Each step was interspersed with distilled water rinses. The samples were gelatinized in weakly acidic water (pH3) at 75°C in an incubator for 20 hours, and the supernatant recovered using an EziFilter™. The supernatant was further treated by ultrafiltration using a Vivaspin™ 30 kD MWCO ultrafilter (see Bronk Ramsey *et al*. 2004; Higham *et al*. 2006). The >30 kD fraction was lyophilized and retained for AMS dating. Samples of ultrafiltered gelatin are denoted by the prefix 'AF' in Tables 11.8 and 11.9 (one sample was not pre-treated further and was dated as filtered gelatin only because it produced a very low yield of collagen. This is termed 'AG' in Table 11.8). The ultrafilter removes low molecular weight particles, including degraded and broken up collagen fragments, salts, and small non-collagenous contaminants and in our experience produces collagen of a higher 'quality' when compared with other preparation methods (principally assessed by C:N ratios and %C and %N on combustion).

Samples of pre-treated bone gelatin were combusted and analysed using a Europa Scientific ANCA-MS system consisting of a 20–20 IR mass spectrometer interfaced to a Roboprep CHN sample converter unit operating in continuous flow mode, using He carrier gas. This enables the measurement of $\delta^{15}N$ and $\delta^{13}C$, nitrogen and carbon contents, and C:N ratios. $\delta^{13}C$ values in this paper are reported with reference to VPDB and $\delta^{15}N$ results are reported with reference to AIR. Graphitization was by reduction of CO_2 over an iron catalyst in an excess H_2 atmosphere at 560°C (Bronk Ramsey and Hedges 1999; Bronk Ramsey *et al.* 2000). The Oxford AMS radiocarbon instrumentation has been described by Bronk Ramsey and Hedges (1999), Bronk Ramsey *et al.* (2000) and Bronk Ramsey *et al.* (2004).

Preservation state

The first series of samples dated at ORAU in 2002 produced collagen which ranged from 0.2–7.6 wt% collagen, with a mean of 2.0±1.9 wt.%. The threshold for acceptance at ORAU is 1 wt.% collagen (equivalent to 10 mg collagen/g bone), therefore many of the samples we extracted collagen from were on the margin of acceptability. In general, the Pontnewydd bone was poorly preserved.

The samples identified in Table 11.8 with an asterisk in the collagen yield column are those that had values of less than 1 wt% collagen. In many instances these produce 'greater than' ages because of the low yield and its function in influencing the background limit for AMS dating. Another major problem in the first series of AMS dates analysed in 2002 was that the majority of bones analysed failed to yield any extractable collagen, and were therefore failed. There were 25 successful AMS dated samples obtained from the first batch (which include two dates on the same animal, noted on Table 11.8), and 25 samples that failed to provide collagen (Table 11.10).

In the light of this excessively high failure rate, ORADS was asked for permission to allow further dating to go ahead. To reduce the failure rate, a systematic programme of screening bones was undertaken by Tom Higham. Percent nitrogen analysis (%N) and C:N atomic ratios were measured from small amounts (*c*. 10–15 mg bone powder) of bone from specimens housed in the National Museum of Wales, Cardiff in 2003. Under most circumstances, percent nitrogen is a reasonable correlate for remaining protein, since nitrogen originates from the proteinaceous fraction of the bone, rather than the hydroxyapatite (Brock *et al*. 2009). However, an acceptably high %N value does not always correlate with a high collagen yield, since the quality of the collagen and its degree of alteration is not being measured and degraded or broken-up collagen will not be extractable using the ultrafiltration technique applied at ORAU. Nevertheless, it was hoped that %N analysis would reduce the failure rate.

The results are shown in Figure 11.5 and the data is given in Table 11.11. Figure 11.5 shows a reasonably good correlation between %N and C:N. As %N decreases, particularly below 1%, the ratio of carbon to nitrogen increases. Generally speaking, C:N ratios of whole bone above 5 are indicative of either the addition of humic complexes or the diagenetic alteration of the bone, for example by deamination. The combination of high C:Ns and low %N is indicative of poor bone protein preservation coupled with the presence of carbon from other sources, for example humic or sediment matrices. Samples that have a %N value below about 1% and a C:N >5 were therefore not expected to be dateable. Modern bone has a %N of *c*. 4–4.5% depending on species. 1%N under ideal circumstances, then, would correlate with *c*. 25% remaining collagen. In reality this is almost never obtained when pre-treating bones because of the difficulties in obtaining 100% efficiency in collagen yield and the likelihood that at least some of the collagen will be degraded and not recoverable. Samples below these cut-offs were not, therefore, sampled further for chemistry and AMS dating, whilst those above it were sampled in Cardiff for dating in 2004 (see Table 11.11).

Find no.	*Species*	*Identification*	*OxA*	*^{14}C age BP*	*error*	*CN*	*$\delta^{13}C$*	*$\delta^{15}N$*	*Use wt. (mg)*	*Pret. yld (mg)*	*% C*	*pcode*
D477	cf. Arctic hare	pelvis (left)	11666	33200	1900	3.3	-20.0	-0.2	150	2.4	40.38	AF
D2990	Arctic hare	pelvis (left)	11565	21330	140	3.4	-19.2	3.8	1400	**12.1**	20.00	AF
S209	Collared lemming	mandible	11667	>22700			-21.8		160	**0.4**	33.00	AF
F3025	Fox	humerus	11501	27120	210	3.2	-18.7	4.8	1020	30	30.75	AF
F4510	Red fox	humerus	11502	27350	250	3.3	-18.7	6.1	660	12.9	38.18	AF
D315	Red fox	mandible (right)	11668	26300	1100	3.1	-20.2	9.1	100	1.6	31.81	AF
F1508	Wolf	caudal vertebra	11566	26950	210	3.4	-18.6	5.5	450	25.4	55.79	AF
F1516	Wolf	caudal vertebra	11682	27790	210	3.3	-19.3	8.4	700	53.6	34.03	AF
D425	? Wolf	upper right incisor	11608	24470	170	3.4	-19.8	13.8	500	15.5	41.45	AF
F1186	Reindeer	humerus (left)	11669	>36700		3.5	-20.0	5.2	450	**1.9**	43.00	AF
D1786	Reindeer	humerus (right)	11670	>40200		3.3	-18.4	2.5	410	**2.8**	42.14	AF
D1063	Reindeer	tibia	11671	>35400		3.4	-19.7	3.0	460	**2.4**	41.04	AF*
F970	Reindeer	tibia	11672	31800	1000	3.3	-17.7	3.0	487	**3.5**	40.91	AF
F1397	Bear	fibula	11673	34400	2500	3.4	-20.5	9.2	449	**1.9**	38.47	AF
F1306**	Brown bear	humerus (right)	11503	32900	800	3.3	-19.8	10.9	486	5.2	42.21	AF
F1163**	Brown bear	humerus (left)	11674	>37400		3.3	-19.9	10.6	481	**1.8**	42.11	AF
F435	Bear	humerus (right)	11675	32100	1600	3.4	-20.3	10.7	502	**2.3**	41.17	AF
D884	Bear	femur (right)	11504	32150	700	3.3	-19.7	10.7	500	5.8	40.21	AF
D1240	Bear	ulna	11505	28650	650	3.3	-20.8	10.4	509	**3.9**	39.67	AF
F1258	Bear	second phalange	11676	>36800		3.3	-20.6	7.5	442	**2.2**	40.14	AF
F1511	Bear	second phalange	11677	41600	1900	3.4	-19.7	9.3	248	6.9	40.42	AF
F1823	Bear	second phalange	11506	31260	320	3.3	-19.4	10.9	453	16.9	41.43	AF
F1394	Greylag goose	femur (right)	12651	28230	170	3.2	-21.0	nd	640	34.8	39.54	AF
F835	Mallard	humerus (left)	12363	28210	150	3.3	-14.0	10.1	700	27.4	40.61	AF
F2232	cf. Brent goose	femur (right)	12381	25950	220	3.2	-15.9	7.5	220	23.6	40.22	AG

All samples are of ultrafiltrated gelatine (code AF, of AF* which refers to a solvent pre-wash to remove conservation material such as glues) with the exception of OxA-12381, which is filtered gelatine (code AG). δ^{13}C values are reported with reference to v PDB with a measurement precision of ± 0.2‰. δ^{15}N values are reported with reference to AIR. %C is the amount of carbon produced upon the combustion of the gelatine in an elemental analyser. Pret[reatment] Y[ie] ld samples in bold are those with a %wt. collagen value that is below 1%, which is the minimum threshold for acceptance at ORAU, Find numbers followed by ** indicates repeat samples from the same animal.

Table 11.8. AMS Radiocarbon results for the first series of samples dated at ORAU in 2002.

Find no.	*Species*	*Identification*	*OxA*	*Date*	*error*	*CN*	$\delta^{13}C$	$\delta^{15}N$	*Use weight (mg)*	*Pret. yld. (mg)*	*% C*	*pcode*
D427	*cf. Lepus timidus*	pelvis (left)	13947	28680	170	3.2	-20.2	2.8	500	22.85	41.19	AF
D455	*Lepus* sp.	astragalus (right)	13948	23110	100	3.3	-19.9	1.3	560	41.8	42.72	AF
D994	Fox	tibia (left)	13983	25500	140	3.3	-19.2	6.3	580	21.25	43.54	AF
D1154	*R. tarandus*	first phalange	13984	25210	120	3.2	-18.4	3.1	600	25.2	39.56	AF
D1206	*Lepus timidus*	astragalus (left)	13985	23840	100	3.4	-19.9	-0.8	520	37.6	43.82	AF
D4382	Fox	scapula (left)	13986	25450	140	3.3	-19.0	5.9	500	24	42.93	AF
F447	*Vulpes vulpes*	metatarsal	13987	29490	170	3.3	-19.8	9.4	720	54.2	43.41	AF
F775	*? Panthera* sp.	second phalange	13988	40000	600	3.2	-18.9	11.2	740	21.35	41.68	AF
F1010	*Ursus arctos*	rt maxilla and premaxilla	13990	34020	360	3.2	-18.9	11.0	440	15.7	41.15	AF
F1010	*Ursus arctos*	rt maxilla and premaxilla	13989	33560	330	3.2	-18.9	10.9	380	17.7	42.92	AF
F1014	*? Panthera leo*	phalange	13991	40300	750	3.2	-18.9	10.7	640	16	43.76	AF
F1018	*Ursus* sp.	second phalange	13992	29790	180	3.2	-19.5	10.0	760	28.6	41.67	AF
F1828	*R. tarandus*	metacarpal (left)	13993	30240	230	3.2	-18.5	3.2	780	17.5	42.91	AF
F4831	*Possible bear*	long bone shaft	13994	30780	390	3.2	-19.6	9.9	854	14.9	37.75	AF
F7041	Fox	metapodial	14049	33700	600	3.4	-20.6	-1.6	540	7.9	45.39	AF
F1629	Red fox	scapula (left)	14050	26820	140	3.3	-19.4	8.5	660	37.5	40.06	AF
F1684	*Lepus* sp.	scapula	14051	25670	150	3.4	-20.5	0.2	600	21	44.58	AF
F1898	*R. tarandus*	right mandible	14052	39600	900	3.4	-18.6	3.1	822	11	44.51	AF
F1964	*Lepus* sp.	calcaneum (right)	14053	30870	240	3.3	-20.5	-1.5	920	18.6	28.67	AF
F2149	*Ursus* sp.	carpal	14054	36100	800	3.5	-19.0	9.5	772	7.4	39.41	AF
F2549	*R. tarandus*	astragalus (left)	14055	41400	1400	3.3	-18.4	3.0	860	8.9	33.79	AF
F2881	Cervid	podial	14056	30020	170	3.4	-18.3	2.5	840	66.1	47.59	AF
F4796	*Lepus timidus*	calcaneum	14057	38800	600	3.4	-20.4	1.7	860	16.9	43.14	AF

Note that F1010 was dated twice as part of the ORAU QA programme. All of the samples dated in this table were above 1% wt. collagen with the exception of OxA-14054 that was marginally below (0.96%).

Table 11.9. Second series of AMS dates on bone from Pontnewydd.

OxA no.	*Find*	*Species*	*Identification*
13362	F422	Collared lemming	mandible
13363	S209	Collared lemming	mandible
13364	S210	Collared lemming	mandible
13365	F1116	Red fox	calcaneum (right)
13366	F1344	cf. Red fox	femur (right)
13370	F1224	Red fox	mandible (right)
13371	F600	Horse	first phalange
13372	D296	Horse	lunate (left)
13373	C340	Horse	metapodial
13374	B336	Horse	podial
13377	D1343	Wolf	cuboid (left)
13378	F1302	? Wolf	radius
13380	D156	*Rangifer tarandus*	astragalus (left)
13381	F915	*Rangifer tarandus*	astragalus (right)
13382	F1390	*Rangifer tarandus*	calcaneum (left)
13383	F1418	*Rangifer tarandus*	calcaneum (left)
13384	F308	*Rangifer tarandus*	calcaneum (right)
13385	F556	*Rangifer tarandus*	calcaneum (right)
13386	F1275	*Rangifer tarandus*	cuneiform
13387	D431	*Rangifer tarandus*	cuneiform (right)
13388	F1329	*Rangifer tarandus*	humerus (right)
13391	C18	*Rangifer tarandus*	radius (right)
13399	F1802	*Ursus* sp.	femur (right)
13401	B457	*Ursus* sp.	tibia
13405	F4622	*Ursus* sp.	second phalange

Table 11.10. List of Pontnewydd samples from the Upper Breccia submitted to Oxford for dating in the first batch that failed during the chemical pre-treatment process.

The screening resulted in a much higher success rate for the analysed bones. Only 11% of the second group of samples failed (see Table 11.12), compared with >50% for the first series. In addition, the collagen yields improved markedly in the second series. The uncalibrated radiocarbon results are given in Table 11.9 and plotted by species in Figure 11.6.

Find no.	*Burn wt. (mg)*	*Wt. N (mg)*	*% N*	*CN*	*Sampled for AMS dating?*
H95	19.6	0.028	0.14	64.18	n
H225	22.1	0.023	0.1	46.5	n
H1958	19.2	0.017	0.09	78.96	n
H2310	19	0.018	0.1	66.83	n
H2470	13.8	0.012	0.08	87.62	n
D427	7.5	0.13	1.7	4.49	y
D455	4.2	0.107	2.5	4.43	y
D465	9.6	0.219	2.3	4.4	y
D994	10.8	0.116	1.1	5.26	y
D1109	5.4	0.002	0.04	48.26	n
D1154	7.7	0.186	2.4	4.46	y
D1206	12	0.259	2.2	4.62	y
D4382	12.8	0.296	2.3	4.14	y
D45060	13.3	0.342	2.6	3.86	y
F447	12.5	0.35	2.8	3.83	y
F684	6.6	0.054	0.8	5.83	n
F775	7.7	0.246	3.2	3.78	y
F995	4.6	0.152	3.3	3.75	y
F1010	18.6	0.492	2.6	3.9	y
F1014	7.1	0.242	3.4	3.66	y
F1018	5	0.148	3	3.81	y
F1279	7.9	0.125	1.6	4.31	y
F1367	7.2	0.023	0.3	13.37	n
F1780	15.5	0.018	0.1	51	n
F1828	6.2	0.17	2.7	4.05	y
F4608	15.2	0.354	2.3	4.13	y
F4831	6.6	0.206	3.1	3.81	y
F7041	7.7	0.188	2.4	4.03	y
D4605	5	0.115	2.3	4.38	y
D5282	8.25	0.004	0.05	39.36	n
D5951	4.1	0.088	2.2	4.19	y
F1197	14.3	0.184	1.3	3.96	y
F1629	8.8	0.19	2.2	3.99	y
F1684	8.7	0.173	2	4.31	y
F1748	8.1	0.213	2.6	3.79	y
F1779	4.4	0.135	3.1	3.91	y
F1819	4.1	0.067	1.6	4.75	y
F1872	10.75	0.035	0.3	10.05	n
F1886	4.75	0.134	2.8	3.99	y
F1898	12.8	0.265	2.1	4.23	y
F1907	6.85	0.234	3.4	3.81	y
F1964	14.3	0.302	2.1	4.29	y
F2149	10.75	0.257	2.4	4.21	y
F2335	8.1	0.196	2.4	4.14	y
F2355	5.4	0.135	2.5	4.07	y
F2549	7	0.15	2.2	4.14	y
F2881	7.4	0.217	2.9	3.94	y
F4773	16.1	0.009	0.06	49.72	n
F4796	9.7	0.232	2.4	4.16	y
F5521	5.5	0.066	1.2	5.44	y

The bone powder samples were measured using an elemental analyser interfaced with an isoptope ratio mass spectrometer. The CN is the atomic ratio of carbon to nitrogen. %N refers to the percentage of nitrogen in the bone powder. At ORAU, we estimate a value >0.76% as being adequate for further chemical pre-treatment to extract collagen *Brock *et al.* 2009). For CN atomic ratios on whole bone, values of around 3.5-6.0 are acceptable. An indication is given of whether the bone was sampled for further dating, or failed at this juncture.

Table 11.11. Results of bone screening for the Pontnewydd fauna selected for dating.

Earlier Oxford methodologies

Earlier Oxford dates were obtained using an amino acid method or an ion-exchanged gelatin method. The first involved dating purified amino acids (ORAU laboratory code for this was AC). The bone was decalcified and the insoluble residue hydrolyzed and treated with activated charcoal, before the separation of the amino acids from inorganic solutes with cation-exchange columns and Dowex 50W-X8 resin (Gillespie and Hedges 1983; Gillespie *et al.* 1984). This method was used for all dates obtained prior to 1989. The ion-exchanged gelatin (code AI) method superseded this. The bone was decalcified, often utilizing a continuous-flow apparatus (see Hedges *et al.* 1989; Law and Hedges 1989). A sodium hydroxide wash was applied to attempt to remove humic contaminants. The insoluble collagen was gelatinized and purified using an ion-exchange column with BioRad AGMP-50 resin. This method was used until 2000 when it was abandoned because of concerns regarding the possibility of column resin bleed and the difficulty in excluding this as a potential contaminant (see also Burky *et al.* 1998). The method itself, with this exception, was a substantial step forward in bone

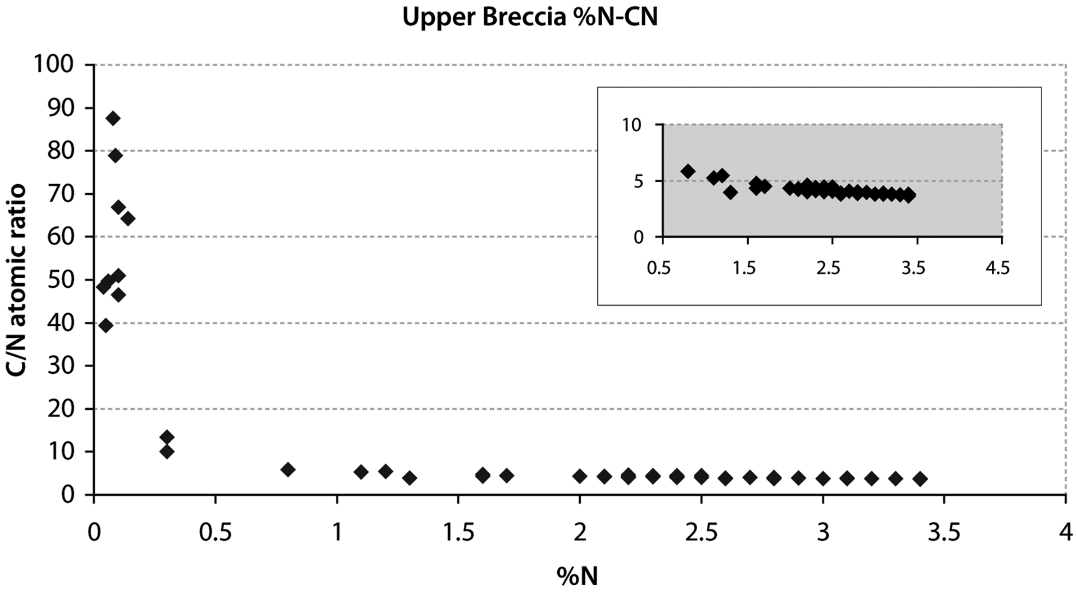

Figure 11.5. Results of bone screening

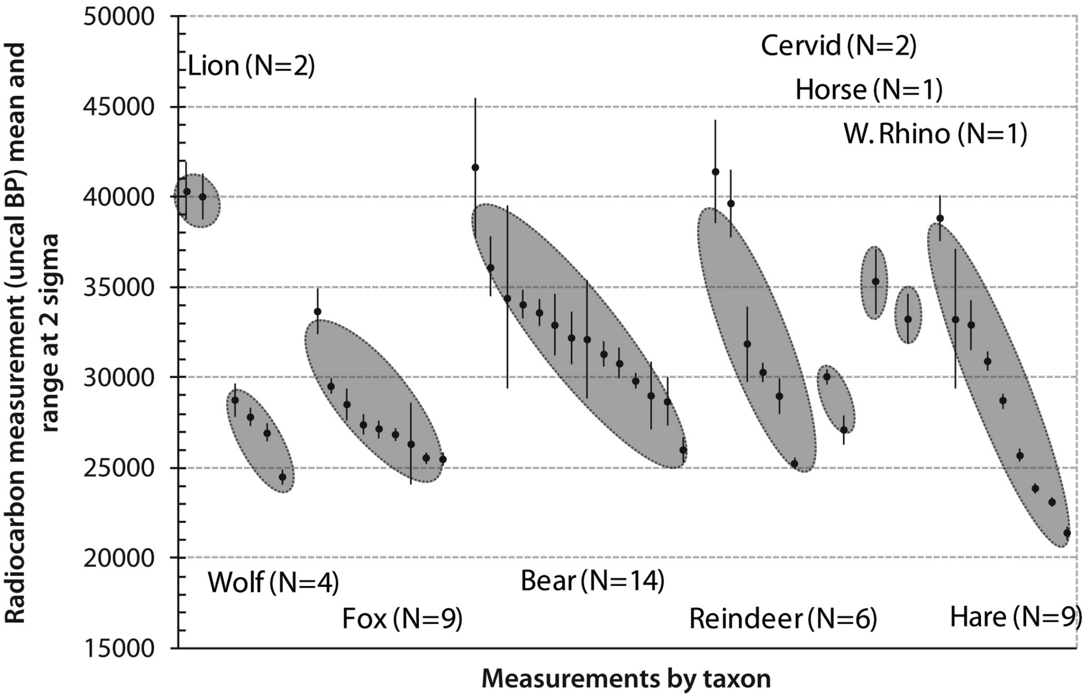

Figure 11.6. Finite 14C measurements on Pontnewydd fauna plotted by taxon.

OxA no.	*Find*	*Species*	*Identification*
15926	D595	Red fox	radius
15929	F1779	*Ursus* sp.	second phalange
15930	F1819	*Rangifer tarandus*	second phalange
15931	F1886	*Ursus* sp.	second phalange
15938	F5521	*Lepus* sp.	calcaneum

Table 11.12. Failed samples from the second batch of fauna submitted to ORAU from Pontnewydd Cave.

pre-treatment chemistry, and a variant of it is now being tested in order to date single amino acids in Oxford.

Comparison/calibration

At the time of writing, there is no agreed way to calibrate radiocarbon dates from the Middle to Upper Palaeolithic. There is no agreed curve for the period prior to 26,000 cal. BP (Reimer *et al*. 2004). In an attempt to gauge approximately the calendrical equivalent ranges for the new radiocarbon series, therefore, we have, tentatively 'compared' (see van der Plicht *et al*. 2004) our results against the Cariaco Basin record of Hughen *et al*. (2006). The Cariaco $\delta^{18}O$ dataset is tuned to the Hulu Cave $\delta^{18}O$ speleothem record of Wang *et al*. (2001), which has the advantage of having been dated reliably using a series of U/Th dates. A new interim calibration curve spanning 0–55,000 BP is expected to be published in 2010 (Reimer, pers. comm.). 'Calibrated' ages prior to 26,000 cal. BP, therefore, are tentative comparisons, essentially. Because of such uncertainty about comparisons we work below with both uncalibrated and calendrically compared ages.

The dating programme

Selection of the dating samples

The earlier ^{14}C analyses undertaken in 1986 and 1993 had demonstrated that the faunal assemblage in the Upper Breccia at Pontnewydd fell well within the limits of modern AMS dating techniques, for the initial results indicated bone accumulation during the Middle Devensian, in the 25,000–35,000 BP age range. In terms of sample suitability for a dating study, the fauna from the Upper Breccia had been well excavated and recorded, and unlike projects on some other British Pleistocene sites that have relied on museum finds from old excavations, there would be no problems of contamination from recently applied preservatives.

During excavation the Upper Breccia (shown in the section drawing in Figure 6.5) was observed to extend over a distance of at least 35 linear metres from the West Entrance inwards to the East Passage. From there, it continued in modified form as far as the New Entrance (shown on the plan in Figure 6.1). Fabric studies (Collcutt 1984) showed that the deposit had formed as the result of debris flow and was emplaced from the direction of the West Entrance. Because of this mode of emplacement, no chronological and spatial information for the associated faunal accumulation is expected. In consequence, the only means of understanding the patterning of use of the cave is by applying radiocarbon. The intermingling of different-aged material in a debris flow ruled out the conventional *biostratigraphic* approach, but the large number of identifiable faunal specimens provided an alternative methodology, which may be best described as the *dynamic* approach. This involved making multiple radiocarbon age determinations on different faunal species in order to construct an age profile of changing faunal representation and biomass with time. This had previously been used at Paviland Cave (Aldhouse-Green 2000; Pettitt 2000; Turner 2000), which was investigated during the infancy of archaeology and where, unlike Pontnewydd, no clear stratigraphic records were made during these 'excavations'. At Pontnewydd the intention was to adopt a similar approach to Paviland but for different reasons; here it was to be used as a way to address the problem of multi-aged material in a mixed debris flow where stratigraphic position had no necessary bearing on the age of the specimen.

The selected dating samples represented bone from the Upper Breccia that displayed the characteristic Upper Breccia preservation type III (Currant 1984 and Currant chapter 8, this volume). The decision to confine the selection to those specimens was to ensure that no potentially intrusive faunal elements to the Upper Breccia were included, whether representing later intrusions or earlier re-worked specimens, which might confuse the subsequent interpretation. Species with preservation characteristic of the Upper Breccia included *Dicrostonyx torquatus* (collared lemming), *Lemmus lemmus* (Norwegian lemming), *Lepus* cf. *timidus* (arctic hare), *Canis lupus* (wolf, most likely the prime faunal accumulator), *Vulpes vulpes* (red fox), *Ursus arctos* (brown bear, the commonest species), *Equus ferus* (horse), *Coelodonta antiquitatis* (woolly rhinoceros), *Rangifer tarandus* (reindeer), *Ovibos moschatus* (musk ox, only rarely present), and a number of avifaunal taxa. The faunal collection from the Upper Breccia comprised most of the typical elements of an MIS 3 assemblage as identified by Currant and Jacobi (1997; 2001). It was distinctive however, in that it lacked the spotted hyaena, so common on many other MIS 3 sites, and was instead dominated by the wolf, *Canis lupus*, which was an important agent responsible for introducing the bone assemblage to the cave (see Scott chapter 8, this volume). There was also a disproportionately high frequency of bear remains from the deposit, which may reflect the relatively frequent use of the cave as a den for hibernating bears. The total absence of hyaenas at first sight seemed surprising, given their common role in accumulating bones in caves during the Pleistocene (including locally in the Elwy valley at Cefn Cave at ~34,000 BP), but an explanation may be that hyaenas became less frequent in localized areas after 30,000 BP. In any event, it was important to rule in, or out, regional chronological patterning of carnivore presences in this study.

The rationale behind the choice of potential specimens from the cave involved the selection of as many suitable samples as possible relative to species frequency within the collection. The MNI (Minimum Number of Individuals) approach produced too few individuals for most species whereas an MNE (Minimum Number of Elements) approach yielded too many specimens for a realistic resource-limited project. Accordingly, MNE sample sizes were trimmed to produce a species balance based for the most part on post-cranial material, selecting those specimens that were best suited to the radiocarbon sampling process. It was possible that, in some cases, two specimens from the same individual may have been dated, but our view was that the destructive and selective nature of bone preservation within a cave debris flow deposit, particularly where carnivores have been involved in the first instance, actually make it highly unlikely that more than one specimen from an individual would survive to be excavated. Repetition of this nature, in any case, would not affect our database, which seeks to reconstruct chronological patterning of taxa, rather than relative abundance in any one period.

Results

Tables 11.13 and 11.14 list the radiocarbon determinations from the Upper Breccia at Pontnewydd. The dates are firstly presented in order of age (youngest to oldest) and then 'calibrated' and grouped by species. As we have noted above, many additional samples were submitted to the Oxford Radiocarbon Unit under the NERC dating programme but could not be dated due to having failed in the chemical pre-treatment stage (Tables 11.10 and 11.12). It is particularly unfortunate that so many of the *Rangifer*, *Equus* and *Dicrostonyx* specimens failed in comparison with the number of specimens of the same taxa which were successfully age measured. For reindeer the overall age distribution may be discernible, but for horse and collared lemming the age patterning remains tentative due to an inadequate number of determinations.

The Pontnewydd Upper Breccia ^{14}C results span an age range from 25,000–55,000 calendar years BP (*c.* 24,500–41,500 ^{14}C BP). They support the sedimentological and fabric analyses that suggest the Upper Breccia incorporated material of many different ages. In archaeological terms the determinations coincide with the Early Upper Palaeolithic – and perhaps a phase of the Mousterian – although at Pontnewydd the faunal assemblage cannot be linked with clear evidence for human activity. At best the Upper Breccia may be coeval with these archaeological period(s), but no direct human presence may be demonstrated. This is dissimilar to the Goat's Hole, Paviland, where humans were present (Pettitt 2000, 67) although a similarity is shared in that at both sites the process of faunal accumulation seems to have ceased prior to the onset of the Last Glacial Maximum.

AMS radiocarbon dating and faunal biostratigraphy at Pontnewydd

Table 11.14 presents the uncalibrated ranges (at 68.2 and 95.4% probability ranges) by faunal taxa. Overall, the resulting faunal age ranges span some 20,000 ^{14}C years from ~41,000 to ~21,000 BP, with the majority falling within some 13,000 ^{14}C years between ~38,000 and ~25,000 BP. We discuss here the chronological patterning for carnivores and herbivores, before comparing these with other pertinent data from the western parts of the British peninsula.

Carnivores

Four carnivore taxa were selected for dating – lion, wolf, red fox, and a brown bear/unspecified bear (to include an omnivore), and 31 dates in total pertain to these. The bears (represented by 16 samples) appear relatively early in the sequence of dated fauna, around or before 40,000 BP, and seem to have had a fairly continuous presence in the region down to at least 26,000 BP. On the basis of one dated sample, fox seems also to have appeared as early, although only two samples predate ~28,000 BP and the majority of dates for this taxon cluster around 28,000–26,000 BP. This may simply reflect the effects of sampling bias on a relatively continuous record of red fox in the region from at least 40,000 BP, or sparse populations of this taxon before ~28,000 BP. The record for lion and wolf is more intermittent. The two dated specimens classifiable as lion fall relatively early in the sequence (~40,000 BP). Wolf (represented by four samples) occupies a relatively narrow age range between ~29,000 and ~25,000 BP, suggesting that it may have been a relatively late addition to the regional carnivore taxa (but see Scott chapter 8, this volume). Taking the distribution of the uncalibrated age ranges at two standard deviations, it may be that in the earlier part of the age range represented by the radiocarbon dates, lion, red fox and bear were the predominant carnivore accumulators at the site, whereas in the later period wolf had replaced lion and, perhaps, bear, although seems to have been sympatric with red fox.

Herbivores

Five herbivore taxa are represented among the dated fauna, and 23 dates pertain to these. Reindeer appear relatively early (around or before 40,000 BP) and persist until ~25,000 BP, although the main cluster of dates for this taxon are ~33,000–30,000 BP. *Lepus* appears from this time (by or after 35,000 BP, possibly as early as 40,000 BP) and persists latest of all of the dated taxa, present in the region down to the Last Glacial Maximum. By contrast to these two taxa the record for woolly rhinoceros, horse and an unspecified cervid are far more patchy and given the lack of dates for these taxa one cannot make any sound inferences about the dates that do exist. The one dated sample of woolly rhinoceros (*Coelodonta antiquitatis*) belongs to the later group at ~33,000 BP, and the single sample of horse is not much earlier at ~35,000 BP. By contrast, the two samples of unspecified cervid are later, spanning ~30,000–27,000 BP.

While it must be remembered that the radiocarbon dates are only sampling the taxa present at the cave, some general observations can be made. Taking the results at face value, there seems to have been a major restructuring of the faunal community around 40,000 BP. Prior to this, lion, bear, and possibly red fox, seem to have been the only carnivore accumulators at the site, and the only dated herbivores reindeer. Shortly after, however, there is a rise in taxonomic diversity, at least from ~37,000 BP, with the concentration of the major series of dates on bear and the possible persistence of red fox, and among the herbivores the appearance of wild horse, woolly rhino and *Lepus.* Somewhat later, perhaps around 29,000 BP, additional changes seem to have involved the floruit of red foxes and the appearance of wolves, possibly in the context of the diminution or disappearance of bear. The two dated cervids fall into this phase, and the only herbivorous taxon that persists through it is *Lepus.* It may also be significant that the three examples of directly dated birds (not plotted) fall into the ~25,000 to ~28,000 BP time range. With the exception of one date, on *Lepus* at ~22,000 BP, no dates are younger than ~25,000 BP, which may reflect increasingly severe conditions in the region as climate declined towards the Last Glacial Maximum.

OxA	***Species***	***Description***	***Find no.***	***Context***	***CN ratio***	***$\delta^{13}C$ (‰)***	***Date***	***Error***
11565	*Lepus timidus* Arctic Hare	Pelvis (left)	D2990	UB	3.4	-19.2	21330	140
11667	*Dicrostonyx torquatus* Collared Lemming	Mandible	S209	UB	n/a	-21.8	>22700	
13948	*Lepus* sp. Hare	Astragalus (right)	D455	UB	3.3	-19.9	23110	100
13985	*Lepus timidus* Arctic Hare	Astragalus (left)	D1206	UB	3.4	-19.9	23840	100
11608	*Canis lupus* Wolf	Upper right incisor	D425	UB	3.4	-19.8	24470	170
13984	*Rangifer tarandus* Reindeer	First phalange	D1154	UB	3.2	-18.4	25210	120
13986	*Vulpes* sp. Fox	Scapula (left)	D4382	UB	3.3	-19.0	25450	140
13983	*Vulpes* sp. Fox	Tibia (left)	D994	UB	3.3	-19.2	25500	140
14051	*Lepus* sp. Hare	Scapula	F1684	UB/SB	3.4	-20.5	25670	150
12381	cf. Brent Goose	Femur (right)	F2232	UB/SB	3.2	-15.9	25950	220
4367	*Ursus* sp. Bear	Femur	F126	UB	n/a	-21.3	25970	330
11668	*Vulpes vulpes* Red Fox	Mandible (right)	D315	UB	3.1	-20.2	26300	1100
14050	*Vulpes vulpes* Red Fox	Scapula (left)	F1629	UB/SB	3.3	-19.4	26820	140
11566	*Canis lupus* Wolf	Caudal vertebra	F1508	UB	3.4	-18.6	26950	210
4373	Cervid (medium sized)	Calcaneum (right)	H231	20	n/a	-20.3	27070	360
11501	*Vulpes* sp. Fox	Humerus	F3025	UB	3.2	-18.7	27120	210
11502	*Vulpes vulpes* Red Fox	Humerus	F4510	UB	3.3	-18.7	27350	250
11682	*Canis lupus* Wolf	Caudal vertebra	F1516	UB	3.3	-19.3	27790	210
12363	Mallard	Humerus (left)	F835	UB	3.3	-14.0	28210	150
12651	Greylag Goose	Femur (right)	F1394	UB	3.2	-21.0	28230	170
4372	*Vulpes vulpes* Red Fox	Radius (left)	F829	UB	n/a	-19.6	28470	410
11505	*Ursus* sp. Bear	Ulna	D1240	UB	3.3	-20.8	28650	650
13947	*Lepus cf. Timidus* Hare	Pelvis (left)	D427	UB	3.2	-20.2	28680	170
4369	*cf. Canis lupus* Wolf	Radius (left)	D3048	UB	n/a	-20.0	28730	420
4368	*Rangifer tarandus* Reindeer	Radius and ulna	D176	UB	n/a	-17.8	28950	450
1025	*Ursus arctos* Brown Bear	Femur (left)	F1024	UB	n/a	n/a	29000	800
13987	*Vulpes vulpes* Red Fox	Left third metatarsal	F447	UB	3.3	-19.8	29490	170
13992	*Ursus* sp. Bear	Second phalange	F1018	UB	3.2	-19.5	29790	180
14056	Cervid	Podial	F2881	UB/SB	3.4	-18.3	30020	170
13993	*Rangifer tarandus* Reindeer	Metacarpal (left)	F1828	UB	3.2	-18.5	30240	230
13994	*Possibly bear*	Long bone shaft	F4831	UB	3.2	-19.6	30780	390
14053	*Lepus* sp. Hare	Calcaneum (right)	F1964	UB/SB	3.3	-20.5	30870	240
11506	*Ursus* sp. Bear	Second phalange	F1823	UB	3.3	-19.4	31260	320
11672	*Rangifer tarandus* Reindeer	Tibia	F970	UB	3.3	-17.7	31800	1000
11675	*Ursus* sp. Bear	Humerus (right)	F435	UB	3.4	-20.3	32100	1600
11504	*Ursus* sp. Bear	Femur (right)	D884	UB	3.3	-19.7	32150	700
4371	*Lepus* timidus Arctic Hare	Calcaneum	F1520	UB	n/a	-21.3	32870	660
11503	*Ursus arctos* Brown Bear	Humerus (right)	F1306	UB	3.3	-19.8	32900	800
6267	*Coelodonta antiquitatis* Woolly Rhino	Terminal phalange	F4515	UB	n/a	-21.2	33200	650
11666	cf. Arctic Hare	Pelvis (left)	D477	UB	3.3	-20.0	33200	1900
13989	*Ursus arctos* Brown Bear	Right maxilla & premaxilla	F1010	UB	3.2	-18.9	33560	330
14049	*Vulpes* sp. Fox	Metapodial	F7041	UB	3.4	-20.6	33700	600
13990	*Ursus arctos* Brown Bear	Right maxilla & premaxilla	F1010	UB	3.2	-18.9	34020	360
11673	*Ursus* sp. Bear	Fibula	F1397	UB	3.4	-20.5	34400	2500
4370	*Equus ferus* Horse	Third phalange	D447	UB	n/a	-20.6	35270	860
11671	*Rangifer tarandus* Reindeer	Tibia	D1063	UB	3.4	-19.7	>35400	
14054	*Ursus* sp. Bear	Carpal	F2149	UB/SB	3.5	-19.0	36100	800
11669	*Rangifer tarandus* Reindeer	Humerus (left)	F1186	UB	3.5	-20.0	>36700	
11676	*Ursus* sp. Bear	Second phalange	F1258	UB	3.3	-20.6	>36800	
11674	*Ursus arctos* Brown Bear	Humerus (left)	F1163	UB	3.3	-19.9	>37400	
14057	*Lepus timidus* Arctic Hare	Innominate (right)	F4796	UB/SB	3.4	-20.4	38800	600
14052	*Rangifer tarandus* Reindeer	Right mandible	F1898	UB/SB	3.4	-18.6	39600	900
13988	*? Panthera* sp. Leopard	Second phalange	F775	UB	3.2	-18.9	40000	600
11670	*Rangifer tarandus* Reindeer	Humerus (right)	D1786	UB	3.3	-18.4	>40200	
13991	*? Panthera leo* Lion	Phalange	F1014	UB	3.2	-18.9	40300	750
14055	*Rangifer tarandus* Reindeer	Astragalus (left)	F2549	UB/SB	3.3	-18.4	41400	1400
11677	*Ursus* sp. Bear	Second Phalange	F1511	UB	3.4	-19.7	41600	1900

Table 11.13. Radiocarbon age determinations on faunal specimens from the Upper Breccia (UB) and UB/SB at Pontnewydd Cave.

Thus, in terms of the questions outlined above, the radiocarbon results suggest a major rise in taxonomic diversity before or around 35,000 BP, possibly coincident with the disappearance of lion and the rise of bear, and another re-structuring some time after 29,000 BP, after which wolf appears to have been sympatric with red fox although bear had probably declined in numbers or disappeared. The wolves and foxes appear to have been the main accumulators of the unspecified cervids, later reindeer, and hares, whereas the only dated candidates for the accumulation of wild horse and woolly rhinoceros are the red fox and bear. Finally, and with only one exception, none of the specimens sampled in the radiocarbon programme date younger than ~25,000 BP.

In Figure 11.7, we show a plot of the comparison ages, produced using OxCal 4.1 and the record from the Cariaco Basin (Hughen *et al*. 2006). The data is compared against the NGRIP GICC05 δ^{18}O climate record of Svennson *et al*. (2006) and Andersen *et al.* (2006) in order to provide a tentative comparison against a climatic record. The data confirm the observations already made above, but what is immediately apparent are the wide uncertainties associated with many of the comparison ages. This makes a precise association with climatic signals quite difficult, and we refrain from doing so for this reason.

Wider comparisons

It is important to see the faunal assemblage from the Upper Breccia in the context of the wider British Upper Pleistocene faunal biostratigraphy. Currant and Jacobi (1997; 2001) have proposed a five stage mammalian chronostratigraphy that extends from the Last Interglacial (MIS 5e) to the Last Glacial Maximum (MIS 2). The first 'Joint Mitnor' mammalian assemblage zone (MAZ) contains temperate elements such as *Hippopotamus amphibious*, and is represented by sites like Trafalgar Square, London and Joint Mitnor Cave, Devon. The next 'Bacon Hole' mammalian assemblage zone, equated with the later sub-stages of MIS 5 (5a–d), is marked by the disappearance of the temperate elements and the presence of roe deer, mammoth and northern vole. The third mammalian assemblage zone, represented by the MIS 4 levels at Banwell Bone Cave, is characterized by a relatively impoverished suite of taxa dominated by bison and reindeer. This is succeeded by the MIS 3 'mammoth steppe' Middle Devensian fauna, formalized as the 'Pin Hole' (cave) mammalian assemblage zone (that replaces Coygan Cave, now no longer available for study), which is noted for its relative species diversity. This MAZ is punctuated by a mammalian assemblage interzone corresponding to the Dimlington Stadial, i.e. the early part of MIS 2. Mammalian fossils do exist for this period although are relatively rare, and at present, there is no available locality with sufficient biostratigraphic integrity to use as a type site. It can be noted, however, that a number of AMS radiocarbon dates on hyaena bones from Creswell Crags and its surrounding region span this period (see Currant and Jacobi 2001). The fifth, and last, mammalian assemblage zone that Currant and Jacobi (2001) propose is represented by the MIS 2 fauna of Gough's Cave that has red deer and horse well represented.

The dated Upper Breccia fauna from Pontnewydd spans later MIS 3 to the beginning of MIS 2, *i.e.* Currant and Jacobi's Pin Hole MAZ and, possibly the Dimlington Stadial mammalian interzone. The dated Pontnewydd fauna shares elements with the scheme of Currant and Jacobi (2001) although differences may be observed. We have discussed above the uncalibrated ^{14}C measurements by faunal taxa shown in Figure 11.6. It can be seen that, overall, the dates span the period ~25,000 – ~40,000 BP, and the abrupt termination of dates at the end of MIS 3/Pin Hole MAZ presumably reflects the marked deterioration of climate into the Dimlington Stadial. Taking the dated faunal from Pontnewydd at face value it might suggest that the onset of severe conditions caused the localized extinction of most MIS 3 faunal taxa; however one looks at it a dramatic impoverishment seems evident. In terms of the specific taxa, eight of the dated fauna from Pontnewydd are found in the type locality of Pin Hole cave, Creswell (Currant and Jacobi 2001, table 5), with Pin Hole lacking only a cervid other than reindeer or *Megaloceros*.

Compared with Pin Hole, Pontnewydd lacks mammoth, *Megaloceros, Bison* and two mustelids, although a highly fragmentary bovid tooth from the Upper Breccia Silt beds matrix (identification A. Currant and E. Walker pers. comm.) may indicate the presence of *Bison* but it is not taxonomically identifiable. Despite the taxonomic similarity, however, diversity is relatively low in the Pontnewydd fauna compared with Pin Hole (nine taxa as opposed to 15) and is the same as that for the 'impoverished' fauna of the preceding Bacon Hole MAZ, with which it shares five taxa (*Canis lupus, Vulpes vulpes, Ursus* sp., *Rangifer tarandus* and *Lepus* sp.). Taxonomically, then, the Pontnewydd MIS 3 dated fauna are somewhat intermediate between the preceding Bacon Hole MAZ of MIS 4 and the Pin Hole MAZ of MIS 3 with which they should be biostratigraphically equated. This could be significant, for example in demonstrating a degree of geographical variability within mammalian assemblage zones.

We now move to more specific comparisons with MIS 3/2 sites. Table 11.15 presents the small number of existing measurements from Welsh caves other than Paviland, which we discuss below. There are serious doubts about the reliability of the majority of these measurements in the light of recent re-dating of several key specimens by new samples using ultrafiltration, but the few dates that exist on taxonomically identifiable bones from Ffynnon Beuno, Coygan Cave, Little Hoyle and Ogof-yr-Ychen probably support the broad picture (Aldhouse-Green *et al*. 1995). That is to say they show dated faunas that appear ~40,000 BP and with some evident biostratigraphic turnover shortly thereafter. At Coygan, reindeer may have persisted after 37,000 BP (BM-499) and woolly rhinoceros dates possibly to well after (OxA-2509); however Higham *et al*. (2006) consider this latter date to be inaccurate due to extremely low collagen preservation. At Little Hoyle, hyaena has been dated to 34,590±1,500 BP (OxA-1491),

OxA	***Species***	***Conventional radiocarbon age (BP)***	***Standard error (1 σ)***	***Comparison age (68.2 prob.)***		***Comparison age (95.4 prob.)***	
				from	**to**	**from**	**to**
Carnivores							
13988	*? Panthera sp.*	40000	600	44318	43050	45192	42628
13991	*? Panthera leo*	40300	750	44964	43170	45342	42652
4369	cf. *Canis lupus*	28730	420	33970	32762	34216	32284
11682	*Canis lupus*	27790	210	32822	32016	32860	31960
11566	*Canis lupus*	26950	210	31932	31608	32838	31350
11608	*Canis lupus*	24470	170	29770	29074	29802	28586
14049	*Vulpes vulpes*	33700	600	39952	37476	40190	36328
13987	*Vulpes vulpes*	29490	170	34270	33682	34958	33370
4372	*Vulpes vulpes*	28470	410	33342	32298	34000	32116
11502	*Vulpes vulpes*	27350	250	32840	31650	32848	31614
11501	*Vulpes vulpes*	27120	210	31964	31638	32846	31580
14050	*Vulpes vulpes*	26820	140	31930	31580	31968	31346
11668	*Vulpes vulpes*	26300	1100	32836	29992	33956	29056
13983	*Vulpes* sp.	25500	140	30928	30208	31312	29842
13986	*Vulpes vulpes*	25450	140	30920	30006	31294	29830
Omnivores							
11677	*Ursus* sp.	41600	1900	47166	43148	55190	42560
11674	*Ursus arctos*	>37400		Date out of range			
11676**	*Ursus* sp.	>36800		63100	47250	...	43370
14054	*Ursus* sp.	36100	800	41962	40498	42570	39444
11673**	*Ursus* sp.	34400	2500	42022	36306	51624	34258
13990	*Ursus arctos*	34020	360	39994	38304	40178	37608
13989	*Ursus arctos*	33560	330	38914	37514	39956	36366
11503	*Ursus arctos*	32900	800	38586	36294	39994	35532
11504	*Ursus* sp.	32150	700	37978	35510	38632	35006
11675	*Ursus* sp.	32100	1600	38734	34996	41166	34028
11506	*Ursus* sp.	31260	320	35854	35028	35890	34614
13994	*Possible Ursus sp.*	30780	390	35842	34542	35862	34352
13992	*Ursus* sp.	29790	180	34390	34052	34994	33428
1025	*Ursus arctos*	29000	800	34288	32760	34992	32070
11505	*Ursus* sp.	28650	650	34002	32318	34326	32006
4367	*Ursus* sp.	25970	330	31326	30452	31580	30386
Herbivores							
14055	*Rangifer tarandus*	41400	1400	45710	43172	48860	42592
11670**	*Rangifer tarandus*	>40200		...	52787	...	52786
14052	*Rangifer tarandus*	39600	900	44202	42604	45262	42404
11669**	*Rangifer tarandus*	>36700		...	49530	...	43366
11671**	*Rangifer tarandus*	>35400		55940	42590	...	42190

11672	*Rangifer tarandus*	31800	1000	37974	35004	39294	34318
13993	*Rangifer tarandus*	30240	230	34926	34322	35020	34236
4368	*Rangifer tarandus*	28950	450	34028	32958	34324	32312
13984	*Rangifer tarandus*	25210	120	30376	29852	30408	29806
14056	Cervid	30020	170	34970	34238	34996	34098
4373	Cervid	27070	360	32012	31592	32848	31328
4370	*Equus ferus*	35270	860	41216	39328	42172	38612
6267	*Woolly rhino*	33200	650	38726	36362	39962	35886
14057	*Lepus timidus*	38800	600	43252	42330	44162	42154
11666	*Lepus* cf. *timidus*	33200	1900	40110	35688	42566	34448
4371	*Lepus timidus*	32870	660	38550	36126	39898	35624
14053	*Lepus* sp.	30870	240	35844	34692	35860	34532
13947	*Lepus* cf. *timidus*	28680	170	33334	32762	33950	32326
14051	*Lepus* sp.	25670	150	31286	30396	31324	30226
13985	*Lepus timidus*	23840	100	29172	28418	29400	28230
13948	*Lepus* sp.	23110	100	28518	27788	28526	27776
11565	*Lepus timidus*	21330	140	25858	25104	25892	25082
11667	Collared lemming	>22700		55296	31680	...	30618
Birds							
12651	Greylag Goose	28230	170	33036	32300	33214	32228
12363	Mallard	28210	150	32924	32300	33212	32222
12381	cf. Brent Goose	25950	220	31314	30460	31550	30410

** Comparison age may extend out of range.

The results are ‘compared’ against the Cariaco Basin record of Hughen *et al.* (2006) as described in the text in the absence at the time of writing of an internationally agreed calibration curve. Comparison data is shown in 68.2 and 95.4% probability ranges. In some instances, the ages are close to the limit of the comparison curve, and these problematic cases are given with a double asterisk. Where ‘greater than’ ages were obtained, these are compared by using the results in Fraction Modern (fM) notation rather than as conventional radiocarbon ages BP. This is not as straightforward as interpreting a comparison age for a finite determination because it becomes increasingly difficult to justify the assumption that each year is equally likely as another within the range covered over long time ranges but they do allow us to consider an upper comparison age limit for the result, which is of some use.

Table 11.14. List of radiocarbon determinations from Pontnewydd Cave grouped by broad type.

reindeer to 29,200±700 (OxA-1028), and brown bear to considerably later (ANU-4347, ANU-4350, ANU-4348 and OxA-2508). Again, we have doubts about the reliability of these results due to low collagen yields and less than adequate pre-treatment chemistry in the earliest days of the Oxford Laboratory. The latter result, for instance, that of the brown bear (OxA-2508 at 23,550±290 BP) is a case in point. The original sample yielded only 0.3% collagen when it was dated in 1989 using ion-exchanged gelatin. On the basis of this, Higham and Jacobi (unpub.) re-dated this specimen and obtained an older result (25,860±350 BP; OxA-X-2288-32). The result was given an OxA-X- result because of a continued problem of low collagen yields (640 mg of bone was treated but only 4.7 mg of gelatin was obtained). This is less than 10 mg and below 1% weight collagen. Other parameters, including the CN atomic ratio (3.3), were acceptable. Only woolly rhinoceros is dated at Ogof-yr-Ychen (Birm-340; 22,350±620 BP) and again we would be very cautious about the reliability of a date measured early in the practice of radiocarbon, and of such a relatively young age for this taxon. Finally, at the type site of the Bacon Hole MAZ, the taxonomically poor faunal assemblage containing reindeer, wolverine and bear noted above has yielded dates of 33,200±950 BP (OxA-5699)

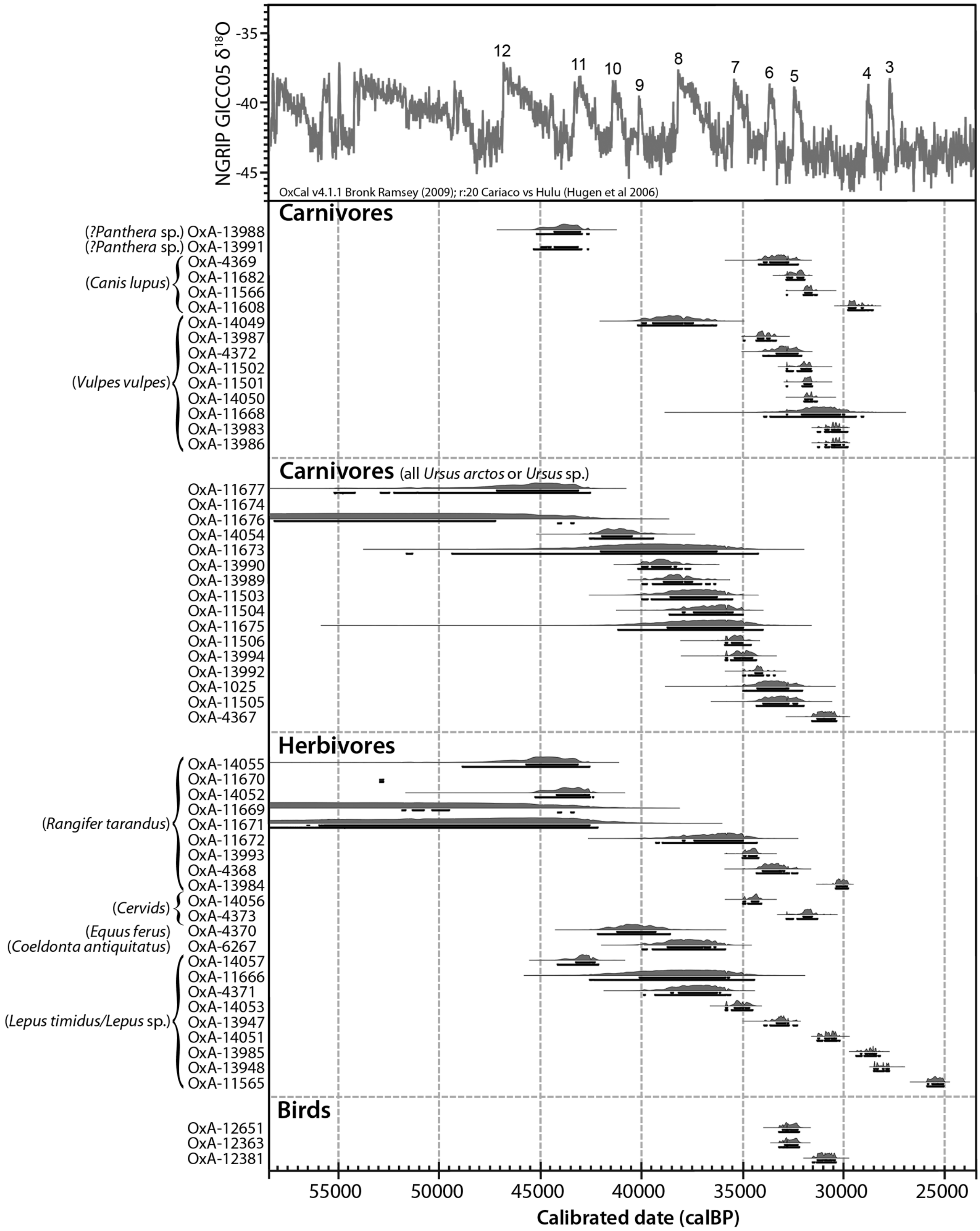

Figure 11.7. Plot of comparison age ranges.

and 31,500±1,200 BP (OxA-6022) both on right second molars of *Ursus* sp. (Hedges *et al*. 1996).

The large number of radiocarbon dates on fauna, human remains and humanly modified faunal material from Goat's Hole Cave at Paviland, Gower, renders it the best biostratigraphy to compare to Pontnewydd. Forty-five measurements have been produced for this site (Pettitt 2000) in the context of a major re-examination of the site and its collections (Aldhouse-Green 2000). The results span a broadly comparable time range to those from Pontnewydd, in this case from ~36,000 BP to ~25,000 BP. Although there are some taxonomic differences – the presence of hyaena at Paviland for example – some broad similarities exist.

Table 11.16 compares the fauna represented at the two sites for the period ~37,000 to ~25,000 BP. With 12 faunal

Site	***Species***	***Ref. no.***	***$\delta^{13}C$***	***Date***
Coygan Cave	*Rangifer tarandus*	BM-499	$\delta^{13}C$ unavailable	38684 +2713/-2024 BP
Coygan Cave	*Coelodonta antiquitatis*	OxA-2509	$\delta^{13}C$ unavailable	24620 ± 320 BP
Little Hoyle	*Crocuta crocuta*	OxA-1491	Estimated $\delta^{13}C$ -21.0 used.	34590 ± 1500 BP
Little Hoyle	*Rangifer tarandus*	OxA-1028	No measured $\delta^{13}C$	29200 ± 700 BP
Little Hoyle	*Ursus arctos*	ANU-4347	$\delta^{13}C$ unavailable	20080 ± 1120 BP
Little Hoyle	*Ursus arctos*	ANU-4350	$\delta^{13}C$ unavailable	20800 ± 910 BP
Little Hoyle	*Ursus arctos*	ANU-4348	$\delta^{13}C$ unavailable	18240 ± 1260 BP
Little Hoyle	*Ursus arctos* (laboratory intercomparison of ANU-4348)	OxA-2508	$\delta^{13}C$ -18.3‰	23550 ± 290 BP
Ogof-yr-Ychen	*Coelodonta antiquitatis*	Birm-340	$\delta^{13}C$ unavailable	22350 ± 620 BP
Ffynnon Beuno 11	*Equus ferus*	Failed No collagen		
Ffynnon Beuno 6	*Coelodonta antiquitatis*	OxA-9020	$\delta^{13}C$ -19.3‰	28030 ± 340 BP
Ffynnon Beuno 21	*Rangifer tarandus*	Failed No collagen		
Ffynnon Beuno 13	*Mammuthus primigenius*	OxA-9008	$\delta^{13}C$ –20.9‰	27870 ± 340 BP
Ffynnon Beuno 51	*Cervus elaphus*	Failed No collagen		
Ffynnon Beuno 29	*Bos sp./Bison* sp.	OxA-8998	$\delta^{13}C$ –20.0‰	24450 ± 400 BP
Ffynnon Beuno	*Mammuthus primigenius*	Birm-146	$\delta^{13}C$ unavailable	18000 ±1400/-1200 BP
Cae Gronw	*Mammuthus primigenius*	OxA-8314	$\delta^{13}C$ -21.6‰	41800 ± 1800 BP
Cae Gronw	*Ursus* sp.	OxA-6335	$\delta^{13}C$ -20.1‰	35100 ± 1500 BP
Cae Gronw	*Rangifer tarandus*	OxA-5990	$\delta^{13}C$ -19.4‰	20200 ± 460 BP
Bacon Hole	*Ursus* sp.	OxA-5699	$\delta^{13}C$ -20.3‰	33200 ± 950 BP
Bacon Hole	*Ursus* sp.	OxA-6022	$\delta^{13}C$ -20.5‰	31500 ± 1200 BP

Table 11.15. Conventional (Birm-146) and AMS radiocarbon measurements on fauna from Welsh caves other than Pontnewydd.

taxa (including humans) Paviland is taxonomically richer than Pontnewydd (nine, lacking humans), although it can be seen that the two sites share seven taxa (three carnivores – wolf, fox and bear, and four herbivores – reindeer, cervid, horse and woolly rhinoceros). At each site all of these taxa overlap chronometrically, with the exception of equids and unspecified cervids, which in both cases are dated earlier at Pontnewydd, although one should not place too much emphasis on this given the small number of dates on these taxa at both sites (a total of three dates for each site). Differences between the two sites can mainly be explained by the presence of additional taxa at Paviland, which saw hyaena denning from ~28,000 BP and the presence of bovids and *Megaloceros* prior to ~27,000 BP, and mammoth (with the exception of one tooth, in the form of humanly-modified ivory artefacts) between 30,000 and 24,000 BP, and Gravettian humans at around ~29,000 BP (Jacobi and Higham 2008). By contrast, both lion and *Lepus* are entirely absent from the fauna (dated and undated) of Paviland.

At Paviland, a parsimonious reading of the faunal age ranges would suggest no dated species earlier than ~35,000 BP, although taking age ranges into account woolly rhinoceros and reindeer may have been present as early as ~37,000 BP. Even in this scenario, taxonomic diversity more than quadrupled after 37,000 BP. Table 11.17 compares taxonomic diversity at the two sites, from which it can be seen that at Pontnewydd the diversity doubles after 37,000 BP. A closer reading of the age distributions of the fauna at Paviland (Pettitt 2000) suggested a major

	Pontnewydd	***Paviland***
Panthera leo	*	
Canis lupus	*	*
Vulpes vulpes / Alopex lagopus	*	*
Crocuta crocuta		*
Ursus sp.	*	*
Rangifer tarandus	*	*
Cervid	*	*
Equus ferus	*	*
Coelodonta antiquitatis	*	*
Bovid		*
Megaloceros giganteus		*
Mammuthus primigenius		*
Lepus sp.	*	
Homo sapiens		*

Table 11.16. Taxonomic composition at Pontnewydd and Paviland between ~37 and ~25 Kyr BP.

Site	***No. Taxa > 37 kyr BP***	***No. Taxa <37 kyr BP***
Pontnewydd	4	8
Paviland	0 or 2	11

Table 11.17. Taxonomic diversity at Pontnewydd and Paviland prior to and after ~37 kyr BP.

faunal restructuring ~28,000 BP, as represented by the apparent appearance of human groups, as represented by the burial of the 'Red Lady' at 29,000 BP, in the context of the disappearance of woolly rhinoceros and bovids (and probably *Megaloceros*) and the appearance of wild horse and mammoth. With regard to the carnivores it is interesting that wolf makes its first dated appearance at Paviland by ~28,000 BP, approximately the time it is first dated at Pontnewydd. This re-structuring could, in addition, be reflected at Pontnewydd with the floruit of fox (present, but poorly-dated at Paviland), appearance of cervid, and possible disappearance of bear. One must perhaps not make too much of these broad faunal changes, although the fact that at both sites *broad* faunal turnovers and re-structurings coincide around 37,000 and 28,000 BP and dated records effectively cease ~25,000 BP is of interest.

Radiocarbon dates from other sites from western England or those on a latitudinal parallel with Pontnewydd are also pertinent to the results, and in this light we include dated samples from Devon (Bench Tunnel Cavern, Kent's Cavern), Somerset (Soldier's Hole, Hyaena Den, Uphill Quarry) and Derbyshire (Pin Hole, Robin Hood Cave, The Arch, and Church Hole at Creswell Crags, Ash Tree Cave). These are presented in Table 11.18. As so few dates exist for fauna from these sites little can be said by way of comparison, but as with the Welsh sites broad agreement can be observed. Seven taxa dated from Pontnewydd can be found varyingly among these sites, and in five cases (fox, reindeer, bear, wolf and cervid (in the case of the latter equating the unspecified cervid at Pontnewydd with red deer)) their broad age ranges overlap and place them within the Pin Hole MAZ. With the exception of the lack of humans at Pontnewydd (see below), which in addition to Paviland are attested at the western English sites around ~32,000–30,000 BP (Hyaena Den, Uphill Quarry) and on typological grounds at Creswell around ~28,000 BP (the *Font Robert* points from Pin Hole), the only fauna conspicuously lacking among the dated examples from western English sites is *Lepus.* All one can really say is that the dated fauna from Pontnewydd is certainly not inconsistent with Pin Hole MAZ dated faunas from elsewhere in the west of Britain.

There are a series of dated faunal specimens from several cave sites in Ireland with which the Pontnewydd Upper Breccia assemblage may be compared. These were dated by the Oxford Laboratory in the early and mid 1990s, using the then prevailing chemical pre-treatment methods involving ion-exchanged gelatin, and reported by Woodman *et al.* (1997). The most relevant sites with Pleistocene faunas that pre-date the Last Glacial Maximum include Castlepook and Foley Caves in Co. Cork, Ballynamintra and Shandon Caves in Co. Waterford. The range of taxa is very relevant to the Pontnewydd Upper Breccia however there are currently questions concerning the validity of some of these determinations. The Oxford laboratory is currently undertaking a small re-dating programme of some of the Shandon and Castlepook determinations and although it is premature to go into details there are indications that some of the older results reported in Woodman *et al.* (1997) are biased and the ages misleading. For these reasons we have omitted detailed discussion of this evidence. Further work, involving ultrafiltration methods, will probably clarify the situation in the near future.

Concluding remarks

One major question is why there is no evidence of the presence of humans at Pontnewydd, during the period

Site	***OxA***	***Species***	***Description***	***Find no.***	***Context***	$\delta^{13}C$	***Date***
Soldier's Hole	691	*Rangifer tarandus*	Calcaneum		Unit 4		>34500
	692	*Rangifer tarandus*	Phalange	13 phal	Unit 4		29300 ± 1100
	693	*Rangifer tarandus*	Astragalus	14 astrag	Unit 4		>35,000
	1957	*Rangifer tarandus*	Humerus	LL 7811	Unit 4		41700 ± 3500
	2471	*Rangifer tarandus*	Phalange (repeat of – OxA-692)	13 phal	Unit 4		29900 ± 450
	1777	Bovid	Tibia		Unit 4		>42900
Bench Tunnel Cavern, Brixham	13512	*Crocuta crocuta*	Right dentary – repeat of OxA-1620/5961 (see Jacobi *et al*. 2006) AF method			-18.4	36800 ± 450*
	13324	*Crocuta crocuta*	Right dentary – repeat of OxA-1620 AG method (see Jacobi and Higham, in prep.)			-18.5	37500 ± 900*
Creswell Crags***	3417	*Rangifer tarandus*	Cut-marked partial tibia indicative of human presence			-17.8	37200 ± 1300
Pin Hole cave, Creswell Crags	4754	*Crocuta crocuta*	Pre-maxillary		66/9'(P.8)		37800 ± 1600
	3405	*Rangifer tarandus*	Antler, worked, indicative of human presence		Main passage, 3'3"	-17.7	31300 ± 550
	3406	*Rangifer tarandus*	Antler		Main passage, 69/6'	-17.7	37450 ± 1050
	3407	*Rangifer tarandus*	Antler		Main passage, 66/4'	-19.7	34360 ± 750
	3409	*Rangifer tarandus*	Antler		Main passage, 67/5'	-17.6	34120 ± 750
Robin Hood Cave, Creswell Crags	3455	*Coelodonta antiquitatis*	Tooth	+7969	Uncemented screes	-20.0	29300 ± 480
The Arch, Creswell Crags	5797	Bovid	Right M3	AH7		-21.0	23140 ± 340
Ash Tree Cave, Derbyshire	4104	*Coelodonta antiquitatis*	Calcaneum	AI, 27	Stony cave earth	-20.3	30250 ± 550
	4105	*Coelodonta antiquitatis*	Right ulna	BII, 8+9	Stony cave earth	-19.8	31300 ± 600

	5798	*Crocuta crocuta*	Right P4			-19.1	25660 ± 380
Kent’s Cavern, Torquay**	4435	*Cervus elaphus*	Molar	11	Vestibule		28060 ± 440
	4436	*Rangifer tarandus*	Tooth	B 6’9”	Vestibule	-19.7	27780 ± 400
	4437	*Vulpes vulpes*	Right mandible	C 5’6”	Vestibule	-20.9	23680 ± 300
	4438	*Vulpes vulpes*	Right mandible	B/c 6’0”	Vestibule	-23.5	28700 ± 600
	5693	*Rangifer tarandus*	Left calcaneum	2084, 3/21/1’/6b	Vestibule	-18.1	27820 ± 500
	5694	*Rangifer tarandus*	Right calcaneum	2024, 3/17/3’/IL	Vestibule	-17.9	28880 ± 440
	5695	*Canis lupus*	Left scapula	1881, 3/2/4’/6L	Vestibule	-18.2	26300 ± 340
	5696	*Megaloceros* sp.	Distal femur	B 8’4”	Vestibule	-20.9	23080 ± 260
	13965	*Coelodonta antiquitatis*	Cranial fragment (repeat of OxA-6108; see Jacobi *et al*. 2006)	C 9’6”	Vestibule	-20.1	37200 ± 550
Uphill Quarry, Somerset	13716	*Rangifer tarandus*	Lozangic *sagaie* indicative of human presence (repeat of OxA-8408; Jacobi *et al*. 2006)			-17.5	31730 ± 250*
Hyaena Den, Wookey, Somerset	13803	Unidentified	Bone or antler *sagaie* indicative of human presence (repeat of OxA-3451; Jacobi *et al*. 2006).			-19.2	31550 ± 340*
	4782	*Cervus elaphus*	Incisor, cut-marked, indicative of human presence	HDH, 1992, V10, 2	Cave earth, north side of cave mouth	-18.9	40400 ± 1600
	5701	*Rangifer tarandus*	Antler	UHDNW, 1994, K17	Top of stony cave earth in fissure at southern side of cave	-18.9	31450 ± 550
	5702	*Ursus* sp.	Canine	UHDNW, 1994, K17	Top of stony cave earth in fissure at southern side of cave	-18.9	32750 ± 700
	5703	*Equus ferus*	Tooth	HDHS, 1994, K15	Bottom of stony cave earth in fissure at southern side of cave	-20.8	37700 ± 1200

	5704	*Canis lupus*	Canine	HDHS, 1994, I14, 6b	Sandy-silts at southern end of cave	-18.7	39100 ± 1300

Sources: Gowlett *et al*. 1986; Hedges *et al*.1994; Higham *et al* 2006; Jacobi *et al*. 2006; Jacobi 1999.
*Indicates that previous measurements exist for these samples which were produced prior to ultrafiltration at Oxford. Results shown are re-measurements on ultrafiltered samples. See Higham *et al*. 2006 for discussion.
**We omit the existing direct AMS radiocarbon date on a human mandible from Kent's Cavern.
*** We also omit AMS radiocarbon measurements on hyaenas from Church Hole and Robin Hood Cave, Creswell Crags, which were previously published in Hedges *et al*. 1996 but which, after re-dating of samples pre treated with ultrafiltration are now demonstrably older than the range of dated Pontnewydd fauna (>40,000 BP: Higham *et al*. 2006). We do, however, include a hyaena specimen from Pin Hole. The determination from The Arch at Creswell Crags is likely to be aberrant. Jacobi and Higham attempted to re-date this and obtained no collagen, implying that the initial date is almost certainly problematic.

Table 11.18. ^{14}C determinations from other Late Pleistocene contexts in the west of Britain.

in which Gravettian activity at Paviland left, among other things, the burial of the 'Red Lady'. At Paviland, human remains and humanly-modified artefacts thought to be associated with a Gravettian occupation, were once interpreted as dating to the range ~24,000 to 28,000 BP, although the presence of diagnostically Aurignacian artefacts at the site presumably indicates occupation prior to this time, perhaps around 32,000 BP on the basis of a direct AMS radiocarbon date on a diagnostic lozangic antler point from Uphill Quarry Cave 8 (OxA-13716 at 31,730±250 BP). The amount of Gravettian material recovered from the site, however, is not great, and one must remember that diagnostic Gravettian material (in the form of *Font Robert* points) has only been recovered from nine British sites (Jacobi 1999). One might infer from this that humans were present in Britain only sporadically, and a parsimonious interpretation of the diagnostic artefacts (*Font Robert* points, which on the continent are securely dated to ~28,000 to 27,000 BP) suggests brief human incursions in this period alone. The intriguing find and date obtained for the human humerus attributed to the Eel Point Cave at the western end of Priory Bay on the north side of Caldey Island, South Wales (Schulting *et al*. 2005) suggests human presence took place once more by 24,500 BP. This is towards the end of a time of extremely cold temperatures and suggests perhaps that Gravettians had become better adapted to colder conditions (presumably with improved shelter, organization and clothing) to allow settlement in much harsher environments. What is confusing is the lack of Late Gravettian lithic remains in the British Isles. The most northerly diagnostic Gravettian artefacts have been found in Pin Hole cave at Creswell Crags, but this of course does not mean that Gravettian groups penetrated as far to the north-west as Pontnewydd. The reason for their absence could thus be one of simple distance. The radiocarbon evidence from Pontnewydd indicates that red fox, wolf, bear, birds, reindeer, cervids and hares were present in the period in which the *Font Robert* phase of the Gravettian belongs, and at Paviland in this specific period the only herbivores dated are *Bos* and mammoth. We would have liked to include the horse vertebrae spatula from Paviland here although despite re-dating using ultrafiltration these still appear to be contaminated and therefore minimum ages. Faunal impoverishment, therefore, does not seem to be a sensible explanation for the lack of human presence at Pontnewydd.

Finally we ask again the questions which we posed at the outset:

1. *To identify changing patterns of faunal composition, biodiversity and biomass intensity over the period 40–20,000 BP.* There seems to have been major faunal restructuring around 29,000 BP, in the form of the appearance of a taxonomically-richer Pin Hole MAZ, followed by a disappearance of this faunal MAZ around 25,000 BP. These results are broadly similar to those observed at Paviland, and the few dates available from other sites are consistent with this patterning.
2. *To seek to identify from this, reasons for a scarce human presence (attested perhaps by a single cut-marked tooth) from the Upper Breccia context at Pontnewydd, which is composed of accumulations probably brought into the cave by the action of bears, wolves and foxes.* The results demonstrate the persistence of fox, wolf and, particularly, bear at Pontnewydd, albeit in the absence of hyaena. This may alone suggest why the cave was not attractive to humans. Traces of Early Upper Palaeolithic humans in Britain are remarkably rare, and it is only with the Late Upper Palaeolithic after ~13,000 BP that a good sample exists. We note the absolute lack of Late Glacial faunas among the dated sample from Pontnewydd, which may suggest the unavailability of the cave for habitation at the time.
3. *To compare Pontnewydd with relevant coeval assemblages – including those from the nearby sites of Ffynnon Beuno and Cae Gwyn – where there is evidence for both human and hyaena presence, both of which are lacking from Pontnewydd.* Paviland Cave is the only site available with a suitably large suite of dates on faunal taxa, and shares a number of similarities with Pontnewydd, including faunal turnover (= a rise in taxonomic diversity consistent with the appearance of a Pin Hole MAZ) around 29,000 BP. The poor database of radiocarbon measurements from other sites is consistent with this. Differences, amounting only to greater taxonomic diversity at Paviland, possibly

reflect regional differences (perhaps latitudinal) and these possibly had an effect on the presence of humans in the south but not in the north.

4. *To examine whether the bear and wolf presences can be differentiated chronologically*. It appears that they can. A parsimonious reading of age ranges for these taxa suggest that by the time wolf appears ~29,000 BP bear populations in the cave were diminished, possibly gone.
5. *To establish whether the accumulations of herbivore remains primarily coincide with the pattern of wolf presence at the cave*. It appears not. With the exception of *Lepus* sp. the herbivore taxa accumulated earlier than the known age range of wolf in the cave, and a number of specimens of *Lepus* itself pre-date wolf. The accumulation of reindeer, cervid, and the individual specimens of horse and woolly rhino occurred in the period that fox and bear were using the cave, and probably pre-date the accumulation of lion.
6. *To examine whether original spatial and chronological configurations of animal bones in the cave can be retrieved.* Despite a large number of failures in the dating of faunal specimens due to lack of collagen, a good degree of success has been evident in the reconstruction of faunal turnover in the cave which is of a pattern observable elsewhere (at Paviland) and which is consistent with the scatter of more isolated results from other caves in the region.