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URANIUM-SERIES DATING OF SPELEOTHEMS FROM MENDIP CAVES.
1: RHINO RIFT, CHARTERHOUSE-ON-MENDIP

by

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Rhino Rift, Charterhouse-on-Mendip N.G.R. ST4847.5557
Altitude 210m O.D. *Length* 320m *Vertical range* 144m

ABSTRACT

The morphology and deposits of Rhino Rift are described. The cave is an 'invasion vadose cave' formed when the local saturation level was 75-90 m O.D. Ten U-series dates on four speleothems show that a boulder and cobble infill at the bottom of the known cave accumulated sometime after c. 45,000 years ago, whereas poorly sorted muddy gravels blocking the entrance passages were laid down before c. 11,000 years ago. The cave itself was formed before 75,000 years ago, probably during Isotope Stages 5 or 6. The implications for the geomorphic history of the Mendip region are discussed.

INTRODUCTION

The geomorphic history of a cave system can often be deduced from the form of its passages and the deposits they contain. Limestone caves which are formed by groundwater often preserve evidence of underground drainage routes or past levels of the water table which can be correlated with surface geomorphic features such as river terraces, or sequential stages in the cutting of valleys and gorges (Warwick, 1976). Similarly the deposits preserved in caves may provide evidence for conditions of climate, erosional activity or vegetation on the surface at the time of their formation. Studies of these topics were hampered until recently by a lack of dateable material which made it difficult to deduce the timescale of geomorphic development and impossible to be certain of correlations between deposits underground and others on the surface. The development of uranium-series methods for dating speleothems has completely reversed this situation and caves can now be regarded as rich depositories of chronological information about landscape development and palaeo-environments. Early descriptions of uranium-series dating of speleothems are by Harmon *et al.* (1975) and Gascoyne *et al.* (1978) while a comprehensive review of uranium-series methods is given in a recent book edited by Ivanovich and Harmon (1982). The application of speleothem dating to geomorphology in the Canadian Rockies has been described by D. C. Ford *et al.* (1972, 1981), by Waltham *et al.* (1977) and Gascoyne (1981; *et al.*, 1983) in Yorkshire, and by T. D. Ford *et al.* (1983) in Derbyshire. Atkinson *et al.* (1977, 1978) have described early work in the Mendip Hills. The present paper is the first of a series in which we describe the systematic sampling and dating of speleothems from several Mendip caves and their interpretation in terms of speleogenesis and geomorphic history of the Mendip region and reconstruction of past environmental conditions.

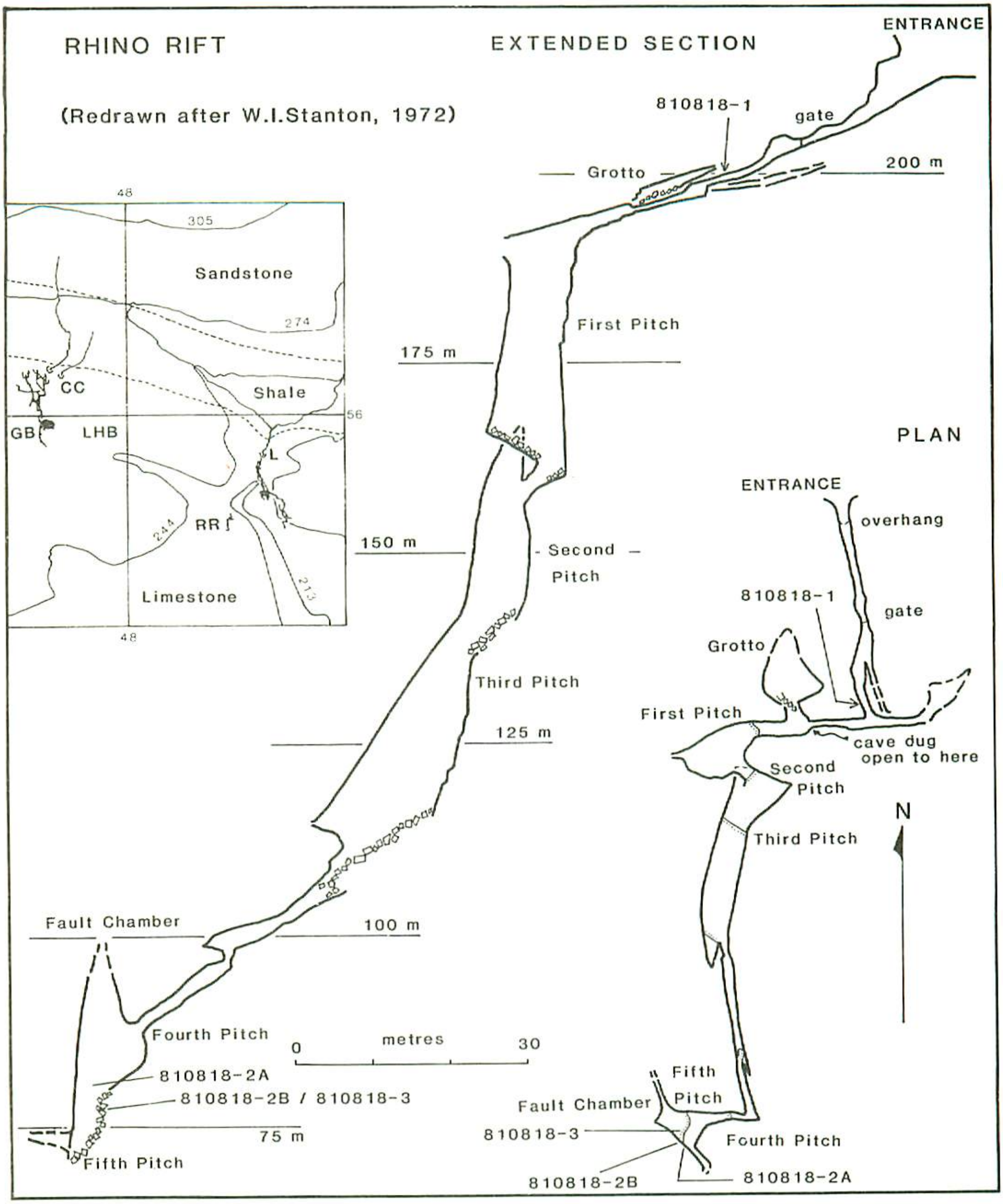

Fig. 15. Plan and elevation of Rhino Rift showing sample locations and relationship to surface features and nearby caves. Key to inset: GB = G.B. Cave; CC = Charterhouse Cave; L = Longwood Swallet and Cave; RR = Rhino Rift: LHB = Long House Barn Valley. Contour heights in metres O.D.; geological boundaries shown as pecked lines. Grid is National Grid. (Redrawn after Stanton, 1972).

MORPHOLOGY AND DEPOSITS OF RHINO RIFT

The entrance to Rhino Rift is at 210 m O.D. in the south side of the Long House Barn dry valley, a few metres from its confluence with the Longwood valley (Fig. 15, inset) and some 6 m above the present Longwood valley floor. According to Donovan (1951) the entrance was excavated in 1928-29 and 1947-48. It was not until 1970-71 that a way was finally dug through the deposits which filled the first 30-40 m of passages and the cave was explored and mapped (Audsley, 1971; Stanton, 1982).

The 'entrance series' consists of rift passages between the entrance and the top of the First Pitch. They were completely blocked with sediment near to the entrance and at a point 7 m back from the top of the pitch (Fig. 15). The rock floor cannot be seen anywhere in the 'entrance series' and the deposits have been greatly disturbed and obscured by the excavation. Above the First Pitch a boulder-floored bedding passage (the Grotto) leads northwards up-dip before becoming choked by boulders.

The first three pitches are large shafts formed in a fault and master-joint (Fig. 15). The ledges between the pitches are covered with boulders, cemented by flowstone in places but mostly loose. A large accumulation of boulders lies at the foot of the Third Pitch from which the cave continues as a narrowing, steeply descending fissure floored with boulders and flowstone. Poorly formed scallops on one wall indicate a downward flow of water in the past An abrupt turn to the west leads to the Fourth Pitch into Fault Chamber which is divided into two floor levels by a 6 m wall of small boulders forming the Fifth Pitch. At the bottom a low tunnel leads northwards for a few metres. The walls and roof of the tunnel have solutional facets and it appears to be of phreatic origin, unlike virtually the whole of the rest of the cave which is vadose in form. Scallops on the tunnel wall suggest a northward water flow during its formation.

The origin of the cave is straightforward. It is an 'invasion vadose cave' as defined by Ford (1965) and Ford and Ewers (1978). It appears to have been formed above the water table by a stream sinking in the Long House Barn valley via the present entrance. Some water probably also entered via the Grotto and the combined flow carved the vertical pitches. Narrow canyons entering the walls of First Pitch may have carried tributaries. Large vertical shafts ('splash pots', 'dome pits') may be formed by quite small streams (Pohl, 1955) and it is probable that the Rhino Rift stream was fairly small since the rift between Third and Fourth Pitches is only 0.3 m wide in places. Not until the very end of the cave are there any clearly phreatic features, in the small tunnel described above, at an altitude of just below 75 m O.D.. Therefore the contemporaneous water table during the main period of the cave's formation cannot have been much above 75 m O.D. and certainly was no higher than c. 90 m O.D., which level is just above the top of the Fourth Pitch.

Speleothems in Rhino Rift are mostly flowstones on the walls of the shafts, cementing boulders, and covering parts of the walls and floor in the lower rift passages and Fault Chamber. Other deposits consist of accumulations of boulders beneath the pitches and two more complex groups of deposits in Fault Chamber and the 'entrance series' respectively.

In Fault Chamber the small phreatic tunnel contains 6-7 cm of reddish brown silty mud resting upon at least 12 cm of coarse sand with calcite pebbles. The base is not exposed. These sediments indicate a formerly active flow of water in the tunnel, but they do not occur in Fault Chamber itself. The Fifth Pitch in Fault Chamber is a 6 m high exposure of angular and sub-angular boulders and cobbles, mostly limestone but with some chert and flowstone. This boulder pile probably once filled the whole of Fault Chamber to the level of the top of the Fifth Pitch but has collapsed or subsided to its present level, splitting the chamber into two. The *in situ* material contains interstitial sand, mud and a calcite cement deposited by water seeping through it. The south-east wall of the chamber is covered with an eroded discontinuous layer of flowstone resting directly upon bedrock. The boulder accumulation rests against this flowstone. Overall, the sequence of events represented by these deposits is as follows:

(i) Erosion of the phreatic tunnel by a northward flowing stream which deposited sand and silt on its floor.
(ii) A fall in the local water level and deposition of flowstone by water flowing down the walls of Fault Chamber.
(iii) Accumulation of boulders, sand and mud washed into Fault Chamber by a stream falling down Fourth Pitch. The boulders are most probably derived from the walls of the shafts higher up the cave.
(iv) Undermining of the boulder accumulation and subsidence of part of it, forming the Fifth Pitch.

The deposits of the 'entrance series' may be very complex, but are now so disturbed by excavation that it is difficult to interpret them. In the interior of the entrance rift and in the complex of small passages beyond it are several separate exposures in which a layer of sediment is overlain by a flowstone with a second sediment layer above it. The lower sediments vary from reddish brown mud to muddy sand containing pebbles and cobbles of angular limestone and sub-rounded limestone and sandstone. The upper sediment varies from gritty mud to gravel. In some places it is overlain by a second flowstone or by small stalagmites. In the Grotto the floor consists of boulders covered in places with reddish mud and flowstone. The flowstone has subsequently been broken and the mud washed away in places, although there is no flowing water at present.

Deposits in the entrance itself have been removed or buried by the excavators. Donovan (1951) describes how the inner part of the 1928-29 excavation terminated in "a loose choke of boulders". The outer part of the rift was filled to a depth of 4.35 m with "loosely packed, angular limestone fragments, with some clayey matter and many open spaces between". The accidental finds in 1947 of teeth of Woolly Rhinoceros (*Coelodonta antiquitatis*) and bones of Hyaena (*Crocuta crocuta*) most probably came from this deposit (Donovan, 1951).

Taken together, the 'entrance series' deposits suggest an early stage of infill by sediment derived from the floor of the Long House Barn valley and transported in part from the Devonian sandstone outcrop a kilometre or so away. This sediment can only have been deposited in the cave when the valley floor was at a similar level to the entrance. There followed a period of flowstone deposition before wetter conditions caused more sediment to be washed into the cave or the existing sediment to be redistributed, burying the flowstone in places. The deposit blocking the entrance itself was a limestone breccia, most probably formed by spalling and rockfall in the entrance rift or on the slope above it.

SAMPLED SPELEOTHEMS

Four speleothems were collected from the locations shown in Fig. 15 and sectioned in the laboratory. In the following notes each sample is referred to by its collection number (e.g. UEA810818-1) and its stratigraphy is described in terms of separate depositional units during which growth appears to have been continuous. Successive units are separated by a growth hiatus. Different numbers (e.g. EAB01) are given for laboratory analyses which were carried out on sub-samples. The analysed portions are indicated on sketches in Fig. 16.

UEA810818-1. *In situ* flowstone and stalagmite on wall 2 m north of junction between entrance passage and the E-W rift leading to First Pitch. The sample overlaid a muddy clay containing angular limestone stones and was buried by muddy gravel containing limestone and occasional sandstone pebbles. Most of the sediments had been removed during excavation. On sectioning the sample revealed two units (Fig. 16). Unit I (20-50 mm thick) contained seams of sand and cemented pebbles of shale and limestone at the base. The flowstone was clearly layered, opaque white to translucent grey-tan. Unit II (0-15 mm) was a buff flowstone forming a thin coating over the stalagmite of Unit I but thickening to 15 mm over the flowstone "plinth". Unit II overstepped the edge of Unit I and rested directly on gravel, filling voids between the larger stones. Subsamples EAB10 and EAB08 were from bottom and top of Unit I and EAB09 was from Unit II.

UEA810818-2A. *In situ* thin flowstone with growth layers exposed by erosion, located on the south-east wall of Fault Chamber, 1.5 m above the top of the boulder accumulation at Fifth Pitch. Unit I (6 mm) rested on the rock wall. Grey-white translucent and buff-brown opaque laminae were truncated by the surface separating it from Unit II. Unit II was up to 14.5 mm thick and composed of creamy buff and dark brown laminations with a prominent white translucent layer near the top. The surface between Units II and III was vuggy, with slight unconformity caused by truncation of the uppermost laminae of Unit II. Unit III (6 mm) consisted of grey translucent and buff-brown opaque laminations. The top surface was pitted to a depth of 1 mm, indicating slight erosion. Each unit was analysed separately, as EAB01, EAB02 and EAB03, respectively.

UEA810818-2B. *In situ*, thin, water-born flowstone resting upon the rock wall 2 m below 810818-2A and partially buried by the boulder accumulation. Slicing showed 14 mm of buff to dark brown laminated calcite, dense and non-porous throughout except for a slightly porous layer 0.5 mm thick and 5.5 mm from the base. This may possibly represent a hiatus in growth. The sample was analysed as a whole, EAB04. From their positions 810818-2A and 810818-2B appear to be roughly contemporaneous.

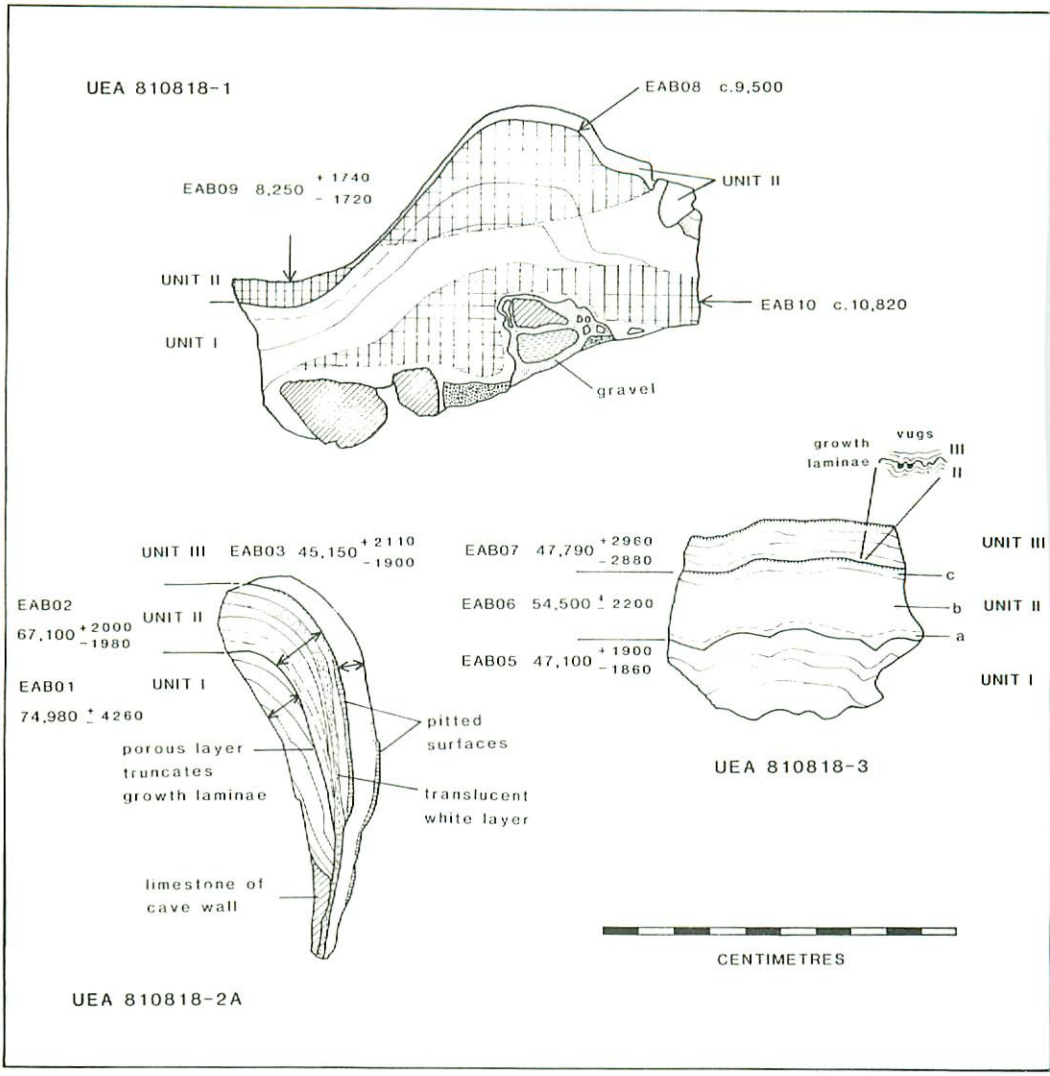

Fig. 16. Details of sectioned speleothems showing growth units, dated portions and 'corrected' dates. (Analysed portions are cross-hatched. If not shown, then whole growth unit was dissolved. Speleothem calcite shown unshaded with prominent growth laminae marked. Clastic sediment stippled, shaded or diagonally hachured.)

UEA810818-3. Flowstone pebble from about 1 m depth in the boulder accumulation of Fifth Pitch. Unit I (20-24 mm minimum thickness) was buff to pale pink calcite with chalky texture and irregularly spaced growth lines. The base was not present. An abrupt transition of colour and texture separates it from Unit II (20-24 mm) which contains three sub-units: (a) mid-brown finely laminated flowstone, passing into (b) crystalline tan finely laminated flowstone terminating in a vuggy layer. Tiny knobbly protuberances c. 1 mm high separate the vugs in this layer and appear to represent the growth surface at the time deposition of Unit II ceased, since they are reflected in growth laminae immediately beneath them. The lowest laminae of Unit III have formed over the tops of the protuberances, leaving vugs between them. Thus, there appears to have been a non-sequence between Units II and III. Unit III (11 mm) consists of white, grey and brown layers of calcite (Fig. 16). Units I, II and III were analysed separately as EAB05, 06 and 07 respectively.

SPELEOTHEM DATING

The principles and practice of speleothem dating are discussed in detail in a book edited by Ivanovich and Harmon (1982). Only a summary will be given here, to enable the reader to make an informed interpretation of the results which are presented in Table 1.

Speleothems consist of two components, authigenic calcite and particles of detritus which were deposited onto the surface of the speleothem as it grew. The detritus may consist of carbonate or silicate rock fragments, clay or organic matter. The uranium-series dating method is based upon the assumption that the authigenic calcite contained no thorium at the time of deposition, but that it did contain small traces of uranium which were present in the solution from which it was deposited. The isotopes of uranium ^{238}U and ^{234}U are part of a radioactive decay chain in which the next long-lived member is ^{230}Th. Thus, the ingrowth of ^{230}Th in the authigenic calcite gives a measure of its age. In principle, a sample may be dated by dissolving the authigenic calcite in acid and assaying the activity ratios of $(^{234}U/^{238}U)_s$ and $(^{230}Th/^{234}U)_s$ and calculating the age, t, from the equation,

$$\left(\frac{^{230}Th}{^{234}U}\right)_{au} = \left(\frac{^{238}U}{^{234}U}\right)_{au} \left[1 - \exp(-\lambda_{230}t)\right] + \frac{\lambda_{230}}{\lambda_{230} - \lambda_{234}} \cdot \left[1 - \left(\frac{^{238}U}{^{234}U}\right)_{au}\right] \cdot \left[1 - \exp((\lambda_{230} - \lambda_{234})\,t)\right] \qquad (1)$$

where we assume that

$$\left(\frac{^{230}Th}{^{234}U}\right)_{au} = \left(\frac{^{230}Th}{^{234}U}\right)_{s} \qquad (2a)$$

$$\left(\frac{^{234}U}{^{238}U}\right)_{au} = \left(\frac{^{234}U}{^{238}U}\right)_{s} \qquad (2b)$$

TABLE 1: RHINO RIFT, SPELEOTHEM AGE DATA

Specimen		*Analysis No.*	*Uncorrected Date (Years)*	*Corrected Date Using $(^{230}Th/^{232}Th)_d$ of Detritus Residue*	
810818-2A	UNIT III	EAB 03	67,300 ± 2,200	45,150	$^{+2,110}_{-1,900}$
	UNIT II	EAB 02	78,600 ± 2,000	67,100	$^{+2,000}_{-1,980}$
	UNIT I	EAB 01	98,800 ± 7,400*	74,980	± 4,260*
810818-2B		EAB 04	$81,900^{+2,900}_{-2,800}$	58,300	$^{+2,700}_{-2,600}$
810818-3	UNIT III	EAB 07	$71,500^{+3,200}_{-3,100}$	47,790	$^{+2,960}_{-2,880}$
	UNIT II	EAB 06	54,500 ± 2,200		—
	UNIT I	EAB 05	68,100 ± 2,000	47,100	$^{+1,900}_{-1,860}$
810818-1	UNIT III	EAB 09	$34,300^{+1,600}_{-1,500}$	8,250	$^{+1,740}_{-1,720}$
	Top of UNIT I	EAB 08	11,200 ± 700	c. 9,500	**
	Base of UNIT I	EAB 10	$14,900^{+500}_{-400}$	c.10,820	**

* Mean value of 3 counts of the sources, with standard error.

** $(^{230}Th/^{232}Th)_d$ of contaminant assumed equal to value in EAB 09.

The subscript 's' refers to activity ratios in the solution and 'au' to ratios in the authigenic calcites. λ are the decay constants of the respective isotopes and t is the age of the sample. In practice it is often impossible to dissolve the authigenic calcite without also leaching some material from the detritus it contains. Unfortunately the detritus usually contains isotopes of uranium and thorium, including ^{230}Th. Thus, the detritus may add these isotopes to the solution, altering the $(^{230}Th/^{234}U)_s$ ratio away from the value of the authigenic calcite (i.e. Equation 2a is not true). This contamination can be detected because usually the detritus also contains the long-lived isotope ^{232}Th which is not derived from natural uranium radioactivity and which acts as a marker of detrital Th in the leachate. The nett effect of Th contamination is to raise the $(^{230}Th/^{234}U)_s$ ratio to a larger value than $(^{230}Th/^{234}U)_{au}$ and thus to overestimate the true age of the sample when calculating a date from Equations (1) and (2). In practice the effect on the date is only significant provided that $(^{230}\mathrm{Th}/^{232}\mathrm{Th})_s$ is less than 20. In this case, a correction can be applied to $(^{230}\mathrm{Th}/^{234}\mathrm{U})_s$ to give a truer estimate of $(^{230}\mathrm{Th}/^{234}\mathrm{U})_{au}$ using,

$$\left(\frac{^{230}\mathrm{Th}}{^{234}\mathrm{U}}\right)_{au} = \left(\frac{^{230}\mathrm{Th}}{^{234}\mathrm{U}}\right)_s - \left(\frac{^{230}\mathrm{Th}}{^{232}\mathrm{Th}}\right)_d \cdot \left(\frac{^{232}\mathrm{Th}}{^{234}\mathrm{U}}\right)_s \qquad (3)$$

where $(^{230}\mathrm{Th}/^{232}\mathrm{Th})_d$ is the ratio in the detritus which can be estimated by dissolving the residue from the initial solution in hydrofluoric and perchloric acids and assaying the solution. The revised estimate of $(^{230}\mathrm{Th}/^{234}\mathrm{U})_{au}$ from Equation (3) can then be used to calculate a 'corrected' date using Equation (1).

The subsamples EAB01 to EAB10 were dissolved in concentrated nitric acid. The U and Th isotopes in the solution were chemically separated, purified and electroplated onto stainless steel discs for determination of isotope activity ratios by alpha-spectrometry. Only one sample, EAB06, gave an uncontaminated $(^{230}\mathrm{Th}/^{232}\mathrm{Th})_s$ ratio greater than 20. For all except EAB06, 08 and 10 the residual detritus was dissolved and assayed for $(^{230}\mathrm{Th}/^{232}\mathrm{Th})_d$ and a 'corrected' date calculated using Equations (1), (2b) and (3). The calculated dates are shown in Table 1, together with one standard deviation uncertainties based upon counting statistics. Table 2 shows the analytical data.

The accuracy of the dates in Table 1 depends upon the validity of the assumptions behind the dating method. These include the requirement that the composition of the authigenic calcite is correctly estimated by the detritus correction method described. This is not entirely certain and it is possible that the $(^{230}\mathrm{Th}/^{232}\mathrm{Th})$ ratio of Th leached from the surface of the detritus by nitric acid differs from the ratio in the bulk of the residue. Furthermore, no attempt has been made to determine $^{234}\mathrm{U}$ and $^{238}\mathrm{U}$ leached from the detritus. If present, they should have the effect of decreasing the uncorrected date, offsetting the $^{230}\mathrm{Th}$ contamination to some extent. Because of these effects, the 'corrected' dates in Table 1 should be regarded as approximate estimates of the true age of each sample, while the uncorrected dates are almost certainly larger than the true age. Only for EAB06 does the uncorrected date give an estimate of the true age, as the $(^{230}\mathrm{Th}/^{232}\mathrm{Th})_s$ ratio for this sample was >20.

DISCUSSION

The Age of the Deposits

At the bottom of the cave, samples 810818-2A, -2B and -3 show that the boulder accumulation in Fault Chamber occurred after about 58 ka (1 ka = 1000 radiometric years before present). This is the date of 810818-2B which was buried by the boulders. Sample 810818-3 was included among the boulders themselves. Its dating is more problematical as the 'corrected' date for Unit I is 47 ka which is significantly younger than the uncontaminated date of 54 ka for Unit II. Over all, this sample is unlikely to be younger than 44 ka or older than 56 ka, so the top 1 m of the boulder deposit must

TABLE 2: RHINO RIFT, SPELEOTHEM ANALYSIS

Specimen	*Analysis No.*	*Weight (g)*	*HNO_3 Insoluble (%)*	*U (ppm)*	$\frac{^{234}U}{^{238}U_s}$	$\frac{^{230}Th}{^{234}U_s}$	$\frac{^{230}Th}{^{232}Th_s}$	$\frac{^{230}Th}{^{232}Th_d}$	*Yield (%)* **	
									U	*Th*
810818-2A										
UNIT III	EAB 03	52.9	2.9	0.21	1.827 ± 0.030	0.481 ± 0.012	3.8 ± 0.1	1.037 ± 0.028	69	73
UNIT II	EAB 02	69.8	0.7	0.19	1.838 ± 0.018	0.540 ± 0.010	8.8 ± 0.2	0.960 ± 0.052	87	71
UNIT I	EAB 01*	29.6	1.3	0.21*	1.564 ± 0.054*	0.625 ± 0.030*	6.9 ± 0.2*	1.176 ± 0.069	95*	86*
810818-2B	EAB 04	57.8	1.2	0.21	1.589 ± 0.024	0.551 ± 0.014	5.1 ± 0.2	1.133 ± 0.031	63	65
810818-3										
UNIT III	EAB 07	49.6	1.4	0.23	1.914 ± 0.041	0.505 ± 0.017	5.5 ± 0.2	1.488 ± 0.029	30	58
UNIT II	EAB 06	91.6	0.4	0.30	2.059 ± 0.031	0.407 ± 0.013	27.3 ± 1.9	N.D.	37	44
UNIT I	EAB 05	83.7	0.8	0.31	1.751 ± 0.018	0.485 ± 0.011	12.1 ± 0.3	1.479 ± 0.038	46	79
810818-1										
UNIT III	EAB 09	27.4	3.0	0.17	1.266 ± 0.026	0.274 ± 0.011	1.4 ± 0.1	1.002 ± 0.031	57	51
Top of UNIT I	EAB 08	53.2	0.2	0.20	1.294 ± 0.036	0.098 ± 0.006	7.2 ± 1.3	N.D.	28	49
Base ofUNIT I	EAB 10	75.7	0.3	0.18	1.296 ± 0.019	1.129 ± 0.004	3.9 ± 0.2	N.D.	50	68

* Mean values and standard errors from three counts of U and Th sources.

** Analyses EAB 01-EAB 04 involved treatment with H_2O_2 and ultra-violet light following dissolution, to breakdown organic matter and increase yield. Other samples dissolved in HNO_3 only.

have accumulated since that time. This agrees with dates from 810818-2A which lies above 810818-2B in the cave and for which Unit III was deposited around 45 ka. Thus, the boulder accumulation took place sometime after about 45 ka.

In the 'entrance series' sample 810818-1 gives an indication of the age of the clastic deposits with which it was interbedded. Unfortunately, the sample is badly contaminated with a wide range of uncorrected dates (Table 1). EAB09 (Unit II) shows an especially large correction for detrital Th and appears to have been deposited sometime between 10 and 6 ka. The uncorrected dates for EAB10 and EAB08 are almost certainly too old, but there was insufficient detritus in these samples for analysis. Correction using a $(^{230}Th/^{232}Th)_d$ ratio of 1.002, the value in EAB09, gives dates which suggest that Unit I grew during the last part of the Late Glacial or in the early Holocene. This would suggest that the muds and gravels beneath flowstone layers in the 'entrance series' were deposited during or before the Late Glacial, while those above were Holocene.

The evidence of the breccia in the cave entrance suggests that the climate at the time the entrance was sealed was cold enough to produce active debris on slopes which today are covered with stable vegetation and soil. It seems most probable that the sediments beneath 810818-1 were transported down the steep entrance passage which was subsequently sealed by the breccia. Sample 810818-1 was then deposited after which water seeping into the cave locally reworked some of the sediment to form the upper layer of mud and gravel.

Overall, the main deposits of Rhino Rift appear to have been formed during the Devensian glacial. Both deposits may represent the same period of debris transport into the cave, in which case they would have been formed between 45-50 ka and c. 11 ka. This agrees well with the last period of gravel deposition in the nearby G.B. Cave, which speleothem dating puts between c. 50 ka and 13 ka (Atkinson *et al.,* 1977; Atkinson, Smart, Ford and Harmon, in prep.). On the other hand it is possible that the lower sediments of the 'entrance series' may be much older than the boulder accumulations in Fault Chamber.

The Age of the Cave

The age of speleothems must be less than that of the cavity within which they formed. Therefore the latest date for the origin is given by EAB01 (810818-2A) as before about 75±4ka. This is about the time of onset of climatic deterioration at the beginning of the Devensian/Weichselian glacial according to the radiocarbon-dated pollen record from the Grande Pile bog in the Vosges, northern France (Woillard and Mook, 1982), and the time of the Isotope Stage 5a/4 boundary in the deep-sea record (Shackleton and Matthews, 1977). Thus the most likely period for the formation of the cave itself is during the preceding interglacial of Isotope Stage 5, corresponding in Britain to the Ipswichian interglacial (*sensu lato*).

A problem with placing the formation of the cave in an interglacial period is its distance from the edge of the limestone outcrop. Today the limestone is completely without streams, and those which originate on the

Devonian sandstones to the north sink into caves promptly on reaching the limestone. A stream sinking in the present entrance of Rhino Rift would have to avoid engulfment in Longwood Cave if it came down the Longwood Valley and in G.B. and Charterhouse caves if it originated at the head of the Long House Barn drainage (Fig. 1). This led Stanton (1972) to argue that Rhino Rift might be older than G.B. Cave. Speleothem dates have since shown G.B. to be at least 350,000 years old (Atkinson *et al.,* 1977). No speleothems from Longwood have yet been dated but Atkinson (1967) compared the geomorphic development of the two caves and concluded that Longwood was at least as old as G.B. If so, both caves are most likely much older than Rhino Rift and would have swallowed the streams draining from the sandstone, in interglacials at least.

One answer may be that Rhino Rift is indeed much older than the other caves and that speleothems formed early in its history have not been preserved or simply were overlooked during sampling. This possibility cannot be denied, but against it must be put the fact that there is no sign in Rhino of such complex deposits as those in G.B., where ancient speleothems are preserved. An alternative, which we regard as the most likely, is that the cave originated from local drainage, probably snow-melt in the Long House Barn valley, during one or more periods of cold climate. The gravelly 'head' which covers the floors of many Mendip gorges and dry valleys testifies to the occurrence of runoff and/or solifluction during glacial periods (Findlay, 1965), as does the fluvial form of the gorges themselves. Runoff and erosion even occur today following exceptional rainstorms like those of 1968 (Hanwell and Newson, 1970). Smaller but more frequent discharges can easily be envisaged as resulting from annual snowmelt in the area of Long House Barn valley between Rhino Rift and G.B. Caves, under a nival climate. Invasion shafts formed by snow and ice meltwater are common, in alpine karsts (e.g. Ford *et al.,* 1983; Ford, Smart and Ewers, 1983) and we suggest that Rhino Rift may be another example, out of equilibrium with the present climate. If correct, this would place the most likely origin of the cave in Isotope Stage 6, or during the colder climates of Stage 5.

Geomorphic Implications

The chronology of the Rhino Rift's development has implications concerning the geomorphic development of the whole Cheddar catchment. At the time the cave formed the local water table must have been at or above 75 m O.D. to account for the phreatic tunnel in Fault Chamber. By 75 ka it had fallen below this level, allowing flowstone to form on the chamber wall. The present saturation level is at 40 m O.D. at the bottom of Renolds' Passage in nearby Longwood Swallet (Moody, 1982) while the water from the area resurges at Cheddar springs at 26 m O.D. (Atkinson *et al.,* 1967). The hydraulic gradient is only 5.2 m/km. A similar hydraulic gradient applied to Rhino Rift in the past would suggest a resurgence level between 61 and 76 m O.D. at Cheddar at a time when the Rhino Rift water level was between 75 and 90 m O.D. This overlaps with the 70-80 m Warren Hill level of Ford and Stanton's (1968) suggested denudation chronology of the central Mendips, and with scalloped passages indicating a palaeo-discharge from

Long Hole at Cheddar. The geomorphology of the Cheddar caves is very complex (Ford, 1965) but Long Hole could have acted as a resurgence (fed via the Fonts in Gough's Cave) when the local water table was at or above 76 m. If the resurgence had been via Gough's Old Cave, the local water table could have been as low as 63 m. Since the present-day gradient from Longwood to Cheddar is probably a minimum estimate for past gradients from Rhino Rift, these figures imply that when Rhino Rift formed, the Cheddar water was resurging either from Long Hole or some lower outlet, perhaps Gough's Cave. The dates from the bottom of Rhino would certainly imply that Long Hole had been abandoned as a resurgence by 75 ka.

The valley floor outside the entrance of Rhino Rift must have been lowered by about 6 m since the last influx of sandstone pebbles into the entrance series. The Woolly Rhinoceros tooth found in the breccia suggests that the cave was sealed during the Last Glacial period and this is supported by the uranium-series dates on 810818-1. Thus, 6 m is the approximate minimum amount of valley floor lowering which has occurred during all or part of the Last Glacial period. We cannot tell whether this represents erosion of the bedrock, or merely the removal of a former, unconsolidated valley fill.

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