Cave Science

The Transactions of the British Cave Research Association

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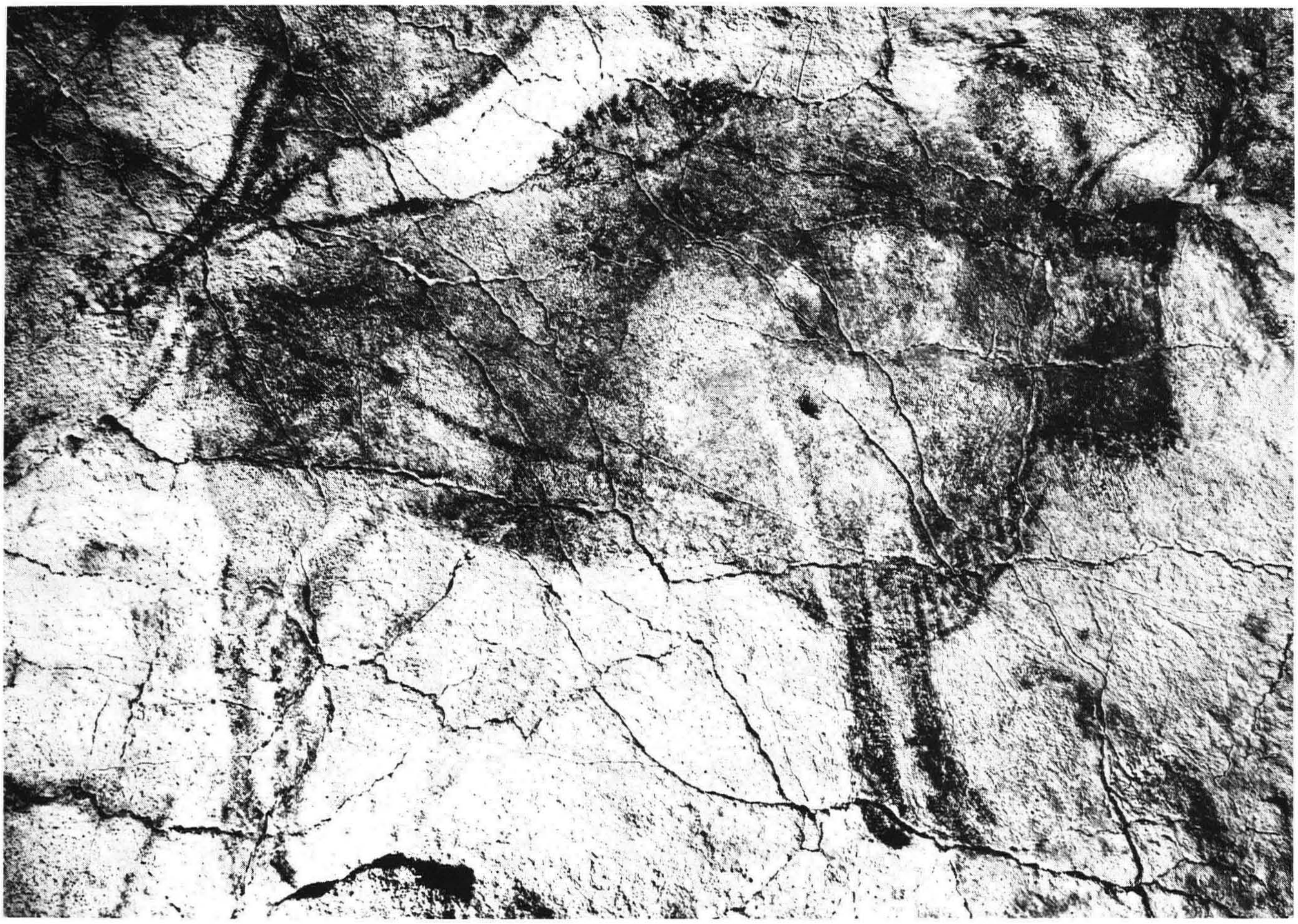
Volume 11 Number 2 July 1984



Bison painting in Altamira

Yorkshire Stalagmite Dates

Castleton Water tracing

Invertebrates from Niah Great Cave

Altamira Temperatures

Fiji Caves

BRITISH CAVE RESEARCH ASSOCIATION

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Abstract: All material should be accompanied by an abstract stating the essential results of the investigation for use by abstracting, library and other services.

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Cover photo: Bison painting in Altamira Cave by Eleanor Dominguez

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CAVE SCIENCE

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URANIUM SERIES DATING OF SPELEOTHEMS, PART II RESULTS FROM THE YORKSHIRE DALES AND IMPLICATIONS FOR CAVE DEVELOPMENT AND QUATERNARY CLIMATES

M.Gascoyne & D.C.Ford

Abstract

Results of dating over 80 stalagmites and flowstones from major Craven cave systems are described and interpreted in terms of speleogenesis and geomorphic development of the Yorkshire Dales. Long term average downcutting rates of 2 to 8 cm per thousand years have been calculated from basal ages of speleothems adjacent to major drainage channels. Extrapolation to valleys outside the caves suggests that the Dales are between one and two million years old. Periods of high speleothem growth frequency are correlated with Holocene and Ipswichian interglacials and low growth with Late Devensian and Wolstonian glaciations in the British Quaternary record.

INTRODUCTION

Caves in the Craven district of the Yorkshire Dales are among the most varied and extensive in the British Isles. Their relationship to one another, to the Carboniferous limestone in which they are formed and to landscape evolution of the area has been considered by many writers in local caving journals and in scientific papers by Sweeting (1950), Waltham (1970, 1971) and several authors in Waltham (1974a). Possible effects of past climatic changes upon rates and types of cave development have been stressed by Warwick (1956, 1971), Eyre and Ashmead (1967) and other authors in Waltham (1974a).

These approaches have relied upon fitting events perceived in the Craven cases (e.g. the draining of a phreatic passage) to some timescale obtained in other parts of Britain where more data are available. The Dales lack almost any surface deposit such as deltaic sands or bog organics that are older than the last glaciation. This glaciation is known as the Late Devensian and it is firmly correlated with the "last glaciations" elsewhere in the Northern Hemisphere. Ice reached its maximum depth and extent about 18,000 years ago, when all of the Dales were buried. Its recession from the area was complete by about 14,000 years B.P.

Many Craven caves appear to preserve much more ancient deposits. These include calcite stalagmites, stalactites, flowstones, etc., collectively known as 'speleothems'. Many speleothems can be dated by Uranium-series or other absolute (radiometric) methods, and by relative methods such as palaeomagnetism and palynology. Ratios of the stable isotopes of oxygen and carbon in the calcite may also give palaeotemperature information. The principles and techniques of these methods were described in detail in Part I of this paper (Gascoyne, Schwarcz and Ford, 1978).

Our purpose in Part II is to present the U-series dates we have obtained for the Craven caves, and to interpret them with particular regard to the history and the antiquity of local cave development.

THE CRAVEN DISTRICT

The principal cave systems in Craven lie towards the southern edge of the Askrigg Block, a major structural feature of the basement rocks that is bounded to the west and south by the Dent and Craven Faults respectively, (Fig. 1). Steeply-dipping slates of Ordovician and Silurian age outcrop in valley floors near the Craven Faults and are overlain unconformably by up to 200 m of Lower Carboniferous Great Scar limestone which dips gently to the northeast (Edwards and Trotter, 1968; Waltham, 1974b). The limestone is a pale-grey, massively-bedded calcarenite that contains several prominent fossiliferous and micritic horizons and numerous shale partings. In its uppermost beds, it grades into the Yoredale Series, a cyclic sequence of limestones, shales and sandstones, unconformably capped by the Upper Carboniferous Millstone Grit. Within the Askrigg Block, the Great Scar limestone is relatively undisturbed except for a few small, discontinuous faults and shallow folds. However, these often play important roles in the cave development.

Physical characteristics of the caves have been described in detail by Brook et al (1981), and are summarised in Table 1. Both phreatic and vadose passage types are common. Sweeting (1950) suggested that passages had tended to develop at three particular elevations, and interpreted these as ancient watertables. Waltham (1970, 1971), in contrast, correlated the caves with geological controls such as frequency of shale partings, lithological differences between limestone beds, and structural influences. More recently, however, the possibility of a regional watertable origin for many of the caves has been revived (Atkinson et al. 1978). Warwick (1956, 1971), Eyre and Ashmead (1967) and Waltham (1974c) have suggested that the formation and entrenchment of the caves occurred during interglacials, or at times of deglaciation when abundant meltwaters were released. Cave collapse or infilling with sediments would be the predominant activities during glaciations.

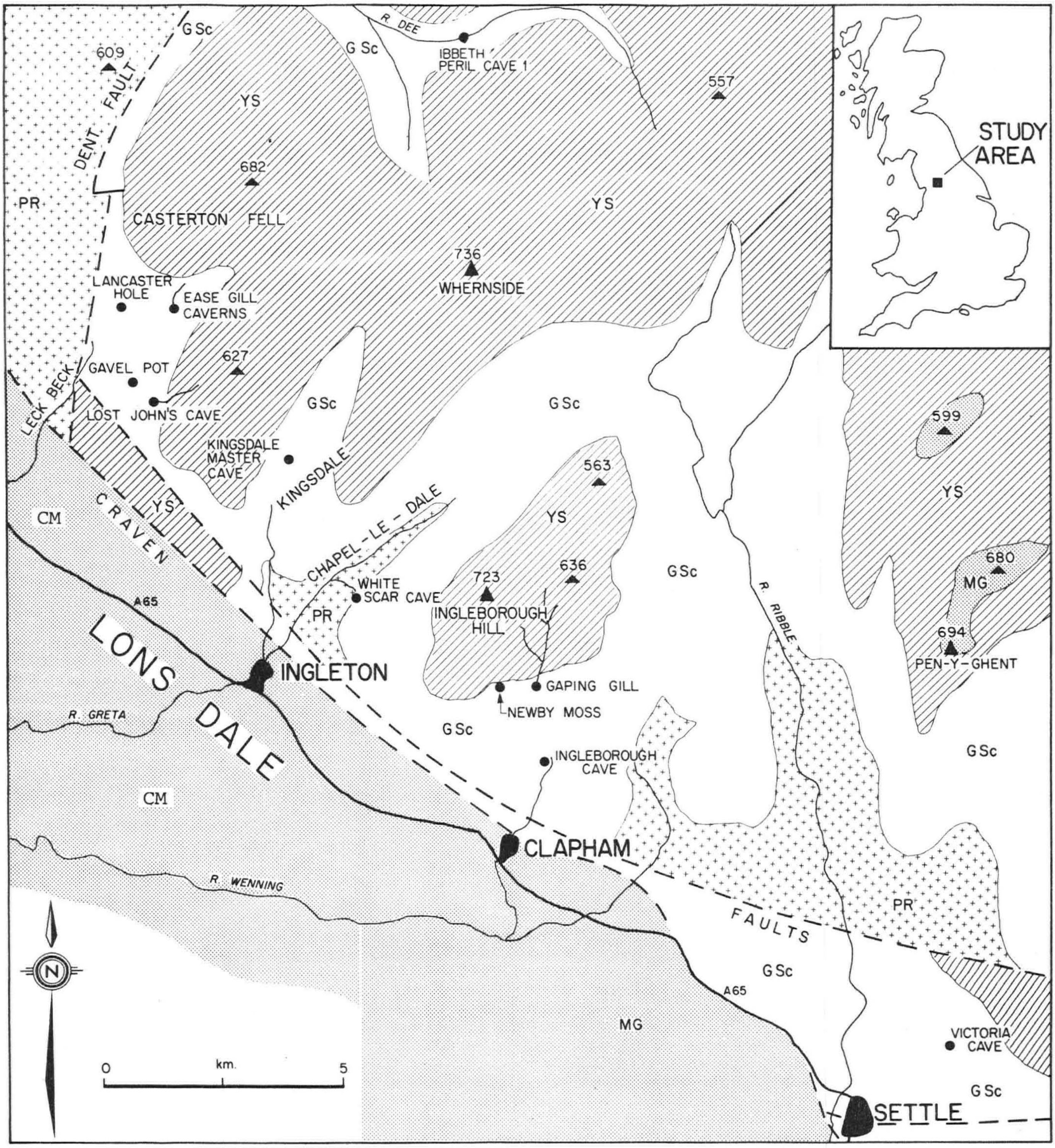


Figure 1. Cave location map of the Craven district of northwest England, showing geological sequence and major faults
C.M. - Coal Measures; M.G. = Millstone Grit, Y.S. = Yoredale Series, G.Sc. = Great Scar Limestone, P.R. = pre-Carboniferous rocks.
Heights are in metres above sea level (from Gascoyne et al. 1983a).

Several estimates of the age of the caves have been made. Eyre and Ashmead (1967) correlated their genetic sequence for the development of the Casterton Fell caves with the glacial chronology proposed by Zeuner (1959). They counted phases of net erosion or deposition back from the present to infer that the large fossil tunnels were formed during the Antepenultimate Interglacial. Brook (1974) considered each phase in the development of the West Kingsdale system to be a response to 20-50 m of lowering of the Dale floor by glacier scour. The system was about 250,000 years old. Glover (1974) was more cautious when interpreting passage levels in Gaping Gill, suggesting that some might be due only to local perching effects. Waltham (1974c) tentatively placed the caves into postglacial, interglacial and pre-glacial groups.

In 1977, Gascoyne, and Waltham and Harmon announced the first U-series speleothem dates for Craven. Atkinson et al (1978) published Craven ages plus others from the Mendip Hills, interpreting them in terms of interstadial and interglacial periods recognised in the British Quaternary record. They obtained high ages for single samples from the Roof Tunnel, Kingsdale, and the streamway in White Scar Cave. These results were used to suggest that the high-level, fossil tunnels of the region had developed in "pre-glacial" times beneath a regional watertable. The tunnels were drained by rapid and considerable downcutting during the first glaciation that occurred.

THE U-SERIES SPELEOTHEM SAMPLE PROGRAMME

For the work discussed here, 87 different speleothem samples were collected from 11 different cave systems (Fig. 1). Table 1 summarises topographic and sample location details. For reasons of conservation, most of the speleothems taken had already been broken by natural processes or by previous visitors. Samples were prepared and analysed at the McMaster University laboratories, using the techniques given in Gascoyne (1977b).

TABLE 1 DESCRIPTION OF CAVE SYSTEMS INVESTIGATED IN THIS STUDY SUMMARIZING SPELEOGENETIC DETAILS AND APPROXIMATE LOCATIONS OF SPELEOTHEM SAMPLES (sources of dimensional data: Brook et al. 1981; Waltham 1977;Thompson 1981).

CAVE	LOCATION	ELEVATION OF ENTRANCE (m a.s.l)	LENGTH (km)	DEPTH (m)	TYPE	DESCRIPTION AND SPELEO-THEM LOCATIONS
Lancaster Hole - Ease Gill Caverns	Casterton Fell	315	46.3	~100	large fossil phreatic upper series, with deep vadose entrenchment	complex system, many entrances formed by vadose tributaries to main stream, upper levels contain much clay fill with speleothems , lower levels are clean-washed, frequently flooded and contain only recent speleothems.
Gavel Pot	Leck Fell	327	1.2	110	fossil phreatic upper series, with shallow vadose entrenchment	main stream rapidly descends in vertical drops to syphon, Glasfurd's Passage above drops is fossil phreatic tube partly-filled with sediments, contains many speleothems.
Lost John's Cave	Leck Fell	353	4.8	140	mainly vadose, some fossil phreatic sections	entrance stream has developed complex series of routes down to intersect Main Drain, a 1.5 km stream-way with fossil high-level section at upstream end (Lyle Cavern Series) and alternating recent phreatic or vadose section downstream to syphon. Speleothems found in Lyle Cavern Series and in Main Drain (upstream).
Kingsdale Master Cave (Valley Entrance)	Kingsdale	268	4.0	-	phreatic upper level with recent vadose entrenchment	major drainage route for caves on both sides of valley, active phreatic section upstream where tributaries enter, fossil phreatic section downstream which floods occasionally, side entrance tube (Roof Tunnel) contains eroded speleothems.
Ibbeth Peril Cave I	Dentdale	181	0.9	23	active phreatic tube with recent vadose entrench-ment headwards from large collapse area	tube intersects large collapse chamber, flowstones overlie gravels in distributary tubes near collapse chamber.

contd....

TABLE 1 (continued)

White Scar Cave	Chapel-le-Dale	250	6.0	73	active phreatic upstream section, deep vadose passage downstream, ancient high-level sections	long continuous streamway to syphons with one major tributary, now largely fossil (Sleepwalker Series), and large high-level fossil tunnels (Western Front, Battlefield) above streamway, speleothems throughout cave.
Ingleborough Cave	Clapham-Ingleborough area	259	3.2	~20	fossil phreatic near entrance, active phreatic upstream, recent entrenchment accompanying stream diversion	floods occasionally via entrance, resurgence cave for water from Gaping Gill system, speleothems mainly in entrance section (Show Cave) and higher-level fossil passages (Giant's Hall) near stream diversion.
Gaping Gill	Clapham - Ingleborough area	396	11.3	179	several fossil phreatic levels well above modern phreas, little vadose development except in tributaries	many entrances with vertical shafts, all tributary streams sink in sediments or deep phreas on entering main part of system (water resurges in Ingleborough Cave), speleothems on sediments in large chambers (Mud Hall, Stalagmite Chamber) and in ancient tunnels to east (East Passage, Far East Passage).
Victoria Cave	Langcliffe Scar, Settle	440	0.2	~15	truncated phreatic (?) remanent	excavated entrance and side loop, flowstones against back wall, among boulders in loop and on cave walls, others removed from entrance clay deposits during excavations.

Table 2 lists the analytical details of the 182 age determinations that were made upon these 87 speleothems. The ages are also displayed as a bar graph in Fig. 2; this better indicates the continuity of growth between dated points up a stalagmite, etc.

Two or more analyses were made on 42 of the speleothems. In 33 of these, the ages decrease in the direction of growth, as they should. In the remaining nine cases, the measured ages either overlap within their error limits (within 2σ) or there was U or Th contamination. Data of Table 2 show that the $^{230}Th/^{234}U$ dating method used here gives reliable results when applied to speleothems that are pure and impervious.

Below, we use "1 ka" to represent 1,000 years Before Present. Craven ages range from as low as 1 ka to greater than 350 ka. The $\pm 1\sigma$ error limits generally increase from 5 percent for young specimens up to 15 percent for ancient ones. The limit of 350 ka is regarded as the maximum age at which the distinction between a finite and infinite age can be made with confidence.

DATING CAVE DEVELOPMENT

Lancaster Hole - Ease Gill Caverns

(1) This system is over 100 m deep and 46 km in length. Most of the length consists of distributary inlets from discrete sinks of the main surface stream, Ease Gill. The system underlies Casterton Fell and resurges at Leck Beck Head (Fig. 1) but terminates in a sump almost 1 km from this spring. The main section contains a high vadose stream passage below a relict phreatic tunnel. Entry to this section is best gained via the Lancaster Hole entrance shaft.

Two sites yielded the most interesting speleothems. The first was Bill Taylor's Passage (the connection between Lancaster Hole entrance and Fall Pot), about 40 m above the modern stream. It contains much silt, clay and gravels. The samples were embedded in these deposits, or washed out of them, or they lay loose. They fall into three distinct age groupings: - (1) stalagmites and flowstones that grew at times during the period 126-70 ka and have not grown since. These all show evidence of water erosion (re-solution) upon their surfaces. Samples 77126 (126-106 ka) and 79124 (126-95 ka) appear to have grown more or less continuously during their measured time spans of 20,000 and 30,000 years respectively. An eroded, unconformable overgrowth on 79124 was dated at 73 ka. It shows that some erosion occurred in the non-growth interval (hiatus) between 95 and 73 ka. 76135 was a flowstone boss 1 m high that was once completely buried by clastic sediments. It grew from >95 ka (a date upon the centre) to 86 ka (top). Stalagmite 76122 shown in Plate 1 is more complicated. It grew

TABLE 2 SPELEOTHEM LOCATIONS, DESCRIPTIONS AND ISOTOPIC DATA FOR $^{230}Th/^{234}U$ AGE DETERMINATIONS FOR SAMPLES FROM CRAVEN CAVES, NORTHWEST ENGLAND (after Gascoyne et al. 1938b).

Cave	Speleo- them No.	Description	Analysis: No.	Location	U (ppm)	$^{234}U/^{238}U$	$^{230}Th/^{232}Th$	$^{230}Th/^{234}U$	Age $\pm$ 1σ (Ky)
White Scar Cave	76100	fs, in streamway	E-1	base	1.46	0.976	126	0.976	>350
			E-2	top	0.88	0.946	103	0.956	>350
	76102	fs, Western Front	-1	top	0.06	1.096	2	1.083	>350
	76106A	fs, Sleep-Walker Passage	-1	top	0.58	1.018	36	0.870	218^{+29}_{-23}
			-2	base	0.61	0.995	21	0.903	256^{+62}_{-39}
	76106B	fs, near to 76106A	-1	top	0.80	0.857	37	1.030	>350
	76108	sg, Far Streamway	-1	base	1.39	1.201	7	0.102	11.6±0.7
			-2	top	2.11	1.082	23	0.053	6.0±0.3
			-3	base	1.17	1.192	25	0.098	11.1±0.4
Ibbeth Peril Cave I	76110	fs, false floor	-1	top	0.72	0.996	25	0.089	10.1±0.5
	76111	fs, near to 76110	-1	bulk	0.30	1.067	15	0.238	29.4±2.2
			-2	top	0.31	0.947	>200	0.118	13.7±1.3
			-3	base	0.40	1.003	13	0.051	5.7±0.6
	76112	thin fs bridge	-1	bulk	1.21	0.960	>200	0.068	7.6±0.7
Lancaster Hole -- Ease Gill Caverns	76121	sg, Bill Taylor's Pass.	-1	top	2.42	1.073	110	0.656	114±7
			-2	base	1.49	1.130	129	0.661	114±7
	76122	sg, near to 76121	-1	base	2.12	1.203	54	0.578	91±5
			-2	top	2.59	1.386	37	0.491	71±3
	76124	sg, near to 76121	-1	base	0.62	1.229	13	0.116	13.3±1.0
			-2	base	0.63	1.330	24	0.087	9.8±0.5
	76125	sg, near to 76121	-1	base	2.01	1.628	105	0.302	38±1
			-4	top	1.17	1.518	66	0.306	39±2
	76126	sg, Stop Pot	-1	top	13.7	0.719	>200	0.007	0.8±0.1
			-2	base	13.3	0.713	22	0.085	9.7±0.3
	76127	fs, Stop Pot	-1	top	13.1	0.878	>200	0.843	225^{+25}_{-20}
			-2	base	5.8	0.911	>200	0.963	>350 *
			-4	near base	14.5	0.848	>200	0.846	237^{+22}_{-18}
	76128	sg. Easter Grotto	-1	base	18.3	0.745	43	0.100	11.5±0.5
			-2	top	2.7	0.727	3	0.011	1.2±0.2
	76129	sg, near to 76128	-1	top	3.1	0.789	3	0.008	0.9±0.1
			-2	base	1.8	0.749	10	0.099	11.4±0.6
			-3	base	2.7	0.799	31	0.104	12.0±0.5
	76130	sg, Stake Pot	-1	base	2.77	1.222	72	0.084	9.6±0.3
			T-2	top	1.90	1.232	153	0.049	5.5±0.2
	76131	sg, Stop Pot	-1	base	17.1	0.760	45	0.080	9.0±0.3
	76133	fs, Eureka Junction	-1	top	4.9	0.820	3	0.054	6.5±0.2
			-2	base	9.5	0.778	>200	0.086	9.8±0.5
	76135	Large fs boss, Bill Taylor's Pass.	-1	upper middle	0.97	1.192	52	0.594	95±4
			-2	top	1.32	1.240	>200	0.558	86±3
	77120	2 overlying fs samples: A = lower, B = upper, hiatus in B, Colonnade Pass.	A-1	base	2.71	1.242	>200	0.750	140^{+11}_{-10}
			A-2	top	1.90	1.161	124	0.647	109±4
			B-2	base	1.64	1.417	>200	0.640	104±4
			B-3	below hiatus	0.43	1.577	>200	0.574	87±4
			B-4	above hiatus	0.42	1.577	11	0.476	67±2
			B-5	near top	0.41	1.380	4	0.567	87±5
			B-1	top	0.38	1.473	>200	0.468	66±5
	79005	fs, overlies 77120B	-3	base	0.57	1.425	23	0.399	54±3
			-1	top	0.43	1.429	12	0.333	43±3
	77121	fs, Bridge Hall	-1	top	0.22	1.198	24	0.418	58±4
			-3	near top	0.23	1.314	44	0.389	52±2
			-4	above hiatus	0.51	1.518	47	0.423	58±2
			-5	below hiatus	0.59	1.178	>200	0.736	137±8
			-6	same as -5	1.18	1.373	89	0.640	104±3
	77122B	fs, Bill Taylor's Pass.	-1	base	1.04	1.284	20	0.525	78±3
	77123B	fs, pool deposit, Bill Taylor's Pass.	-1	bulk	1.32	1.565	75	0.280	35±1
	77126	sg, Bill Taylor's Pass.	-1	base	6.11	1.031	160	0.691	126±5
			-2	top	3.93	1.152	>200	0.635	106±4
	79003	fs, boss, entrance shaft	A-1	top	0.21	1.117	62	0.860	199^{+21}_{-17}
			C-1	near base	0.42	1.178	29	0.944	257^{+22}_{-18}
	79120	same as 79003	-1	top	0.38	1.313	>200	0.942	236^{+20}_{-17}
			-3	middle	0.38	1.156	69	0.984	313^{+69}_{-48}
			-2	base	0.44	0.993	178	0.928	288^{+36}_{-27}
	79121	sg on fs, Bill Taylor's Pass.	-1	fs base	0.83	1.622	103	0.324	44±1
			-2	sg top	1.42	1.553	>200	0.278	35±1
	79124	sg, near Graveyard	-1	base	1.17	1.113	>200	0.698	126±6
			-5	top	1.05	1.131	>200	0.699	126±6
			-3	outer	0.43	1.420	49	0.604	95±5
			-2	overgrowth	0.37	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 2 continued

Inglehorough Cave	76140	sg, Giant's Hall aven	-1	base	0.10	1.270	6	0.784	152^{+35}_{-27}
	76141	fs, Giant's Hall aven	-1	base	0.07	1.462	10	0.668	111±11
			-2	top	0.10	1.341	19	0.475	68±5
	76142	fs, Giant's Hall aven	-1	below hiatus	0.04	1.306	14	0.798	156^{+45}_{-33}
			-2	base	0.04	1.287	8	0.623	101^{+14}_{-13}
			-3	above hiatus	0.10	1.132	4	0.728	136^{+43}_{-31} *
	76143	fs, Giants Hall	-1	base	0.07	1.267	3	0.857	186^{+41}_{-30}
	76144	sg, Show Cave	-1	base	0.37	0.952	2	0.100	11.5±1.2
			-2	top	0.41	1.078	3	0.185	22.2±1.2
	76145	sg, Show Cave	C-1	middle	0.95	0.784	2	0.103	11.9±0.6
	77143	2 overlying fs samples A = upper, B = lower Giant's Hall aven	A-1	base	0.07	1.480	26	0.621	98^{+14}_{-13} *
			A-2	top	0.06	1.392	22	0.617	98±10
			B-1	base	0.12	1.192	41	0.702	125±8
			B-3	middle	0.14	1.343	72	0.677	115±8
			B-2	top	0.11	1.337	24	0.658	110±10 *
Victoria Cave -- excavated samples now in Pigyard Museum, Settle.	76151	fs, from block pile in loop	-1	base	0.38	0.974	46	0.954	>350
	76152	fs, near to 76151	-1	base	0.38	1.006	3	0.869	219^{+45}_{-32}
	76153	sc, on block pile	-1	top	0.18	1.301	4	0.162	19.0±1.6
	76154	fs, near to 76151	-1	top	0.52	1.049	53	0.818	180^{+16}_{-14}
	76155	fs veneer on wall, in tube	-1	top	0.61	1.028	81	1.009	>350
	77150B	fs layers in laminated clays, near entrance	-1	bulk	0.39	1.019	9	1.104	>350
	77151	3 overlying fs samples, A = base, B = middle, C = Top. Hiatus near base of C. In loop.	A-1	sg in base	0.36	1.152	59	0.875	205^{+34}_{-26}
			A-2	base	0.50	0.984	26	0.925	287^{+33}_{-25}
			B-1	base	0.43	1.037	47	0.935	281^{+43}_{-31}
			B-2	top	0.45	1.059	130	0.927	265^{+29}_{-23}
			C-4	below hiatus	0.41	1.057	128	0.914	250^{+29}_{-23}
			C-3	above hiatus	0.46	1.081	102	0.836	188^{+13}_{-11}
			C-5	as C-3	0.45	1.112	118	0.930	255^{+28}_{-23}
			C-1	top	0.48	1.081	56	0.848	195^{+19}_{-17}
			C-2	as C-1	0.46	1.020	>200	0.831	191±9
	77159	fs, contains 3 hiatuses, on wall in loop	-1	base	0.39	1.104	25	0.969	307^{+54}_{-37}
			-2	top	0.32	1.143	9	0.627	104±7
	77230	fs/fill layers, on back wall A = basal layer, H = top layer.	A-1	base	1.97	1.039	21	1.103	>350 *
			F-1	base	0.35	1.138	23	0.933	253^{+56}_{-38}
			H-1	bulk	0.13	0.872	3	0.209	25.5±3.6
	77231	sg, in loop	-1	top	0.50	0.982	42	0.889	243^{+27}_{-21}
	77234	fs, in loop	-1	top	0.38	0.947	12	0.848	214^{+32}_{-24}
	77236	fs, overlying clays in entrance	-1	bulk	0.65	0.915	31	1.156	leached
	77237	fs, near to 77236	-1	top	0.58	1.001	88	0.968	>350
	77238B	fs, near to 77236, underlies clays	-1	middle	1.00	1.052	43	1.006	>350
	79150	fs, in loop, near 77151	-4	base	0.53	1.055	>200	0.888	226^{+16}_{-14}
			-5	top	0.46	1.003	>200	0.815	183±10
	79151	same as 77151, but single block cut from fs boss	-1	above hiatus	0.49	1.087	66	0.922	252^{+23}_{-19}
			-2	below hiatus	0.50	1.061	84	0.926	263^{+19}_{-16}
			-3	base	0.72	1.047	47	0.962	321^{+37}_{-28}
	79153	fs, in loop	-1	top	0.49	1.042	52	0.800	171^{+11}_{-10}
	79155	fs, near 77230	-1	base	1.86	0.999	26	1.087	>350
	79158	sg, overlies 79151	-1	base	0.54	1.076	80	0.824	181^{+14}_{-13}
			-3	as -1	0.59	1.072	146	0.830	185±10
			-2	top	0.46	1.043	123	0.804	173±9
	79000	fs, overlying rhino tooth	-1	adj.to tooth	0.62	1.000	44	0.610	102±11 *
			-2	near tooth	0.63	1.019	20	0.672	120±7
	79001	fs, overlying rhino jaw bone	-1	adj.to jaw	0.50	1.100	20	0.623	104±6
			-2	near jaw	0.40	1.033	152	0.691	126±9
			-3	as -2	0.43	1.022	34	0.714	135±8
	79002	fs, coating red deer antler	-1	bulk	0.50	1.012	16	0.702	131±9
	79021	fs, overlying rhino teeth	-1	near teeth	0.43	1.057	31	0.690	125±7
	79023	fs, overlying giant deer teeth	-1	near teeth	0.50	0.994	71	0.678	123±7
	79025	part of large fs block containing rhino and hippo bones on lower side	-1	at bone level	0.88	1.120	111	0.484	71±3
			-2	top	0.43	1.048	84	0.654	114±5
			-3	near to bone level	0.58	1.037	47	0.672	120±6
	79026	fs overlying rhino teeth	-1	top (?)	0.46	1.022	>200	0.668	119±5

TABLE 2 Continued

Lost John's Cave	76160	fs, Lyle Cavern high level	-2	base (?)	0.20	1.295	16	0.717	128±12
			-3	top	0.18	1.283	15	0.702	123^{+29}_{-23} *
	76161	sg, Lyle Cavern high level	-1	base	0.25	1.273	0.7	0.106	12.1±5.5
	76164	fs, Main Drain	-1	top	3.84	1.003	178	0.598	99±4
			-2	near top	4.31	0.929	>200	0.612	105±7
			-3	base	5.68	0.945	>200	0.620	106±4
	76165	<u>fs</u>, Main Drain	-1	pieces	9.35	0.938	111	0.649	116±12
	77162	same as 76165, large section	-1	top	6.23	0.944	127	0.568	92±4
			-4	near top	7.16	0.898	>200	0.597	101±3
			-6	near top	7.29	0.941	>200	0.584	96±3
			-9	upper middle	8.85	0.914	85	0.581	96±3
			-8	middle (porous)	7.00	0.862	45	0.668	126±5
			-10	upper middle	8.43	0.927	>200	0.628	109±5
			-7	base	9.33	0.947	37	0.638	112±3
			-3	base	7.21	0.916	92	0.638	113±5
Gavel Pot	76190	sg, Glasfurd's Passage	-1	base	0.57	1.398	5	0.127	14.7±0.6
			-2	top	0.50	1.368	5	0.046	5.1±0.6
			-3	base	0.37	1.409	27	0.089	10.1±0.6
	76191	sg, Glasfurd's Passage	-1	base	0.44	1.238	65	0.114	13.1±1.4
			-3	near base	0.37	1.235	29	0.095	10.7±0.5
			-4	near top	0.22	1.204	13	0.082	9.3±0.9
	76192	sg, near to 76191	-2	near base	0.30	1.326	28	0.085	9.6±0.4
Gaping Gill	76201	sg, Stalagmite Chamber	-1	base	2.07	1.279	16	0.068	7.6±0.4
			-3	base	1.89	1.337	16	0.063	7.0±0.3
	76202	fs, Mud Hall	-2	base	0.46	1.056	40	1.074	>350
	76206	<u>fs</u> veneer, Hensler's Upper Pass.	-1	bulk	1.81	1.181	48	0.333	44±1
	76207	sg, Nevada Pass., Far Country	-1	base	0.89	1.290	76	0.672	114±8
			-2	top	0.30	1.233	27	0.735	135^{+16}_{-14}
	76208	sg, Stalagmite Chamber	-1	top	0.42	1.512	3	0.017	1.9±0.2
			-T	top	0.91	1.580	8	0.007	0.8±0.2
			-3	base	0.74	1.542	6	0.031	3.4±0.3
	76209	<u>sg</u>, overlying varves, Sand Cavern	-1	base	9.38	1.120	6	0.008	0.8±0.1
	76210	sg, Old East Pass.	-1	base	1.39	1.370	99	0.303	39±2
			-2	top	2.38	1.200	122	0.297	38±1
	76211	<u>fs</u> on wall, Old East Pass.	-1	bulk	0.39	1.164	28	0.938	253^{+30}_{-24}
	77209	same as 76211	-2	top	0.25	1.185	20	0.995	$319^{+>43}_{-44}$
	76212	fs, Old East Pass.	-2	base	2.10	1.218	4	0.126	14.6±0.7
			-3	top	0.90	1.274	7	0.107	12.2±0.4
	76215	sc, on fill, West Chamber	-1	bulk	3.92	0.972	3	0.012	1.4±0.1
	76216	sg, Old East Pass.	-1	base	8.93	1.144	6	0.012	1.3±0.1
	77200	fs, North Craven Pass.	-1	top (?)	0.95	1.296	181	0.994	289^{+24}_{-20}
			-2	base (?)	1.94	1.239	69	1.032	>350
	77201	fs, Old East Pass.	-1	bulk	1.47	1.337	15	0.091	10.3±0.3
			-2	bulk	1.44	1.351	55	0.095	10.8±0.4
	77205	sg, Far East Pass.	-1	base	1.85	1.842	95	0.358	46±1
			-2	top	1.84	1.858	29	0.379	50±1
	77210A	sg, Far East Pass.	-1	top	0.44	1.927	12	0.097	11.0±0.6
Newby Moss Cave	76220	fs, near entrance	-1	top (?)	1.34	1.257	82	1.065	>350
Kingsdale Master Cave	77240	<u>fs</u>, on roof arch, Roof Tunnel	-2	bulk	0.20	1.145	83	0.989	324±>100
	77241	<u>sc</u>, Roof Tunnel	-1	below hiatus	0.41	1.123	35	0.804	168^{+11}_{-10}
	77242	fs, below aven, Roof Tunnel	-1	bulk	1.55	1.015	74	0.941	$300^{+>70}_{-43}$
	77243	fs, Roof Tunnel	-1	base (?)	1.17	1.053	73	0.891	230^{+23}_{-19}

* low U or Th yields (5 to 10%);
sc = stalactite)
sg = stalagmite) <u>in situ</u> or growth position is known, if underlined.
fs = flowstone)

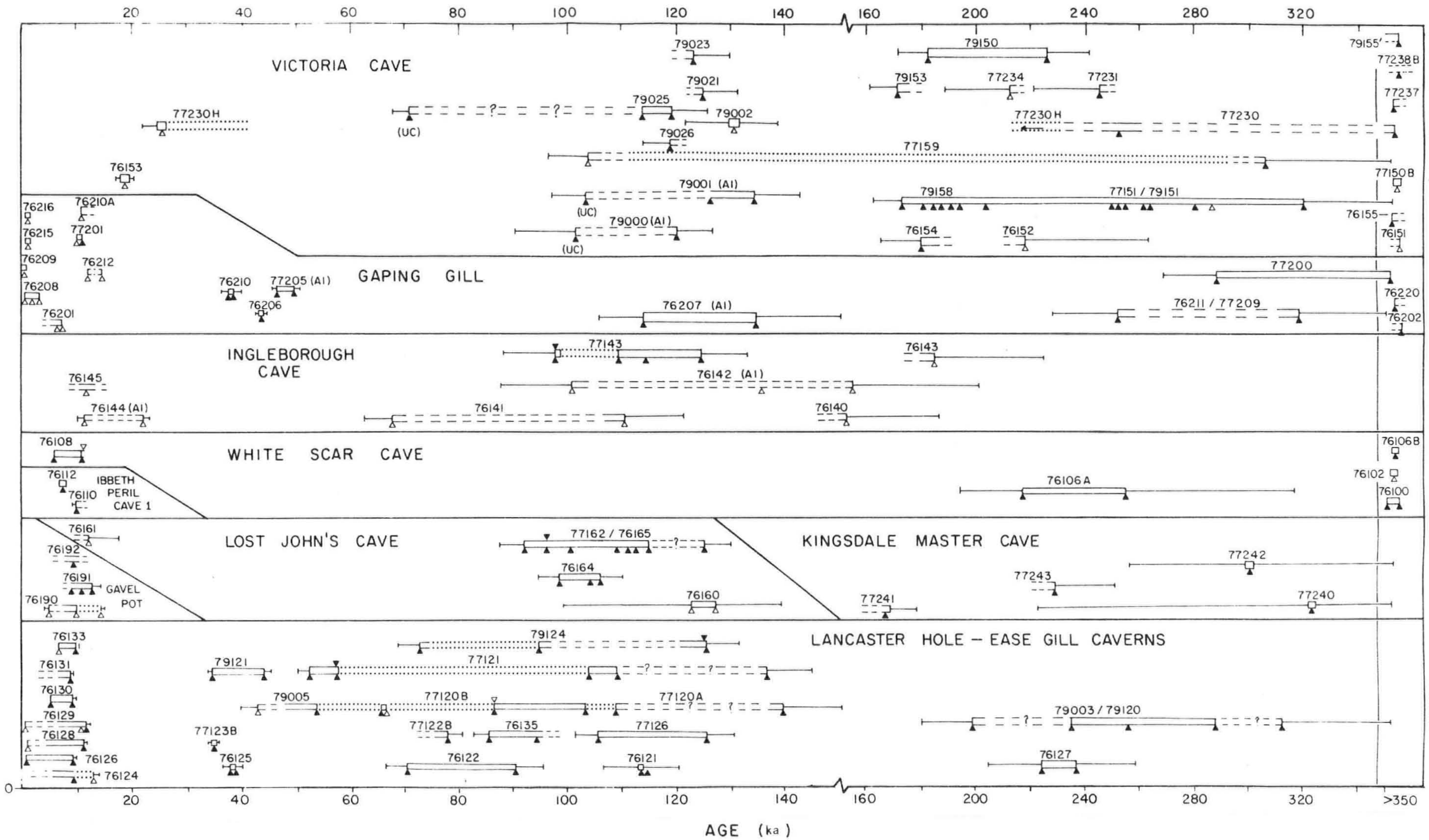
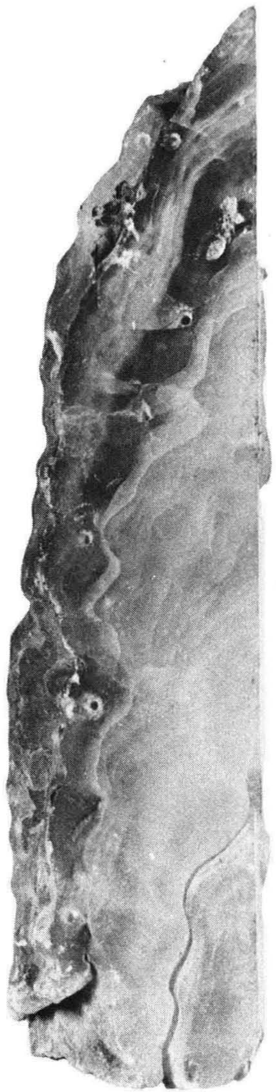


Figure 2. Bar graph of $^{230}Th/^{234}U$ ages and growth periods of speleothems from Craven caves. Error bars are $\pm 1\sigma$ of ages nearest to base and top of speleothem. Dashed lines show periods of discontinuous growth (undated) and dotted lines show a considerable hiatus between adjacent parts of a speleothem. AI = Ages inverted with respect to stratigraphy, U.C. = Contaminated by uranium (from bone). Open triangles show ages contaminated by detrital thorium. From Gascoyne et al. (1983a).



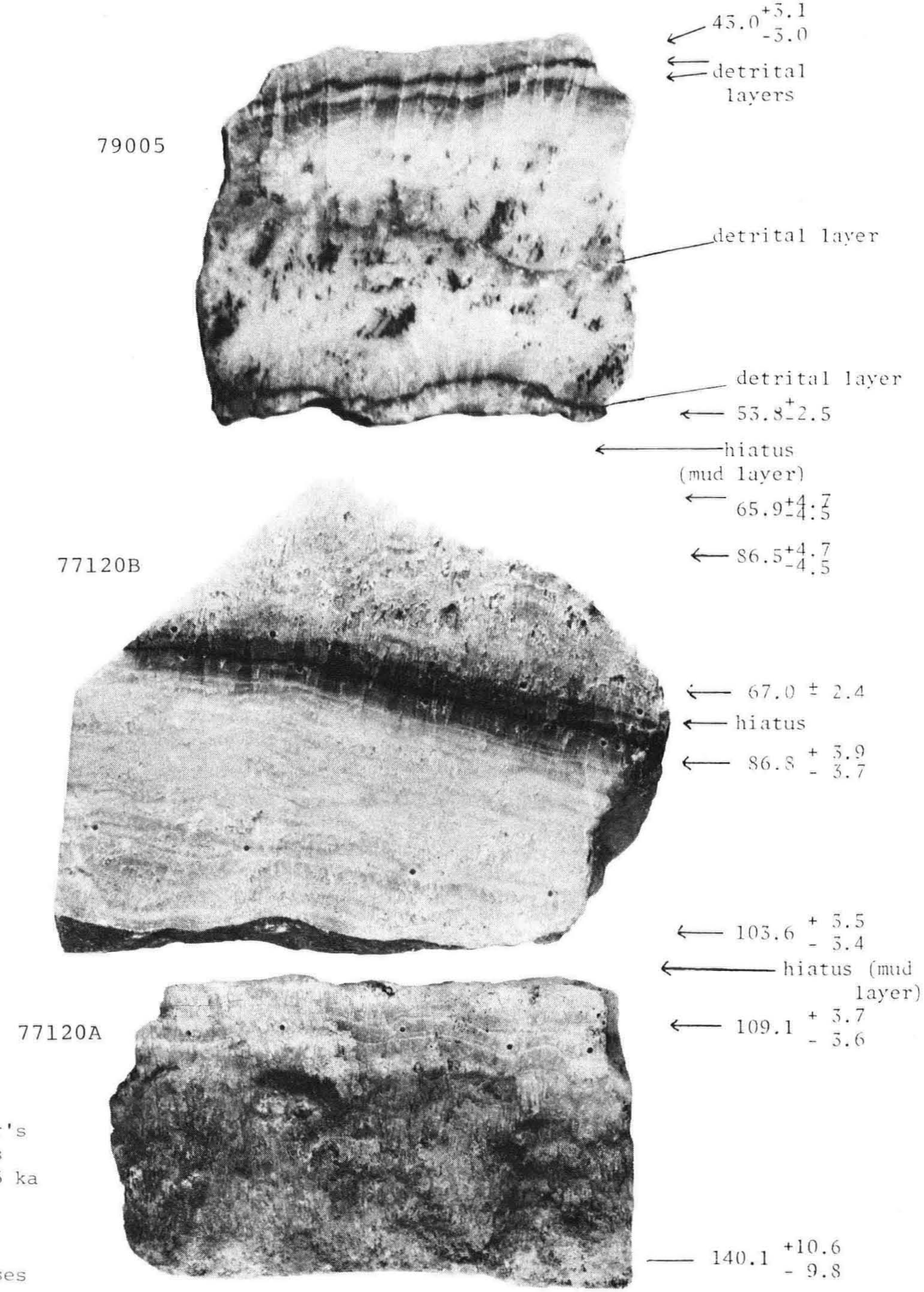


Plate 1. Longitudinal section of stalagmite 76122 from Bill Taylor's Passage in Lancaster Hall showing three internal hiatuses marked by dessicated or mud layers. Basal age was 91 ± 5 ka and top age was 71 ± 3 ka.

Plate 2 Sections of flowstone sequence 77120A/B/79005 from the Colonnades Passage, Lancaster Hole, showing growth hiatuses and dated horizons.

Plate 3 Section of a flowstone, 76106, from Sleepwalker Series, White Scar Cave, showing at least four hiatuses. Top age was > 350 ka.

(a)

(b)

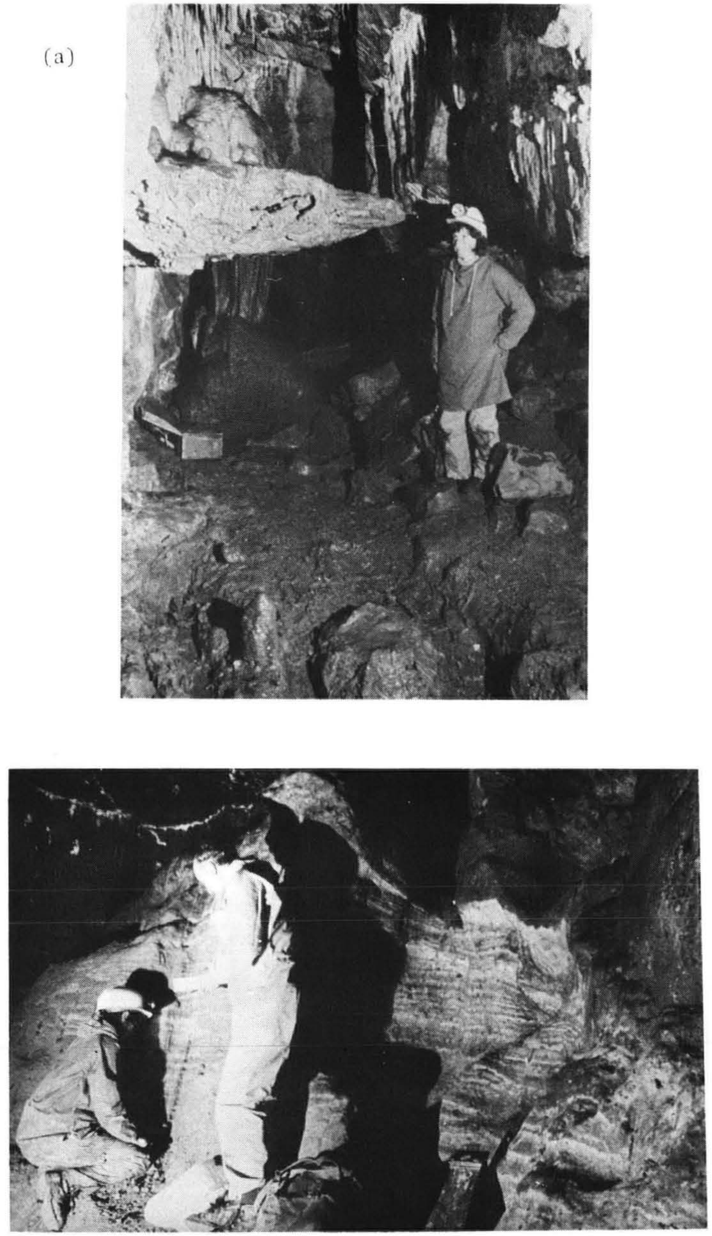


Plate 4 Features of speleogenetic and geomorphic significance in the Gaping Gill system: a) an ancient false floor consisting of calcite-cemented cobbles in Old East Passage (adjacent flowstone on the wall dated at about 300 ka, and b) a 4 to 5 m thick sequence of varved sediments in Sand Cavern, overlain by a 0.8 ka stalagmite.

between 91 and 71 ka but displays three internal breaks in deposition. These are marked by thin layers of detritus that suggest possible floods.
(2) stalagmites aged between 44 and 35 ka. These show no evidence of re-solution. 79121 is a section, 50 cm deep, cut from a thick stalagmite in the excavated rubble of the Passage. It grew from 44 to 35 ka. Several thin detrital layers within it suggest flood effects but, as noted, there is no solution damage; so, it appears that the floods were minor.
(3) recent (post-glacial) deposits that are fresh. 76124 was a displaced stalagmite that began growing 13.3 ka (an age from a contaminated specimen) or 9.8 ka.

The second site was Colonnade Passage and Bridge Hall where some recently collapsed flowstones and others still in the growth position were taken. The site is about 55 m above the modern stream.

Samples from Colonnade Passage include the interesting sequence shown in Plate 2. Three flowstone sheets are separated by two layers of clay. The upper sheets also have growth hiatuses within them. The basal sheet, 77120A, perhaps began to grow about 140 ka but this basal age may be too great because of suspected leaching effects. Once begun, the sheet grew continuously without evidence of erosion or other flood damage until 109 ka. Layers of mud were then laid upon it. Growth began again as a separate sheet, 77120 B, around 104 ka. It continued until about 87 ka. The period, 87-67 ka, is represented by a hiatus in growth but with no significant flood damage or deposition. More mud accumulated at some time(s) between 66 and 54 ka when the top sheet (79005) began to grow. This shows at least four detrital horizons, probably representing more floods, before all growth finally ceased at this place about 43 ka.

The Bridge Hall flowstone (77121) was a complete section fallen from a false floor that is now 10 m above the modern floor of detritus. It first grew around 110 ka; there was little or no deposition between $\sim$100 ka and 58 ka, and then quite rapid growth until 52 ka.

Samples 79003 and 79120 were taken from a collapsing boss in Lancaster Hole entrance shaft, close to the Bridge Hall flowstone but at higher elevation. The base of the boss gave a date of $\sim$290 ka, one of the oldest in this system. The top age is $\sim$220 ka. Ages of 238 (base) to 225 ka (top) were measured on a loose block of flowstone close to the top of Stop Pot ladder.

All other speleothems taken from the Caverns are post-glacial in age. These include detached stalagmites from Easter Grotto, East Montagu Passage and Eureka Junction and one in the growth position on fallen blocks near Stop Pot. Their basal ages range from 12 to 9 ka.

There is an unusually large variation in the concentration of uranium measured in different speleothems in these Caverns. It ranges from 0.21 to 17.1 ppm. The ratio of the two U isotopes, $^{234}U/^{238}U$, at the time of initial deposition varies from 0.74 to 1.74, which is also a wide range for one small locality. Ancient and recent samples in the neighbourhood of Easter Grotto, Eureka Junction and Stop Pot all have ratios below 0.82. Initial ratios outside of it are all higher than 1.0. We can find no unusual geological, hydrological or topographical features to account for these patterns; they can be placed in the whole new class of interesting problems being raised by isotopic studies of karst waters and their deposits.

We arrive at the following general conclusions for Lancaster Hole-Easegill Caverns:-
a) few speleothems are older than about 140 ka. This is probably because large erosion or infilling events have destroyed or buried most older deposits.
b) the entrance shaft at Lancaster Hole was at least 20 m deep and vadose at 300 ka. It is probably much older.
c) the major high-level trunk passages such as that at Stop Pot were drained by 240 ka. One or more floods or filling events destroyed speleothems in them at times during the period, 200-140 ka.
d) there was vigorous speleothem growth over wide areas of the cave during the last interglacial, which extended from 140 ka to 85 ka. It is likely that the Colonnades began to grow then.

There is good evidence of a brief period of no growth around 105 ka. After 85 ka some samples ceased all growth, others were eroded by the drip waters that had previously deposited them and some continued to grow sporadically but often showing flood mud layers. These conditions continued to about 38 ka and, tentatively, can be taken to represent a sequence of cold phases and merely cool (interstadial) phases.
e) at some time between 65 and 38 ka Bill Taylor's Passage and all below it were flooded (returned to phreatic conditions) for a long period. This is indicated by widespread re-solution of speleothems. Such re-solution is not apparent in Bridge Hall and Colonnades Passage deposits which are at higher elevation.
f) there was major flooding with erosion or re-working of deposits at some time during the period, 35-12 ka. This can be considered to be an effect of the Devensian (Last) Glaciation.

Gavel Pot.

Gavel Pot is one of several caves on Leck Fell that are genetically related and drain to a common resurgence, Leck Beck Head. The Pot forms the lower part of the Short Drop Cave drainage route and contains an active vadose streamway which drops to a sump via several vertical pitches.

Our dates are limited to three samples from Glasfurd's Passage, a well-decorated, relict phreatic tube above the pitches and about 75 m above resurgence level. All three are of post-glacial age ($<$13 ka). This was surprising because 76190 was a large stalagmite, 89 cm long, that had been toppled and partly buried by boulders that were cemented by calcite. The stalagmite was expected to be older. It seems that there has been a lot more erosional and depositional activity in the Passage during post-glacial times than its abandoned position and relict appearance would suggest.

Stalagmite 76190 yielded the fastest speleothem growth rate amongst our Craven samples. It was lengthening at a mean rate of 18 cm, and gaining 5.4 kg of calcite, per 1,000 years.

Lost John's System

This cave, also on Leck Fell, has a complex series of phreatic rift and active vadose canyon passages in its upper levels. These enter a high meandering streamway (the Main Drain) about 140 m below entrance level. Now known as the Leck Fell Master Cave, this passage originates upstream at Lyle Cavern, close to the surface inlet from Lost Pot, and ends in a sump 1 km from the Leck Beck Head resurgence, after collecting inlet streams from two other Leck Fell caves.

Three samples that appeared to be old were collected from the lower reaches of the system. All grew during the last interglacial. 76160 was a flowstone block in a boulder choke at the end of the Lyle Cavern High Level Series. It grew from 128 to 123 ka and contained detrital layers that suggest occasional flooding. Another broken flowstone (76164) was embedded in mud in a bedding plane in the Main Drain, a short distance above Groundsheet Junction. It grew from 106 to 99 ka and contains a prominent growth hiatus dated on each side at 106.3 and 104.5 ka. It seems likely that this is the 105 ka break in deposition noticed in some Lancaster-Ease Gill samples although the cause of the break remains conjectural.

Samples 76165 and 77162 were collected nearby, from a flowstone preserved in the growth position and about 2.5 m above the modern stream. It appears to have grown from 113 to 92 ka; there is no clear break of deposition in the middle, where a 105 ka hiatus would be expected. However, the calcite is very porous there, which may be concealing it. This deposit clearly shows that the Main Drain was vadose and close to its modern dimensions 113,000 years ago. The maximum mean rate of channel entrenchment since then cannot be more than 2.2 cm/ka.

Kingsdale Master Cave

This cave is the main drainage route for all systems on the West Kingsdale slopes and from some East Kingsdale caves. The cave is entered a few metres above valley floor level via a fossil phreatic tube known as the Roof Tunnel. This tube continues to a 5 m drop into the Master Cave, close to the sump of the main stream. A high, wide, vadose canyon, with roof tube, continues upstream to several low inlets from feeder caves further up-valley.

Our sampling was limited to four specimens from the Roof Tunnel. Two were in situ flowstone/stalactite deposits on upper walls and the others were detached fragments. Sample 77240 gave an age of 324 ka, but with large error limits due to low U concentrations (up to ± 100 ka). It was in situ and close to the Master Cave. Dr. R. S. Harmon (personal communication from Dr. A. C. Waltham, and reported in Atkinson et al, 1978) obtained an age of >400 ka for a sample taken near it. Both had suffered re-solution by waters flowing up the Tunnel.

The youngest sample taken (77241) was also in situ and displayed similar re-solution. It was 168 ka in age.

The Roof Tunnel rises to about 15 m above the modern water table. This result shows it to be a surprisingly old feature. It was certainly drained and inactive before 168 ka and most probably before 320 ka or even 400 ka. However, it has been reactivated by waters flowing up and out of it into Kingsdale, dissolving flowstone in the process. There have been one or more such periods of reactivation since 168 ka.

Ibbeth Peril Cave I.

This, the most northerly of the caves investigated, is a cave formed at or below valley floor level. It is frequently flooded by the River Dee and contains few fully relict sections.

Three samples were taken from flowstones overlying stream deposits that largely filled a side passage. All are post-glacial in age, but began growing perhaps as much as 13,000 years ago (although replicate analyses of 76111 suggest this speleothem has suffered some alteration). The sediments beneath them are possibly of fluvio-glacial origin. Those not cemented by calcite have been eroded by flooding since 6 ka.

It seems that the cave must have attained very much its present size and to have been drained before the Late Devensian Glaciation.

White Scar Cave.

This resurgence cave is the major drainage route for the western slopes of Ingleborough. The cave is entered at the base of the Great Scar limestone and is a show cave in its lower reaches. Large relict tunnels (the Western Front and Battlefield series) overlie the main vadose streamway about 2 km from the entrance. Further upstream, beyond the Sleepwalker Series (a smaller fossil network), the streamway becomes a succession of sumps which lie close to surface inlets.

Sampling was largely limited to broken and displaced flowstones. 76100 was a flowstone boulder found in the stream channel just below the Pulpit. All parts of it are older than 350 ka. It probably grew in the Western Front, 20 m above the modern stream and fell via the Pulpit collapse area. 76102 was a smaller fragment collected near the end of the Western Front. It confirms that this area was drained before 350 ka.

76106B is a richly complex fragment collected from boulders in the Yard, at the beginning of Sleepwalker Series. It contains at least four clear breaks of growth, each of which was succeeded by calcite of a different colour from that below (Plate 3). All of the sample is beyond the dating limit so the ages of these breaks cannot be measured. However, they do show that the same sort of start-stop growth that we have measured elsewhere during the last 140,000 years, was occurring here more than 350,000 years ago.

Only the flowstone boulder in the modern stream showed evidence of re-solution by flowing waters. It appears that the high level passages, Western Front and Sleepwalker Series, were drained before 350 ka (probably, long before) and they have not been significantly flooded since that date. Atkinson et al (1978) obtained an age of 225 ± 60 ka for a stalagmite growing in the streamway. This underscores the great antiquity of the vadose entrenchment that comprises the modern tourist cave.

Gaping Gill.

This system, which divers have recently connected to Ingleborough Cave, is probably the best known cave in Britain. Entered by a 110 m vertical drop, the stream is lost immediately into gravels, and is not seen flowing again until its resurgence in Terminal Lake at the end of Ingleborough Cave. Several relict levels of cave development can be seen in Gaping Gill, many of which are formed by other inlets to the system intersecting fault zones or relatively impervious beds (e.g. the Porcellanous Band).

A total of 16 samples were collected from many different parts of the cave. Half of them proved to be post-glacial in age. This confirms the impression of others who have studied the system, that there was widespread erosion and/or deposition at times during the last glaciation. This destroyed or buried most earlier speleothem decoration.

Two samples were older than 350 ka. 76202 was a flowstone boulder found in Mud Hall. 77200 was flowstone on a fallen block in the aven of North Craven Passage. Its growth ended ~290 (± 22) ka. 76211 and 77209 are pieces of flowstone veneer found on the wall respectively near to, and beneath, the prominent cemented cobble false floor in Old East Passage that is shown in Plate 4(a). They are ~300 ka in age, and scalloped by later floods.

Collectively, these samples show that high-level fossil tunnels such as the Old East and Far East passages were vadose by 300 ka and probably before 350 ka. After 300 ka, Old East Passage filled at least to the level of the false floor, was stable for a while, then scoured down to its present debris floor.

Sample 76220 is a displaced flowstone collected by R. R. Glover in the entrance passages of Newby Moss Cave, almost 1 km southwest of Gaping Gill shaft. It, too, is ~350 ka and so indicates the general antiquity of higher level caves on this flank of Ingleborough. It is also very close to the contact between the Great Scar limestone and the Yoredale Series, showing that the rate of recession of the Yoredale caprock has been very slow in this particular area.

Only one of the Gaping Gill samples was of last interglacial age. 76207 was a detached, eroded stalagmite resting on clays in Nevada Passage, Far Country. It testifies, first, to vadose conditions during the last interglacial, and then to powerful, disruptive floods in passages that are backwaters today.

Three samples from different passages show that there was quite widespread growth (some of it rapid) between 50 and 35 ka in Gaping Gill, as there was in Lancaster-Ease Gill. The false floor in Hensler's Upper Passage was being cemented about 44,000 years ago. Most of the underlying sediment has been eroded away since then.

Some of the most striking deposits in Gaping Gill are the varved clays that are exposed in an erosional section in Sand Cavern (Plate 4(b)). They indicate at least one comparatively recent period when the cave was underneath or adjoining a melting glacier. A small stalagmite growing on top of them was dated. Unfortunately, it is very young indeed (800 years at its base), so that it does not help to determine whether the varves are Late Devensian or older.

Ingleborough Cave.

The lower, entrance section of this cave is a show cave. The cave and its continuation as far as Giant's Hall are largely fossil now and only take water in severe floods. In normal flow, low wet passages beyond Giant's Hall drain via Beck Head Cave.

Most samples here were flowstones (broken or in situ) from the Giant's Hall aven. The majority have unusually low U concentrations plus considerable detrital thorium (probably from frequent floods) so that they cannot be dated with great accuracy. However, 77143 contained more uranium and negligible detrital contamination. It yielded a series of reliable ages between 125 and 98 ka. These tend to confirm the ages obtained on the low U specimens. They belong to the last interglacial.

These flowstones ranged from 3 to 13 m above the modern drought watertable in the cave; thus, it was vadose to within 3 m or less of the modern waterline 120,000 years ago. High level chambers and phreatic rifts such as Giant's Hall, Second Gothic Arch and Upper Inauguration Series must be much older than this.

Re-routing of Gaping Gill water from Cellar Gallery and the show cave, to the modern outlet at Beck Head Cave must have been well established by 125 ka because there is negligible flood damage to the oldest flowstones. Older, truncated, outlet tubes near the beck head, such as Foxholes, are probably a lot older than 200 ka.

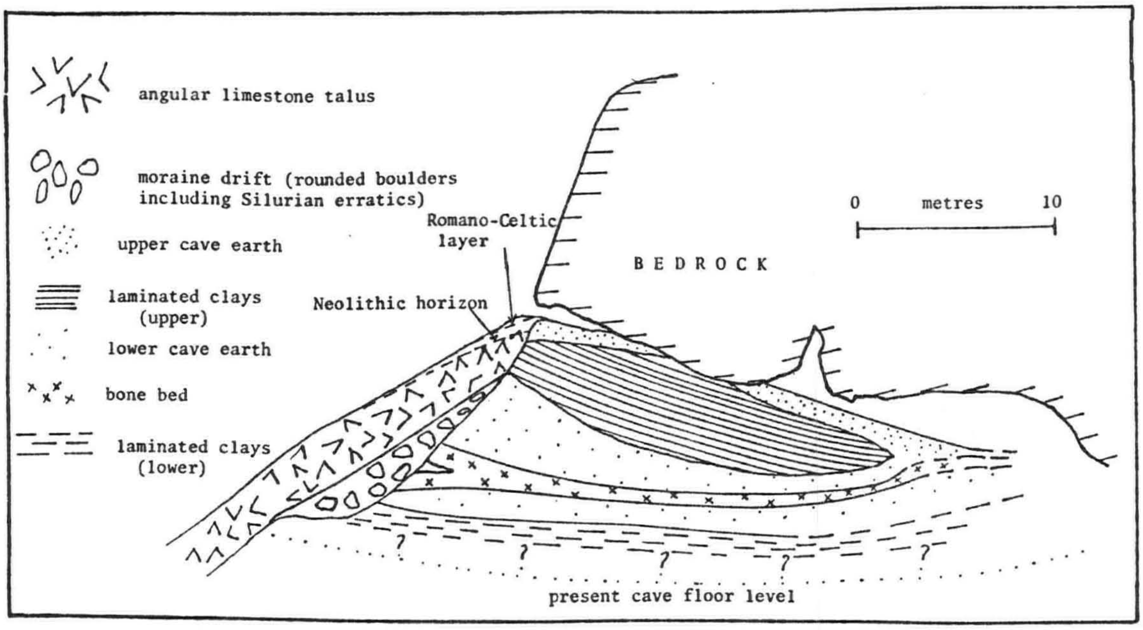
Thus, the area about Ingleborough seems to have looked much the same 125,000 or 200,000 years ago as it does today - but, then, you might have met a hippopotamus on your path - read on!

Victoria Cave.

This is probably one of the oldest caves in Craven. It lies near the upthrust southern limit of the limestone between the North and South Craven Faults. About 140 years ago the cave entrance was a small opening in Langcliffe Scar. About 1840 A.D. excavation began, revealing evidence of Romano-British and Upper Palaeolithic occupation. These finds overlay laminated clays and bone beds containing remains of hippopotamus, hyaena, rhinoceros, deer and lion (Tiddeman, 1873).

Fig. 3a shows the sequence of debris fills as Tiddeman drew them, when he excavated more than 100 years ago. Fig. 3b shows the stratification that we could recognise when sampling from the debris remnants in the floor of the entrance passage in 1977. Fortunately, many of our samples are flowstones which, though buried, remained in their growth positions.

Seven in situ flowstones (plus one loose block) are older than 350 ka and demonstrate that much of Tiddeman's "lower laminated clays" are also of this great age. Some of these flowstones contain 'no growth' hiatuses that may represent long time intervals. Even their youngest parts are out of range of the $^{230}Th/^{234}U$ dating methods. We have made some chemical assumptions



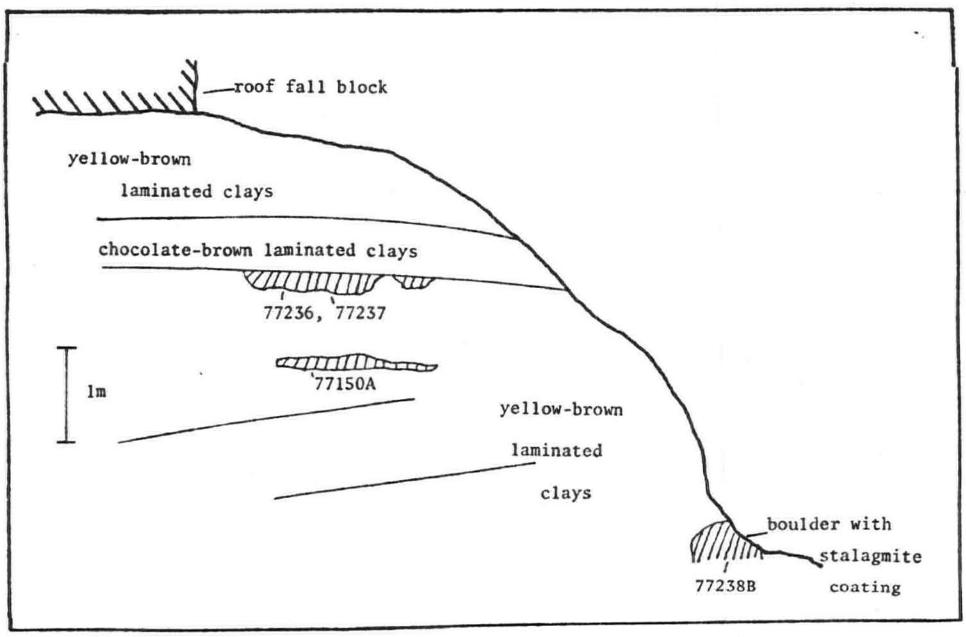


Figure 3 a) Diagrammatic section of Victoria Cave showing original sediment - cave earth sequence, as described by Tiddeman (1873) with amendments by T. Lord and A. King (pers. comm. 1979).

b) Sketch diagram of location of in situ flowstones in floor sediments of Victoria Cave entrance passage (view looking into cave).

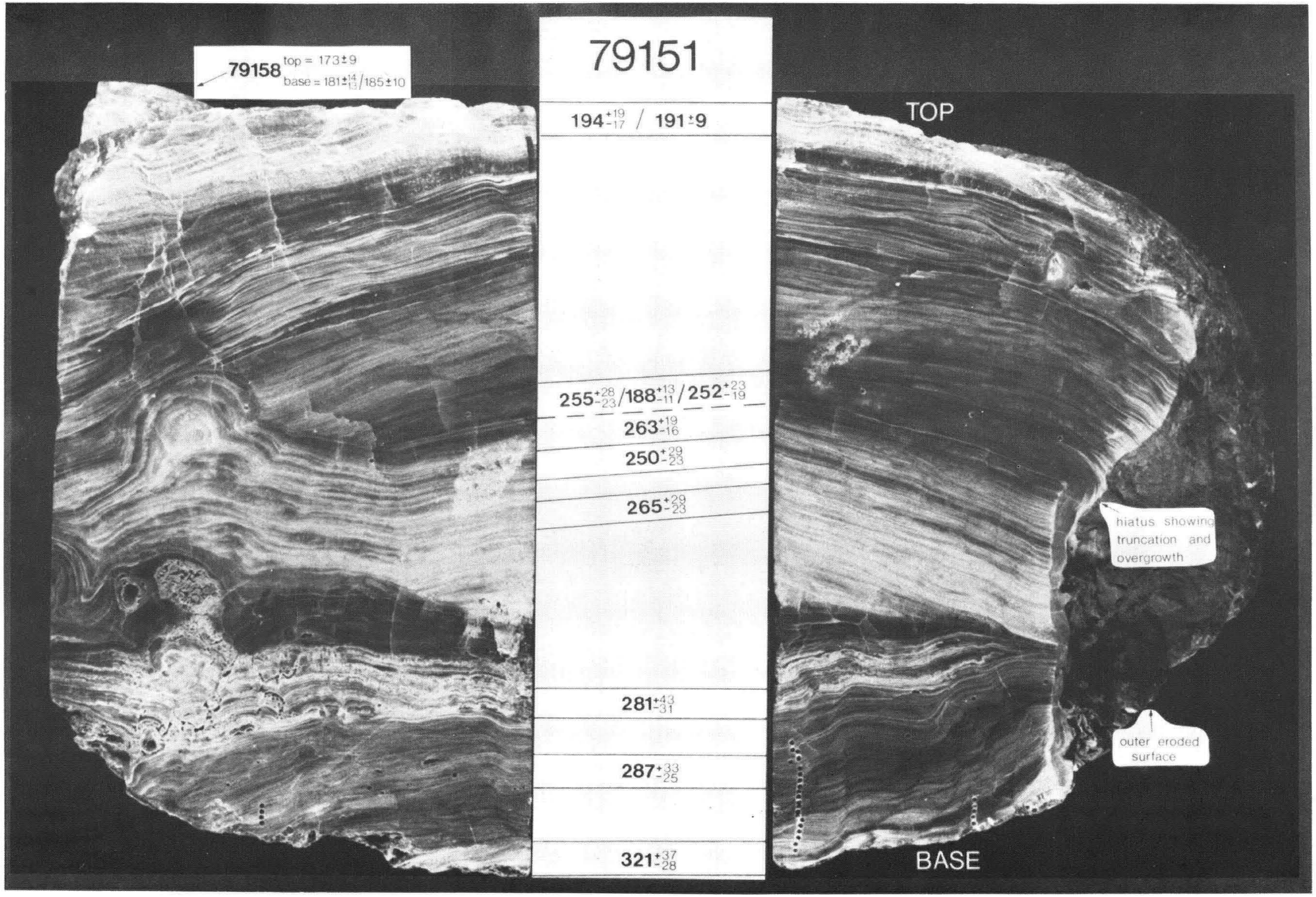


Plate 5 Longitudinal sections of two faces of flowstone block 79151 from Victoria Cave showing $^{230}Th/^{234}U$ ages (including ages determined on original sample of same deposit, 77151). Note the prominent hiatus in the centre, above the small stalagmite, ending in a sharp truncation on the right.

and resorted to statistical methods using $^{234}U/^{238}U$ ratios of the samples to suggest that much of the flowstone was growing before 500 ka (see Gascoyne, Ford and Schwarcz, 1983a); i.e. the phreatic cave was already drained and relict.

Many of our samples grew at intervals during the period 310-180 ka. For example, 77159 is a flowstone collected in situ at the back of the cave, 5 m above the present (excavated) floor. It is probably a remnant of a once-continuous flowstone cover in the back. It consists of four thin calcite layers each of different colour separated by detrital horizons. The lowest layer is ~307 ka in age and the top layer, ~104 ka. Just 10 cm of calcite and clastic deposits accumulated during a 200,000 year span at this protected place.

The most important Victoria Cave speleothem was a sample taken from a large, slumped and buried flowstone in a loop passage against the cave back wall. It was exposed in a trench excavated by Alan King in 1977, when sample 77151 was collected (Table 2). In 1979, sample 79151 was collected for further stratigraphic studies. It is shown in Plate 5.

The flowstone grew upon a calcite-cemented, fragmental clay resting on bedrock. The clay has been studied by Dr. John Catt. He found the sand size fraction to comprise clay aggregates cemented by iron oxides. When compared with other clastic sediments in the cave, this characteristic suggests a fairly cold environment before the calcite deposition began. Plate 5 shows how richly varied this deposit is. It displays strong colour banding that indicates variations in the amount of organic or fine clay contaminants in the feed waters. It shows a first growth hiatus at the 281 ka position and a second, much stronger, hiatus at its centre (263 ka). Shattered straw stalactites rest on this central break and are incorporated into the base of the overgrowth. Their presence may suggest a phase of effective frost shatter here in the back of the cave, though other explanations are possible.

A total of 12 U-series dates have been obtained for 77151/79151, as shown in the Plate. One of these, 205 $^{+34}_{-26}$ ka, has been rejected as it was based on only a small weight of calcite and was out of stratigraphic sequence. There are three additional dates for this deposit from a stalagmite, 79158 (Plate 5), growing on top of the flowstone nearby. The age record for the entire speleothem appears very consistent except for one anomalous date of 188 ka in the centre. Two repeat datings of the same calcite layers gave more acceptable ages of 255 and 252 ka and so the 188 ka age is rejected.

This flowstone began to grow on top of a cool or cold phase deposit about 320 ka. Growth ceased, apparently briefly, around 280 ka. There was a longer halt from approximately 263 to 255 ka, when shattered straws fell onto the surface. Growth was then renewed and appears to have continued rather steadily to some time between 170 and 180 ka. All growth then ceased permanently at this site. The deposit was buried by clays at some later time. Because the error margins on the dates are quite large, the periods of no growth in the sample (especially, the central hiatus) could be much larger than the interval suggested, perhaps as long as 30,000 years.

From our collections in the cave in 1977 and 1979, only one sample (the thin upper flowstone of 77159) proved to be of last interglacial age. However, the archaeological excavators had recovered many bones of warm climate animals from the Lower Cave Earth (Tiddeman, 1873; Sutcliffe et al 1976). These included hippopotamus and rhinoceros and were considered to be Ipswichian or Last Interglacial fauna. Many of the bones were encased in cave calcite. We obtained seven dates from such samples (donated by Tom Lord of Settle). Their ages range from 135 to 114 ka, which completely confirms the supposition that this is a fauna from the climatic peak of the last interglacial (Gascoyne et al, 1981).

Two speleothems (76153 and 77230H) are of recent age. Both were contaminated with detrital thorium and may be much younger than quoted. Lack of other young samples suggests that earlier visitors had taken them, as they are the most attractive and accessible.

All geomorphological evidences suggest that Victoria Cave is a particularly old feature in the Craven karst (Sweeting, 1974). It is a phreatic relict truncated by cliff erosion. Our speleothem dates indicate that it is much older than 350 ka and it is likely that the cave was drained before 500 ka. Statistical interpretations of the U isotopic ratios in certain samples suggests that drainage could even have occurred before 1.5 million years ago.

Deposits older than 350 ka, whatever their true age may be, display patterns of growth and hiatuses similar to younger ones. This suggests alternating warm, cool and cold periods (i.e. glacial types of climate) in Yorkshire before 350 ka. A great deal of flowstone was deposited between 320 and 180 ka. It seems that this long period was more moderate than later times, with no protracted glaciation occurring in the Dales.

GENERAL CAVE CHRONOLOGY AND EROSION RATES

Cave Chronology in Craven.

The foregoing pages have shown that the major cave systems in Craven were developed over 350,000 years ago. Waltham (1970, 1974) regarded the relict high-level tunnels in these caves as evidence for 'preglacial' development up to 55 m below a common, regional watertable. The apparent lack of vadose forms in the tunnels was thought to be due to rapid draining when valleys were incised during glaciation. Waltham also considered most currently-active vadose caves to be post-glacial and therefore younger than 15 ka. These ideas were criticised by Brook (1971) who pointed out that many caves at present contain flooded sections which are perched well above base level, due to damming by sediments or structural features. Brook also noted that the interval between 'preglacial' and post-glacial cave formation was considerable and was not considered by Waltham (1970). Based on sequences seen in the Leck Fell caves, Waltham (1974c) revised his concept of cave development and proposed instead five stages of erosion or sedimentation. These correlated, respectively, with interglacials and glacials.

The regional watertable concept was given new life by Waltham and Harmon (1977) and Atkinson et al (1978). In a paper reporting the first dates on British speleothems, they placed the watertable at 265 m a.s.l. in the west near the Dent Fault, rising to over 300 m a.s.l. in the Ingleborough area. They also tied it in with elevations of erosion surfaces and rejuvenation points seen in valley profiles. Dates on White Scar and Kingsdale Master Cave speleothems were evidence that glacial deepening of major valleys occurred before about 400 ka. Deepening of up to 75 m and consequent rejuvenation were thought to be rapid and were attributed to the first British glaciation (the Anglian Stage).

Results from the present study generally agree with the great antiquity of Craven caves proposed by Atkinson et al (1978). We prefer a less catastrophic process of valley lowering and cave development, however, for the following reasons:

(1) the classical watertable concept is not generally valid in karst regions, except on a very localised scale. Many of the relict tunnels may have formed under a perched phreas. Glover (1974), for instance, has noted four types of phreatic passage at similar levels in the Gaping Gill system, but each of different origin.

(2) the first glacial event in Britain is unlikely to have caused over 80 percent of the total valley entrenchment in Craven. The marine palaeoclimatic record claims multiple glaciations of similar intensity were more characteristic of Pleistocene time. The 75 m rejuvenation is more likely a product of three or more glaciations spread over several hundred thousand years. The apparent lack of vadose features which indicated a rapid downcutting may simply be due to infill by sediments and blockfall. Several ancient tunnels, in fact, do contain such features, e.g. Gavel Pot main streamway, the Lancaster Hole-Ease Gill Caverns main streamway and upper tunnels, the Lyle Cavern Series in Lost John's and Sand Caverns in Gaping Gill.

The general chronology of cave formation in Craven is one dominated by the rate of valley incision into the Great Scar limestone. Differing erosional conditions have caused these rates to vary over Quaternary time. Large tunnel formation may well have occurred during preglacial times (more than 1-2 million years ago) but at elevations controlled by local base levels of erosion, rather than a regional watertable. With the onset of glaciation in Britain, more rapid downcutting of valley floors ensued, tempered by lithological and structural variations in the limestones. There is, as yet, no definitive evidence to show that one single glaciation in Britain caused most of the valley formation and cave development in the Dales.

Vadose channel entrenchment rates.

Some entrenchment rates are quoted in Table 3. These are obtained by taking the height of an in situ stalagmite sample above the present bedrock channel floor, and dividing this by the basal U-series age obtained. Results are the mean maximum entrenchment rates over the span of time between the basal age and the present day. They vary from 2.2 to 8.3 cm per 1,000 years.

TABLE 3 PASSAGE ENTRENCHMENT RATES FOR CAVES IN THE CRAVEN DISTRICT USING BASAL $^{230}Th/^{234}U$ AGES AND ELEVATION OF SPELEOTHEMS (from Gascoyne et al. 1983a)

Cave	Type of deposit	Height above stream (m)	Basal age (ka)	Mean maximum downcutting rate (cm/ka)
Lost John's Cave	Wall flowstone	~ 2·5	115	2.2
Kingsdale Master Cave	Resolutioned roof flowstone	~11	300	3.7
Ingleborough Cave	Flowstone	~ 4	≥120	≤3.2
Ease Gill Caverns	Loose flowstone	~20	240	~8.3
White Scar Cave	Loose flowstone	~20	≥350	≤5.7

The measurement from the Main Drain at Lost John's Cave is the best because the samples were collected in the growth position directly above the channel. The Lancaster Hole and White Scar samples were displaced. We have assumed that they had not moved great distances from their growth positions when collected but it is possible that they had, in which case the values quoted in the Table are not mean maxima but something less than that. The Kingsdale and Ingleborough Cave samples were in the growth positions but modern stream channels have shifted laterally so that they are some metres distant. A cutdown rate, as in the table, does not express this lateral erosion.

It is interesting to compare these rates with those obtained by directly measuring bed lowering in limstone channels by means of micrometers, (High and Hanna, 1970; Coward, 1975). The micrometer rates, calculated from measuring periods ranging from a few months up to two years, are about an order of magnitude greater than our rates. This is probably because there is always a tendency to place the micrometer in the most active places because the most reliable measurements can be obtained over short periods there. Our U-series-based rates are determined by averaging very long time intervals (90,000 years at Lost John's). It seems quite likely that for substantial parts of these intervals no entrenchment was occurring because channel beds were buried ("armoured") by a protective detrital layer.

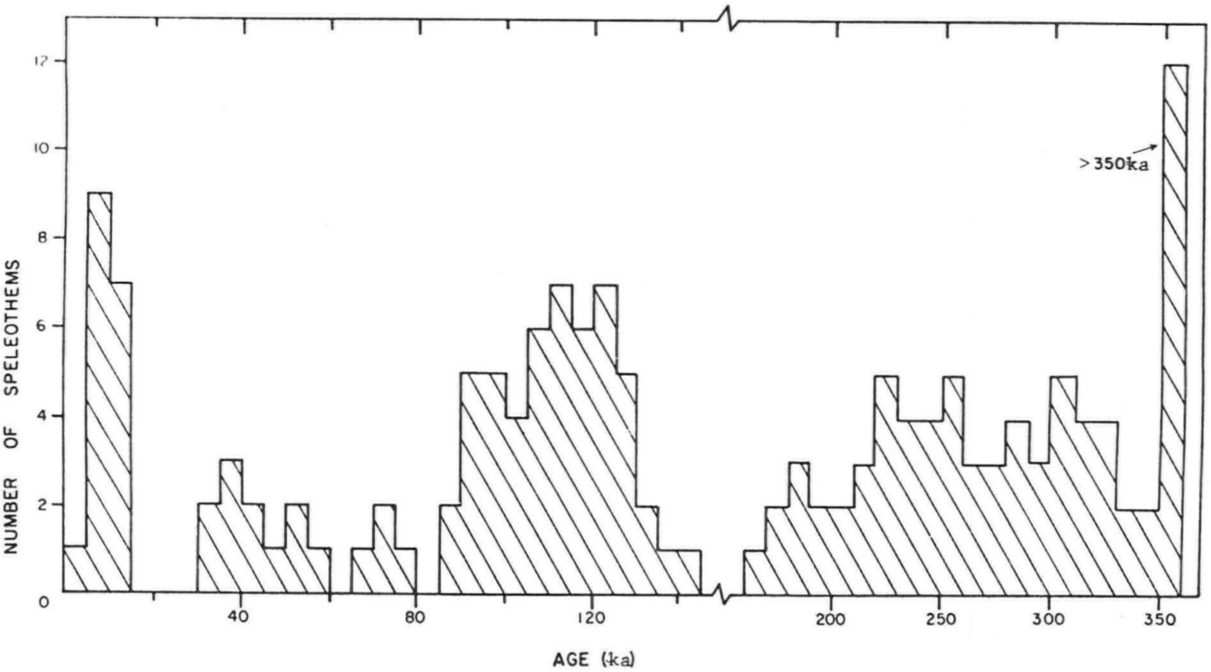


Figure 4 Histogram of $^{230}Th/^{234}U$ ages for all speleothems from caves in Craven except those showing detrital thorium contamination (from Gascoyne et al, 1983b). Top and basal ages of a speleothem define the limits of growth. Ages above and below a hiatus are used instead, when applicable. Peaks and troughs in growth frequency are correlated with warm and cold climates, respectively (see text).

The entrenchment of valley floors

In the same fashion, the elevations of dated stalagmites above adjoining springs and valley floors may be used to obtain maximum average rates of valley deepening during the measured time spans. We have determined rates for only two valleys, so far, and neither is as precise as we would wish. Nevertheless, they are interesting and tend to contradict earlier estimates.

The speleothems in Kingsdale Master Cave are approximately 11 m above the modern watertable. They are only about 5 m above the present floor of the dale, because the dale is infilled with gravels which bury bedrock to a depth that is perhaps as great as 25 m. Assuming this latter (likely maximum) value, then the bedrock floor has been entrenched no more than 30 m since the first speleothem growth began in a drained and abandoned Roof Tunnel about 300,000 years ago. This gives a maximum mean deepening rate of 10 cm per 1,000 years. The stalagmites may well be a little older and the dale floor was almost certainly a few metres below their level when they began to grow. The maximum mean rate has, therefore, most likely been less than 10 cm. This result is very similar to rates we have obtained for glaciated valleys in the Rocky Mountains of Canada (Ford et al, 1981).

The oldest speleothems at Whitescar Cave are about 70 m above the floor of Chapel-le-Dale, which is incised into basement rocks. The speleothems are older than 350 ka. This gives a maximum mean rate of $<$20 cm per 1,000 years for the last 350,000 years.

Most previous authors have attributed valley deepening in Craven to glacial scour. Atkinson et al, (1978) suggested that there may have been as much as 75 m of deepening during the first glaciation that is recognised in the British record, the Anglian. Brook (1974) proposed 20-50 m of entrenchment per glaciation, supposing that there have been three or more glaciations. More conservatively, Sweeting (1974) estimated 60 m for the sum of all glacial deepening in the Dales.

The frequency distribution of speleothem ages (discussed below) suggests that there have been either two or three full glaciations of the District during the past 350,000 years. Assuming the latter, we obtain a glacial/interglacial cycle period of about 120,000 years. A lot of quite independent evidence for such a periodicity has been obtained elsewhere in the world. Maximum mean rates of $<$12 to $\ll$24 m per cycle result, for Kingsdale and Chapel-le-Dale, in fair agreement with Sweeting's estimate if it is assumed that the three glaciations recognised in the British record were, in fact, all that occurred in the Dales. Northern Hemisphere deep sea core data suggest 10 glaciations during the past one million years (Shackleton and Opdyke, 1973), so it is quite possible that the amount of glacial deepening is much greater than 60 m.

If we assume that there have been many glaciations of the Craven District, with mean deepening proceeding at the maximum rate suggested for the past 350 ka, then the incision of the uppermost beds of the Great Scar limestone to form the Yorkshire Dales will have begun between one and two million years ago. If the mean rates are lower, then the dates are greater than two million years in origin and the earliest surviving caves are truly 'preglacial' in the chronological sense. This is highly speculative. It is obvious that we need more dated cave/dale floor correlations, and new methods to extend cave dating back beyond 350 ka.

CLIMATIC SIGNIFICANCE OF SPELEOTHEM AGES

Frequency of growth and relation to climate.

In Fig. 4 we have plotted uncontaminated speleothem age results as a frequency histogram. Only growth periods are actually used in this plot, rather than individual ages, because this avoids bias given to speleothems which were dated several times.

A number of periods of plentiful speleothem deposition can be seen in the age range 0 to 350 ka and beyond. There are many results for speleothems under 15 ka. This is largely due to the better chance of preservation of the younger deposits. Older samples are more likely to have suffered erosion or burial during the last glaciation. This bias is offset to some extent by our deliberate collection of 'old-looking' speleothems, so that more ancient morphological events could be dated.

In Part I of this paper (Gascoyne et al, 1978) we showed how the frequency of speleothem growth may be related to past climates. Warm periods were marked by many deposits; increased CO_2 production in soils and presence of freely-flowing groundwater encouraged the limestone dissolution-calcite precipitation process. The last ten thousand years is known to have been such a period (the Holocene) and is well-represented by high frequency growth in Fig. 4. Other intervals of plentiful growth are also likely to be of interglacial character although frequencies will be lower because of removal by erosion and burial.

In contrast, lower temperatures prevent CO_2 production and freeze groundwater so that periods of low or zero age frequency probably correspond to cold or glacial climates. Lack of deposits between 15 and 35 ka is such a period and correlates with the Late Devensian glaciation, dated independently by ^{14}C analysis of surface deposits. A similar period occurred between 140 and 165 ka and is likely also to have been a very cold event in the area. Other periods of intermittent growth, such as 35 to 80 ka suggest cool to mild conditions.

The results in Fig.4 agree well with the timing of glacial-interglacial stages seen in ocean core isotopic records and fossil reef terrace dates. Detailed correlation of the Craven speleothem record with these global indicators is described by Gascoyne et al (1983b).

Correlation with the British climate record.

By analogy with the Holocene growth record, the broad peak between 90 and 140 ka in Fig.4 can be correlated with the last interglacial. This is known as the Ipswichian in the British sequence. In fact, the Ipswichian is more accurately defined as the period between 115 and 135 ka, from the Victoria Cave mammal-flowstone dates. It is possible that 90 to 115 ka may be a second (unnamed) interglacial stage. Alternatively, the same animals as dated at Victoria Cave may have inhabited Britain during this interval also, to account for the many similar remains elsewhere in the country.

Carbon-14 dates of organic deposits in soils and beetle remains (Coope, 1975) have shown that the period 35 to 70 ka was one of alternating cold to mild climate. This agrees with the sporadic speleothem growth seen in Fig. 4. A short warm event (the Upton Warren inter-stadial) has also been recognised from beetle data and this can be seen in speleothem dates as a slight increase in growth frequency between 38 and 44 ka. Before this, growth was more discontinuous, probably due to cold climates with occasional flooding of the caves, seen as mud layers in many of the dated deposits. This is the non-glacial, Early Devensian stage in the British record.

The results in Fig. 4 allow us to place dates on the penultimate glaciation in Britain, between 140 and 165 ka. This interval of zero growth may be correlated with the Wolstonian glaciation. The lack of accurate ages for earlier periods in the British Pleistocene record prevents us from directly correlating other stages with the speleothem record. The broad peak from 180 to 320 ka may relate to the Hoxnian interglacial and perhaps the Anglian glaciation is close to the dating limit (about 350 ka). Unfortunately, this remains speculative because the Hoxnian and earlier stages rest on a floating time scale which is determined only by the inter-relationship of the type-sections for which these events are defined. Correlation of dated speleothems in the cave to the type section for a given stage is seldom possible, largely because karst regions, because of their elevation, tend to be centres of erosion, not deposition.

SUMMARY AND CONCLUSIONS

Uranium-series ages of 87 speleothems from caves in the Craven district have shown the antiquity of relict, upper levels of these systems. Individual ages have been used to infer local chronologies of passage development. Maximum average rates of cave passage entrenchment of between 2 and 8 cm/ka have been determined from dated speleothems adjacent to a local base level. Extrapolation of these results allows calculation of the rate of erosion during glaciation and an age of up to two million years is estimated for the Yorkshire Dales. Cave formation in the Dales is inferred to be a gradual process, controlled both by climate and local geological characteristics.

It is probable that valley entrenchment in the Craven district has been a more gradual process than that proposed by Waltham (1970) and Atkinson et al (1978), and has occurred in steps of <25 m over several interglacial/glacial cycles for perhaps the last 1 to 2 million years. We might therefore anticipate the presence of even higher-level fossil tunnels, dating from a time when the limestone was only partially exposed and valleys were entrenched into the upper most beds alone. Victoria Cave and others in the area may be evidence of this situation, but few are known today, probably because of truncation and extensive collapse.

Ages of Craven speleothems have also been used to determine the climate of the Dales over the past 300,000 years. Periods of high frequency growth are seen in the Holocene. and a similar abundance between 90 and 135 ka is interpreted as the last interglacial in the British climate record. The Ipswichian interglacial forms at least one part of this period, from 115 to 135 ka. For the first time, absolute dates have been placed on the Wolstonian stage commonly accepted to be the Penultimate glaciation, from 140 to 165 ka.

At the moment, older events cannot be easily resolved from the speleothem results, but with care and the right deposits (higher uranium speleothems and longer counting times) it may be possible to better define limits of climatic events in Britain prior to 165 ka. Other dating methods must ultimately be used, however, to extend the record back beyond 350 ka. The uranium isotopic ratio, $^{234}U/^{238}U$, is one such technique and has been used tentatively to estimate the age of Victoria Cave. Thermoluminescence and electron spin resonance techniques have potential for dating to beyond one million years, but much work remains to be done before they can be used confidently for speleothem dating.

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FURTHER WATER TRACING EXPERIMENTS AT CASTLETON, DERBYSHIRE

N.S.J.Christopher

Abstract

Three sinks on Rushup Edge, Derbyshire, were simultaneously marked with three separate dyes. Using a combination of charcoal and cotton detectors the water from all three sinks was found to enter Speedwell Cavern at the Main Rising. Observations of flow conditions show that the principal flow from the Rushup Edge swallets either enters at Main Rising or at Whirlpool Rising, but not both. Surveying shows Whirlpool Rising to be 8.35m higher in altitude than Main Rising and therefore open passage must exist upstream of Main Rising with a divergence of waters being caused by a temporary blockage such as a sandbank at times.

INTRODUCTION

The work carried out during 1980 at Castleton (Christopher et al, 1981) attempted to apply modern hydrological techniques, notably quantitative dye tracing and flood pulse studies to the Castleton aquifer. The results generally confirmed the pattern established by Ford (1955 and 1977) and supplemented it with a considerable amount of detail.

A major problem was encountered with the use of detectors for in-cave studies where water samplers could not be installed or regularly serviced; this problem was also associated with high and variable background fluorescence caused by organic matter adsorbed onto the charcoal with the dye. To overcome this a special technique has been developed (Christopher, in prep.).

Towards the end of the 1980 project it became apparent that flow conditions in Speedwell were more variable than previously thought and that the main flow could come from either Main Rising or Whirlpool Rising, but apparently not both.

In view of the difficulty encountered with interpretation of in-cave detectors because of the absence of background readings with no dye present and the newly revealed complexity of the Speedwell hydrology, a further series of dye traces was thought essential, after a study of background fluorescences obtained in the absence of dye. The results of the background study will be reported later (Christopher, in prep.). The geological and geographical outlines of the Castleton area have already been adequately described by the author, (Christopher et al, 1981) and Ford (1977).

FLOW CONDITIONS IN SPEEDWELL

During the period 1978-1983, Speedwell Cavern was visited irregularly by the author, Dr T. D. Ford, R. P. Shaw and J. D. Harrison, for the purpose of hydrology, water chemistry and surveying. During these visits the flow conditions were noted and they are summarised in Table 1.

TABLE 1

Flow Conditions in Speedwell Cavern 1978-1983

Date	Event	Main Flow From	Water Chemistry Main	Water Chemistry Whirlpool
Feb. 1978	Visit	Main rising	A	P
March, 1980	Visit	Whirlpool rising	A	A
Sept. 1980	Visit	Whirlpool rising	A	A
Oct. 1980	Visit	Whirlpool rising	A	A
March, 1981	Major Flood	-	-	-
July, 1981	Visit	Main rising	A	?
Oct. 1981	Visit	Main rising	A	P
Nov. 1982	Visit	Main rising	A	A
Feb. 1983	Visit	Whirlpool rising	A	A

A = Allogenic type water
P = Percolation type water
? = Percolation type water based on visual evidence only (very little flow).

From this table it can be seen that the principal flow only comes from Main Rising after a major flood. Once low flowl conditions prevail for several months the flow reverts to Whirlpool Rising until the next major flood. Secondly, the Whirlpool Rising only ebbs and flows when it is regularly taking the principal flow.

On one occasion only the Main Rising has been seen to ebb and flow. In November 1982 water was standing at the Boulder Piles downstream of Main Rising about 10 feet (3 m) above normal. During the next hour it fell by 6 feet (2 m), thereby draining a lot of ponded water right up to Main Rising, and then rose rapidly towards its previous high level. This was soon after a mild flood and may occur quite often but visits under such conditions are rare. (Verbal information from TDF).

Table 1 also includes a summary of water chemistry at the two risings. The characteristic chemistry of the two types, namely allogenic swallet water and autogenic percolation water, are identified by calcium, sodium and potassium concentrations (Christopher and Wilcock, 1981). Allogenic water is low in calcium (60-70 mg/l), but high in sodium (8-12 mg/l) and potassium (0.9 - 1.2 mg/l). Autogenic water is high in calcium (~90 mg/l), low in sodium (3-5 mg/l) and potassium (~0.5 mg/l).

THE DYE TRACE

The flow conditions in November 1982 indicated that the principal flow of all the Rushup Edge swallets went to Main Rising, Speedwell and thence to Russell Well and Slop Moll.

It was therefore decided to repeat the 1980 tracing pattern but using fluorescein in place of lissamine. The same injection points were used, namely P1, P8 and Giants Hole (P12). Because of the shorter flow time established in 1980 for P8 (40 hours) to Russell Well compared to 7-9 days for P1 and 95 hours for Giants Hole, it was decided to tag P8 with amino G acid and Giants Hole with fluorescein as only a limited supply of amino G was available. As before, rhodamine WT was used at P1: the details are set out in Table 2.

TABLE 2

Dye Injection Details on 7th November 1982

Dye	Quantity	Injection Site	Time
Rhodamine WT	150 ml (20%)	P1	15.15
Fluorescein	460	P12 (Giants Hole)	12.00
Amino G Acid	243 gm	P8	15.00

Cotton and charcoal detectors were prepared as previously described. As before, detectors were placed on all principal inlets in Speedwell, together with integrated flow sites in the Main level and at the head of the Bunghole. Two detectors of each type were used at each site and both cotton and activated charcoal detectors. All detectors inserted were recovered on 14th November 1982.

All detectors were individually bagged and returned for examination and then washed free of mud and sediment in a stream of tap water. The cotton detectors were then dried and examined under a UV lamp for the characteristic blue fluorescence by three people, independently, to prevent bias. The charcoal detectors were eluted with a solution of propanol 5 parts, 10% KOH solution 3 parts, distilled water 2 parts. The whole detector was eluted overnight in 50 ml of elutant which was subsequently filtered and diluted up to 100 ml with clean solvent mix. The results obtained using the method of Christopher (in prep) are presented in Table 3.

TABLE 3

Speedwell Detector Results 7th-14th November, 1982

Site	Amino G Acid (P8) (Cotton)	Fluorescein (P12) (Charcoal)	Rhodamine Wt(P1) (Charcoal)
Cliff Cavern	-	-	-
Whirlpool Rising	-	-	-
Bathing Pool	(+)	-	-
Main Rising	+	+	+
Main Passage (Pit Props)	+	+	+
Bunghole (Top)	+	+	+

- = negative
(+) = doubtful positive
+ = positive

DISCUSSION

The results in Table 3 conclusively show that all the flow of the Rushup Edge swallets went to Main Rising on 7-14th November 1982. This contradicts the rather complex pattern obtained during the previous set of tests (Christopher et al, 1981). Due to high background fluorescence and incorrect analytical technique, the previous amino G acid (P12) and lissamine FF (P8) results reported then should now be discounted. However, the fluorescence at the rhodamine wavelength is negligible and the negative result at Main Rising in October 1980 is highly significant as it could not be obtained other than by the absence of dye. These results, therefore, suggest that in October 1980 the P1 water flowed to Whirlpool Rising and Bathing Pool, also it is highly probable that all other sinks flowed to these resurgences, to be rediverted to Main Rising by the major flood of March, 1981.

R. P. Shaw (personal communication) has now surveyed both Main Passage and Whirlpool Passage, making altitude measurements not previously available. Whirlpool Rising is 8.35 m above Main Rising and approximately 2 m above the Bathing Pool. Therefore, as the main flow from the Rushup Edge swallets goes to both Whirlpool and Main Risings, there must be open passage after the divergence to the two risings. The mechanism of the diversion is unclear, but it may be either a deep sediment-filled U tube with a high level passage to Whirlpool Passage, or another down-dip analogue of Whirlpool Passage beyond Main Rising connecting Faucet and New Rake, containing one or more restricted sumps that become blocked by sediment. This allows flow to proceed to Whirlpool Rising. When a major flood flushes all the sediment out, the flow reverts to Main Rising. Whatever the mechanism, the prospect of further extensions by diving Main Rising appear bright. Diving has shown that the rising is 30 m deep (C.D.G. Newsletters

ACKNOWLEDGMENTS

The author would like to thank Dr S.Trudgill for supplying the amino G acid and rhodamine WT dyes, Dr T.D.Ford, for arranging access to Speedwell Cavern, and Richard Shaw and John Harrison for accompanying the author during these trips, also J.Gillett of Crewe Caving Club for putting the dye into Giants Hole.

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CAVE SCIENCE

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INVERTEBRATES AT NIAH GREAT CAVE, BATU NIAH NATIONAL PARK, SARAWAK

Phil Chapman

Abstract

The enormous Niah Great Cave contains a small but interesting guano-associated fauna which is threatened by the removal of its food supply and destruction of its habitat by commercial guano-gathering and the tramping feet of tourists.

In May, 1978, the Speleological team of the Royal Geographical Society Mulu Expedition was given the opportunity to visit Niah Great Cave, as guests of the Sarawak Government's Department of Forests. The cave, a famous tourist attraction and archaeological site, passes right through an enormous limestone tower, the Batu Niah, situated close to Niah town in the Gunung Subis area of Sarawak (3°58'N, 113°46'E). An account of the cave is given by Wilford (1964).

During our two-day stay at Niah, I made a small and by no means exhaustive collection of invertebrates in the Great Cave. This paper describes the results of this collection.

The only previous literature concerning invertebrates from the Niah Caves of which I am aware is the description by Chopard (1959) of the large egg-eating cricket, *Rhaphidophora oophaga*.

THE FAUNA

The bat and swiftlet fauna of Niah Great Cave is well known (Medway, 1958). Nests of the swiftlet *Aerodramus fuciphagus*(Thunberg) are harvested from near-inaccessible ledges at roof level by local Iban men via terrifying pole climbs. Guano sweepers collect bat and swiftlet droppings by the sackload for use as fertilizer. So efficient are they, that I had difficulty in finding any undisturbed patches of guano. The large scale removal of guano has seriously depleted the guanobious fauna which now numbers only a fraction of the species found, for example, in Deer Cave in Mulu (Chapman, 1981). The wall-dwelling (parietal) fauna by comparison, is rich, comparing favourably with that of Deer Cave. Apart from bats and swiftlets, the cave contains reptiles(I saw a cave racer snake, *Elaphe taeniura grabowski* (Fischer), and the Niah cave gecko, *Cyrtodactylus cavernicolus* Inger) and a white fish is locally reported to live in a stream running beneath the cave and connected to it by a deep vertical shaft.

A few interesting invertebrate species inhabit the cave. Many are dependent on guano as their food supply. Three are cave-limited, and one of these, the crab *Adeleana chapmani* Holthuis, may be entirely confined to a few pools in the Great Cave. The cave floor in the more visited parts of the cave is trampled hard and flat and is devoid of life. It would therefore seem desirable that one or two passages with a variety of microhabitats and resident bat or swiftlet populations should be protected from guano sweeping and barred to visitors in order to conserve the few remaining species of interest.

A brief account of the invertebrate fauna is presented below:

PLATYHELMINTHES

TURBELLARIA: Tricladida - an undetermined white troglobitic, and a grey troglophilic flatworm inhabit small, guano-floored pools.

MOLLUSCA

GASTROPODA: Stylommatophora - two snails, *Assiminea* sp. and *Lamellaxis clavulinus* (Potiez and Michaud) live in wet guano.

ARTHROPODA

CRUSTACEA:

Amphipoda - The white, eyeless troglobite *Bogidiella (Medigidiella) sarawacensis* Stock, 1983, is found in shallow, guano-floored pools. This ancient species (perhaps pre-dating the break up of Pangaea) is also found in the Gunung Mulu National Park (Chapman, in press).

Decapoda : Gecarcinucidae - The small-eyed troglobite, *Adeleana chapmani* Holthuis, 1979, is found in shallow, guano-floored pools.

CHILOPODA:

Geophilomorpha - *Orphnaeus brevilabiatus* Newport and a *Mecistocephalus* sp. inhabit guano.

Scutigeromorpha - A large undetermined species hunts rhaphidophorid crickets on the cave walls and floor.

ARACHNIDA:

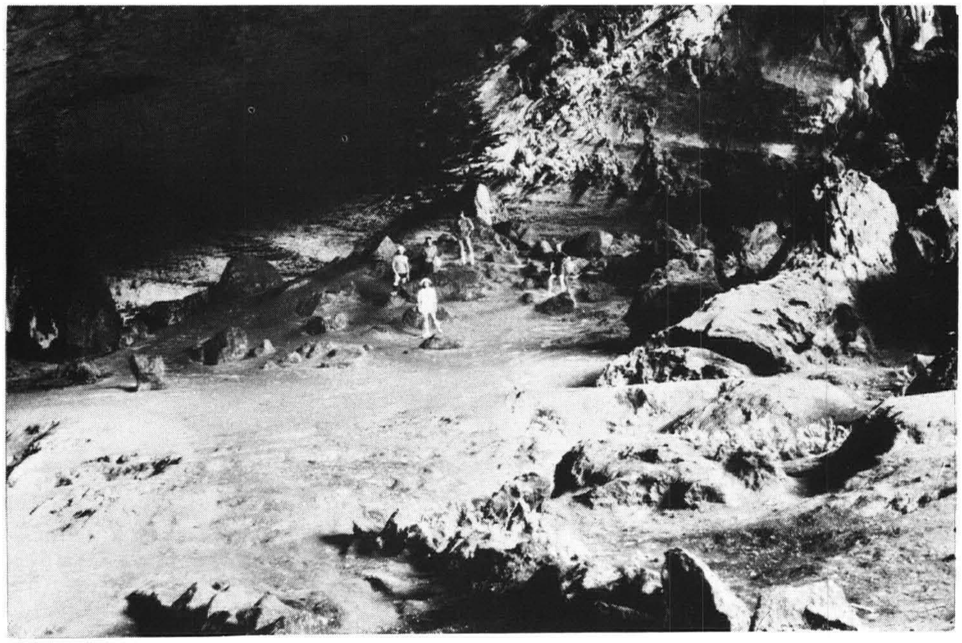
Scorpionida - an undescribed species of *Lychas* is present in surprisingly large numbers on the cave walls.

Pseudoscorpionida - *Oratemnus saigonensis* (Beier), common in guano, is a widely distributed species also found in Deer Cave in Mulu.

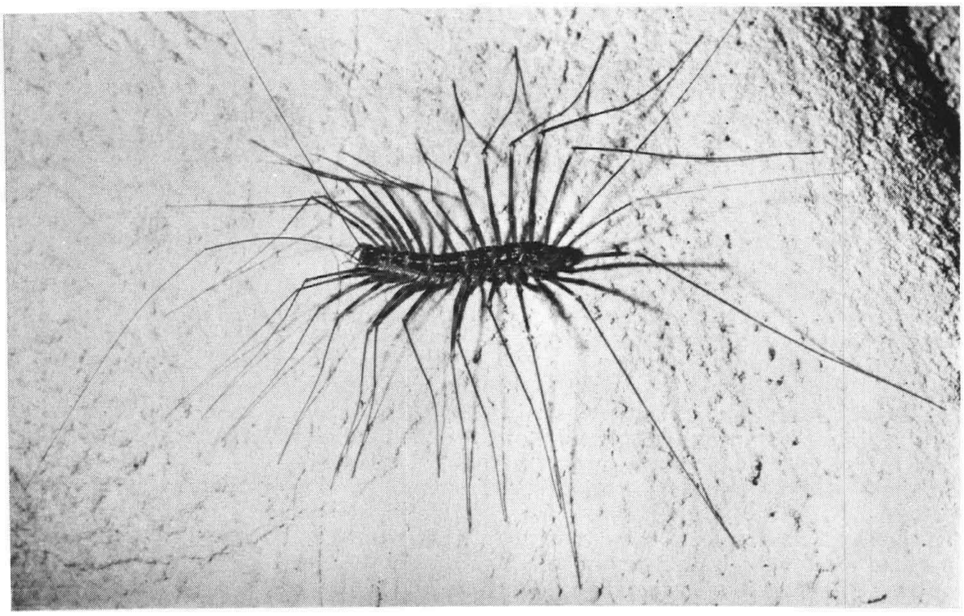
Araneae - there is a rich spider fauna, so far largely undetermined.

INSECTA:

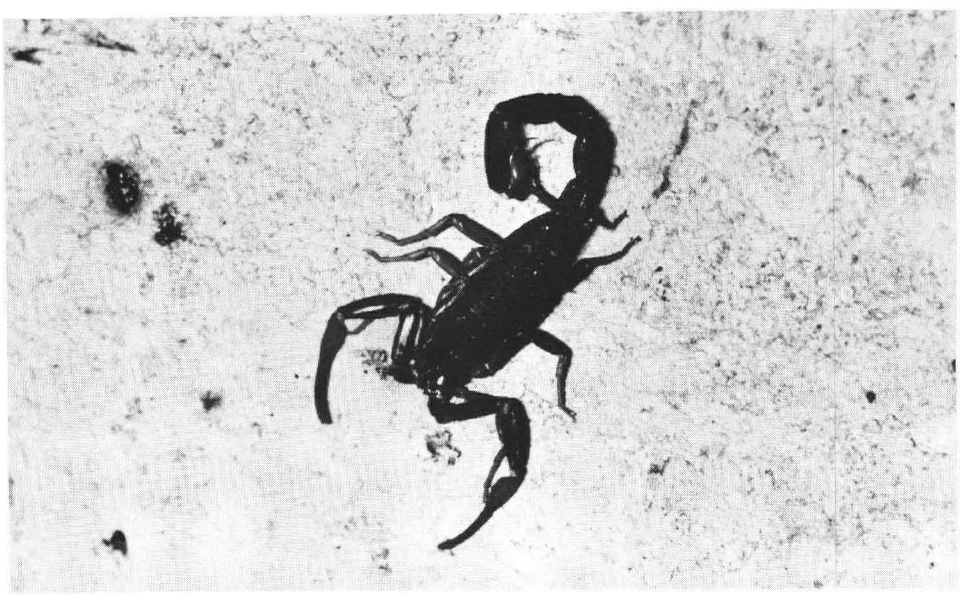
Orthoptera : Rhaphidophoridae - the large, robust *Rhaphidophora oophaga* Chopard is common on the cave walls.



1. Giant solution notches in cliff close to Niah Cave entrance (P.Chapman)



2. An undescribed scutigerid centipede, Niah Cave (.P.Chapman)



3. Cave scorpion, Guano Cave, Niah (Jane Foster)

Dictyoptera : Blattaria - the guano-burrowing troglophile *Pycnoscelus striata* (Kirby) is locally common in the few untrampled guano patches.
Hemiptera : Reduviidae - a slender *Bagauda* sp. hunts on the cave walls.
Lepidoptera : Tineidae - *Tinea porphyropa* Meyrick is common on guano.
Coleoptera : a *Melanoxanthus* sp. (Elateridae) and a *Hister* sp. (Histeridae) are common on guano.
Diptera - only Milichiidae were attracted to a light trap placed in the centre of the cave.
Hymenoptera - the large stinging ant, *Pachycondyla tridentata* is a guano burrower, and several small wasps are also found in guano.

ACKNOWLEDGMENTS

I wish to thank the Director and staff of the Sarawak Department of Forests at Kuching and Miri, who made our visit to Niah possible, for their friendship and hospitality. Thanks also to Dave Brook and the other members of the speleological team who helped with work at Niah.

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AIR TEMPERATURES AND AIR INTERCHANGES AT ALTAMIRA CAVE (SPAIN)

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Abstract

The air temperature in a series of chambers in Altamira Cave was measured in natural conditions (that is, with the cave closed to visitors), over a period of a year and a half. The results provide a detailed description of the temperature range to be found within the Cave. By comparing the values found with the temperature of the rock surface, it is possible to predict certain characteristics of the air exchanges which take place.

The air temperature within the Altamira Cave is the fundamental variable that governs natural air interchanges within the Cave itself and between the Cave and the exterior. Since convection is the principal mechanism for the transport of matter within a gaseous mass, it is air temperatures within the Cave that determine the interchange of the substances transported, mainly water vapour and CO_2. These substances are two of the main causes of any deterioration processes that may attack the paintings on the roof of the Hall of Paintings through the evaporation and condensation of water on the surface of the rock and the dissolution and precipitation of carbonates.

No doubt this is why the first air temperature measurements in the Hall of Paintings were carried out at a very early stage (Breuil and Obermaier, 1935), shortly after the initial discovery of the Cave. However, subsequent air temperature measurements (Garcia Lorenzo et al, 1970) lack sufficient continuity and were affected by the presence of visitors. In the light of these circumstances, we have carried out a series of air temperature measurements within the Cave in order to obtain a sufficiently detailed description of its internal microlimate.

The air temperature in each of the chambers of the Altamira Cave must depend basically on the surface temperature of the rock in the different chambers (Andrieux, 1977; Brunet et al, 1980), because it is a cave system with only one opening to the exterior, i.e. a static cave where air movements are close to the limits of perceptibility. The tendency towards a temperature equilibrium between the mass of air and the mass of rock in each chamber will result in an air temperature close to the temperature of the rock due to the great difference of mass between the two. Because of its great calorific capacity, the rock can interchange a large amount of heat without appreciably varying its own temperature and yet producing variations in the air temperature as it does so. Consequently, the existence of differences between these two temperatures may be interpreted as being due to a failure to achieve a thermal equilibrium owing to air interchanges with other chambers.

EXPERIMENTAL METHOD

The air temperatures in the different chambers of Altamira Cave were measured simultaneously by two different methods over a period of a year and a half, between May 1980 and October 1981. The first of these methods used a series of platinum resistance thermometric probes to supply electrical signals to a chart recorder. This method provided a continuous record of the temperature at four points inside the Cave and another one outside (near to the entrance of the Cave), but it has the double disadvantage of low sensitivity and a high degree of measurement error, $\pm$ 0.2°C.

The second method used conventional thermometers with an accuracy of $\pm$ 0.1°C sited at ten different points inside the Cave. In this case, temperature measurements were carried out by direct readings taken between two and three times per week. Fig. 1 shows the points in the Cave at which the temperature was measured by either of these methods.

EXPERIMENTAL RESULTS

The results obtained by the continuous recording method indicated no appreciable variations in the air temperature at any of the points inside the Cave measured in this way, in response to daily variations in the external temperature at the entrance of the Cave, measured by the same method. More accurately, it can be said that no variations in excess of 0.2°C were recorded in either the Hall of Paintings or the corridor to the Wall Chamber, against daily variations of some 4°C in the external temperature. The same cause may lead to some variations in excess of 0.2°C in the air temperature in the Hall Chamber, but these are slight. Such significant variations in the temperature occur during extremes of the external temperature, such as those to be found on some winter nights or some summer days. Under these conditions, sharp variations may occur in the air temperature in the Hall Chamber. These sharp variations in the temperature in the Hall Chamber must be due to the inflow of air from the outside, although this does not lead to temperature variations in the deeper chambers due to the slowness of the air circulation inside the Cave, which equalizes the air and rock temperatures. When the external temperature returns to less extreme levels, the temperature in the Hall Chamber slowly reverts to its initial value, generally after several hours.

The results obtained by the direct reading method, together with those obtained by continuous recording, are summarized in Figs. 2, 3 and 4, which show annual variations in the montly average, obtained by averaging the air temperature values measured at the different points selected within the Cave. This annual variation is similar at all points, presenting basically a sine curve with a period of one year. Nevertheless, both the amplitude and the phase of these temperature variations are different for the various points measured. The amplitude of the temperature variation is greater in the Hall Chamber than in any of the other chambers which lie deeper below the surface. Also, the maximum point in the annual temperature variation occurs earlier in the Hall Chamber than in any of the other chambers. Overall, the general characteristics of air temperature variations in the various chambers of the Cave coincide with those we found by measuring the surface temperature of the rock in the respective chambers (Villar et al, 1983a). Bearing in mind the fact that this surface temperature is in turn determined by the annual thermal wave, the air temperature in each chamber must be determined by the same cause.

AIR INTERCHANGES INSIDE THE CAVE

The existing temperature distribution within Altamira Cave enables certain predictions to be made with respect to air interchanges between the different chambers as the result of temperature differences.

Air movements between the different chambers of the Cave must take place by means of convection currents, the intensity of which will depend on differences in the air temperature of these chambers and their relative depth beneath the surface (Cigna, 1968; Wigley and Brown, 1976). Generally, air masses at some distance from the Cave entrance are constantly at a lower temperature than the air to be found in areas close to the entrance. As the topography of the Cave (Foestra, 1975) shows that the former lie deeper than the latter, no significant air interchanges should take place between them. The Hall of Paintings and the corridor to the Wall Chamber have similar temperatures and both may experience a certain amount of convective interchange with the Hall Chamber located at the entrance of the Cave. These occur principally when the difference between their temperature and that of the Hall Chamber is at its peak and consequently are to be found in February, March and April and again in August, September and October, as can be deduced from Figs. 2, 3 and 4. Similarly, the greater the difference between the air temperatures of the Hall Chamber and the exterior, the greater will be the amount of air interchanges between them. The maximum differences between the Hall Chamber and external temperatures occur in July and August and in January and February. The maximum differences between external temperatures and temperatures within the rest of the Cave are to be found in August and September and in January and February.

To compare these predictions with the air movements that actually take place inside the Cave, it is worth studying the variations over the period of measurements in the temperature differences between the surface of the rock and the air in each chamber. If the average monthly values for both temperatures are compared in the four more representative chambers of the Cave (the Hall Chamber, the Hall of Paintings, the Wall Chamber and the Great Chamber), it will be observed that no great differences are to be found in any of these chambers (figs. 5, 6, 7 and 8). Air interchanges with the exterior are minimal, as is borne out by the fact that the relative humidity of the air is close to 100% (Villar et al, 1983b). The temperature differences shown in the figures are always greater in December, January and February and during these months the external temperature is lower than that of the Cave chambers. This indicates the existence of convection processes with the exterior during these months, although it should be added that this does not necessarily indicate the existence of maximum interchanges during this period since the different temperature of the interchanged air produces quantitativelydifferent effects. A comparative study of the temperature differences between the rock and air in each chamber reveals differing values for each chamber in the Cave. This fact may be explained as a consequence of the different degrees of air interchange that take place in each chamber. If this hypothesis is accepted, examination of Figs. 5, 6, 7 and 8 allows one to conclude the existence of a gradual series of air interchanges of greater to lower magnitude in the Hall Chamber, the Hall of Paintings, the Wall Chamber and the Great Chamber, respectively.

CONCLUSIONS

We have carried out a study of air temperatures in different chambers of the Altamira Cave over a period of one year and a half. The air temperature was measured by two different methods, not only to obtain any daily variations but also to ensure a sufficient degree of accuracy in the measurements. The results obtained provide a detailed description of the range of air temperatures in the Cave, and reveal the absence in most areas of any sharp variations in this temperature. They also reveal the existence of a basically sinusoidal annual variation in all chambers of the Cave, although the phase and amplitude are different in each one. These results are similar to those obtained by studying annual variations in the rock surface temperature in each chamber. Taking this agreement into account, predictions can be made with respect to air interchanges within the Cave itself and between the Cave and the outside world.

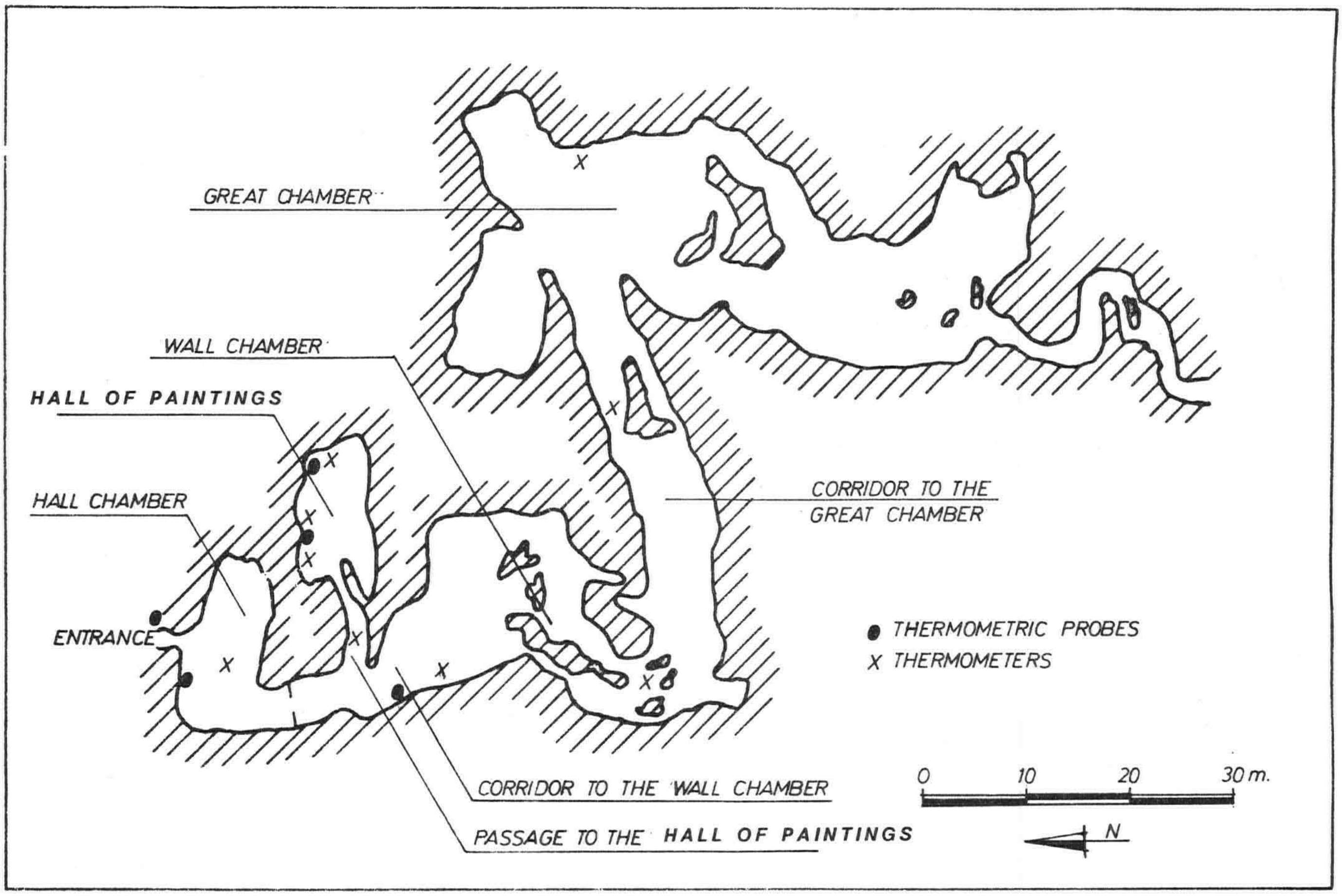

Fig.1. Measurement locations in Altamira Cave.

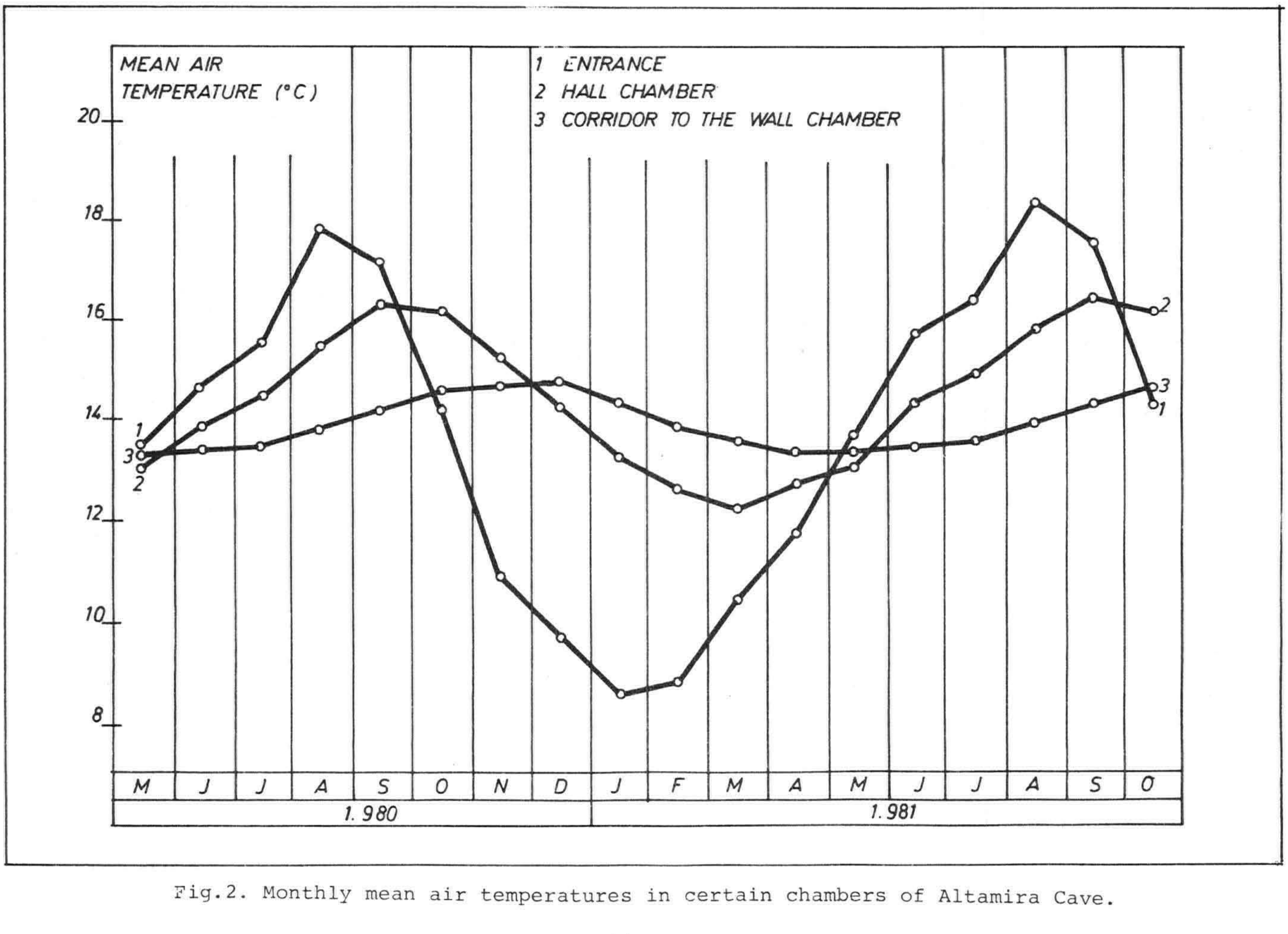

Fig.2. Monthly mean air temperatures in certain chambers of Altamira Cave.

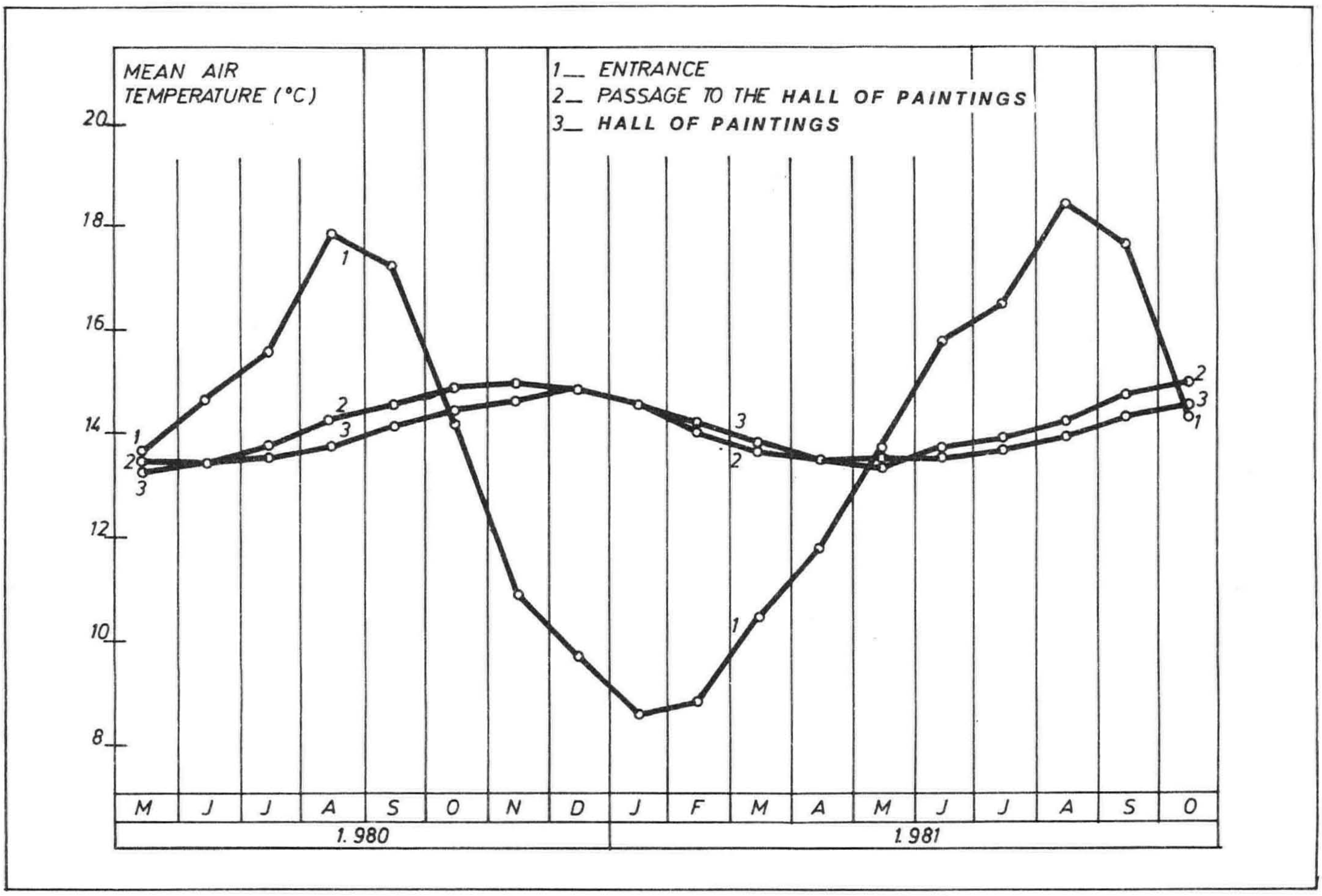

Fig.3. Monthly mean air temperatures in certain chambers of Altamira Cave.

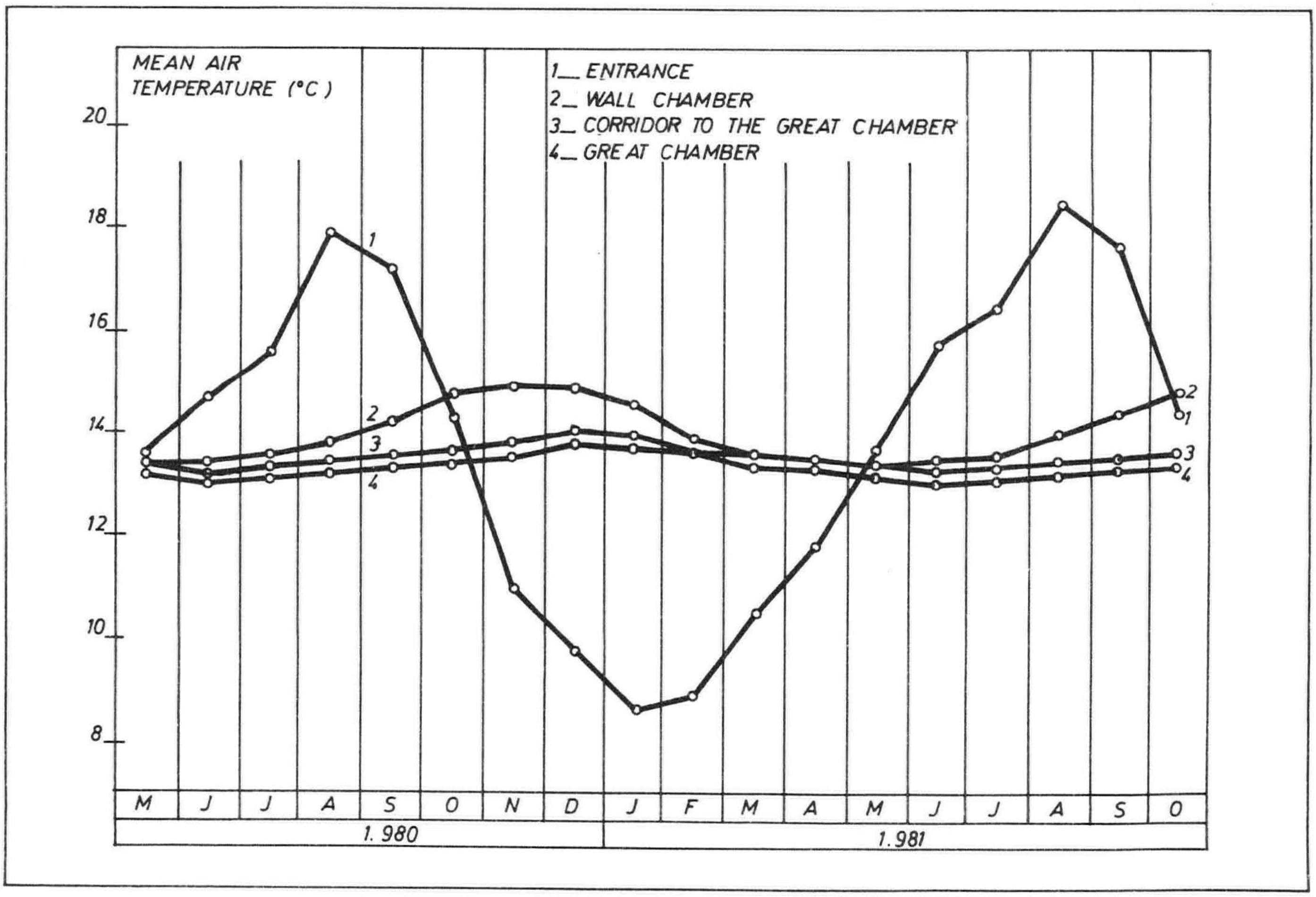

Fig.4. Monthly mean air temperatures in certain chambers of Altamira Cave.

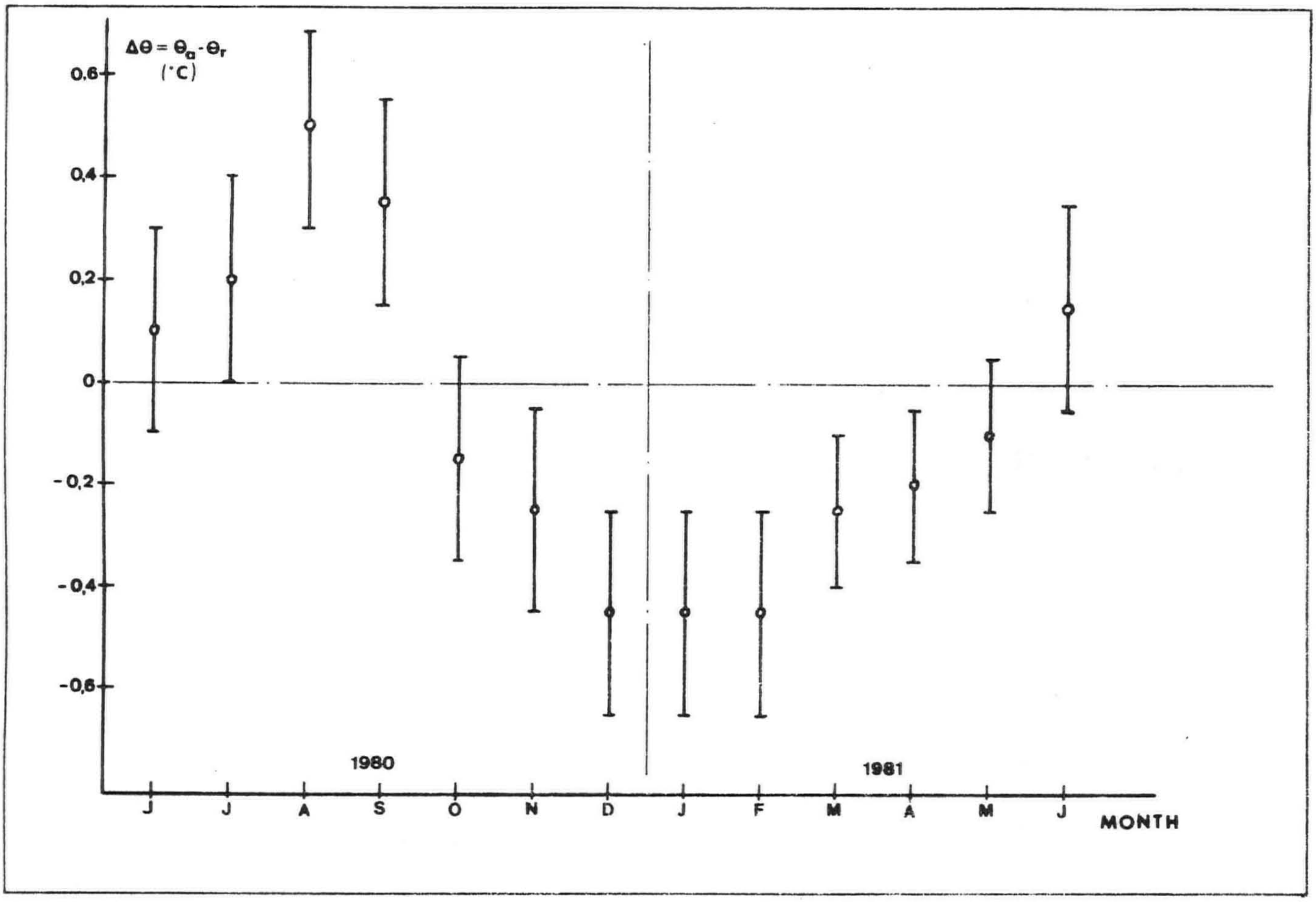

Fig.5. Annual variation of monthly mean temperature differences between the air and rock surface in the Hall Chamber.

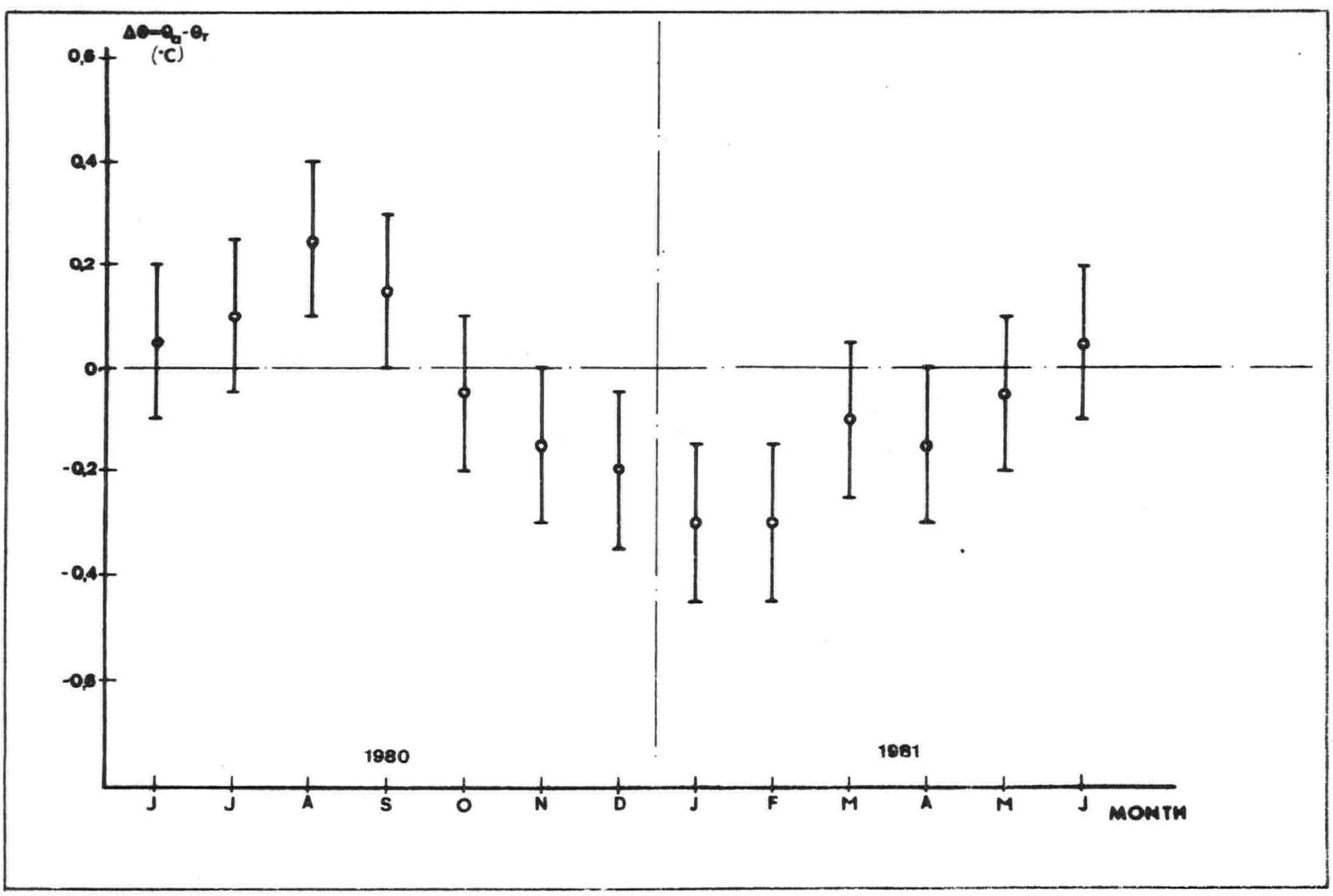

Fig.6. Annual variation of monthly mean temperature differences between the air and rock surface in the Hall of Paintings.

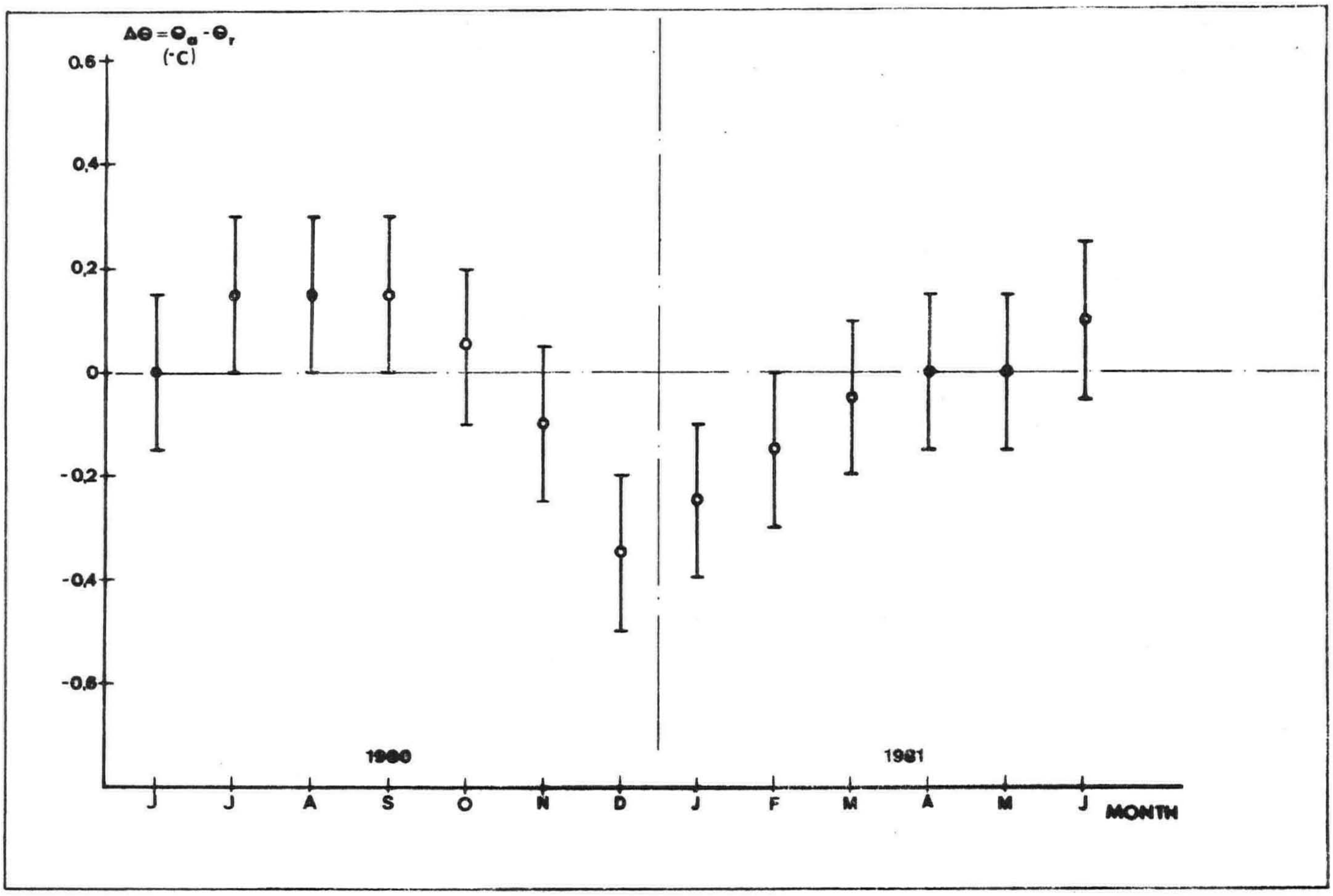

Fig.7. Annual variation of monthly mean temperature differences between the air and rock surface in the Wall Chamber,

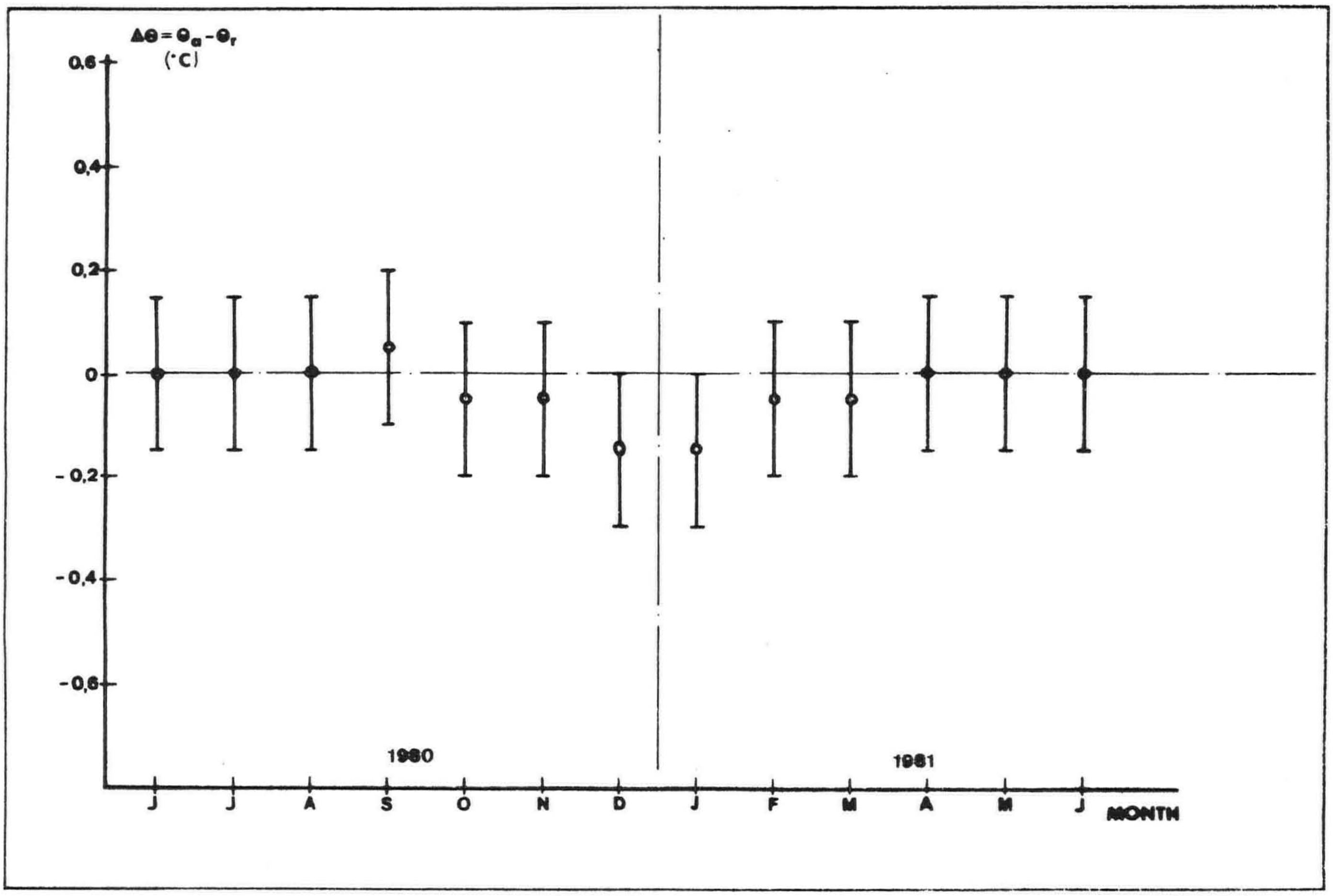

Fig.8. Annual variation of monthly mean temperature differences between the air and rock surface in the Great Chamber.

These predictions can be based on temperature differences between the different chambers and the exterior and can be corroborated, at least partially, by studying the differences between the rock and air temperatures in each chamber.

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AMBIENT TEMPERATURE VARIATIONS IN THE HALL OF PAINTINGS OF ALTAMIRA CAVE DUE TO THE PRESENCE OF VISITORS

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I. Gutierrez, L. S. Quindos, J. R. Solana and J. Soto.

Abstract

Measurements were taken over a period of one year of the temperature variations that occur in the Hall of Paintings at Altamira Cave due to the presence of visitors. A theoretical model has been developed that allows these temperature variations to be determined regardless of the number of visitors and the time they remain in the chamber. This model satisfactorily reproduces the experimental results.

INTRODUCTION

Although the Altamira Cave has aroused considerable archaeological interest since its discovery (Breuil and Obermaier, 1935), in recent years this interest has revolved around the conservation of its famous polychromatic paintings and their possible deterioration due to the massive influx of visitors to the Cave (Garcia and Enderiz, 1970; Cendrero et al, 1976; Villar, 1981; Villar et al, 1983 a and b).

Within this context, exhaustive studies have been made over the last few years of the microclimatic (Villar et al, 1982; Villar et al, 1983 c and d; Villar et al, 1984 a and b) and hydrogeological (Hoyos et al, 1984) characteristics of the Cave when visitors are not present, with the aim of first finding a natural basis of reference for the environment in which the paintings are located and then studying those variations introduced into this pattern by visitors.

In this present study, we analyse the results obtained from data taken over a measurement period of one year with respect to ambient temperature variations in the Hall of Paintings produced by the presence of groups of varying numbers of persons and compare them with those obtained from a theoretical model.

THEORETICAL DESCRIPTION

We shall assume that, due to his or her metabolism, a person produces a heat emission of about 82 (Marion, 1979) to 116 watts (Bartlett and Braun, 1983), without including the approximately 20 watts necessary to vaporize water in the lungs and the skin, since this contributes to increase the water vapour content in the air, but not its temperature. In the conditions that take place in the Hall of Paintings at Altamira Cave (moderate temperature, relative humidity near saturation, negligible air currents, etc.), we may consider that about 70% of the heat is emitted by radiation and some 30% by convection, including in this last term the heat necessary to increase the air temperature from the ambient one to about 37°C in the lungs.

This calorific energy is distributed more or less uniformly throughout the Hall of Paintings, which has a volume of 326 m^3 and which, since the communicating door between it and the access passage has an extremely small area in comparison with the total surface area of the chamber, may, for practical purposes, be taken to be an enclosed space that interchanges hardly any matter or energy with the outside during the periods that visitors remain within the chamber.

The heat that visitors emit through convection appreciably raises the air temperature within this space since the specific heat of humid air at ambient pressure is 1.71 $kJ.Kg^{-1}\,{}^{o}K^{-1}$ at 15°C (Raznjevic, 1970), which remains practically constant for the temperature intervals of interest. However, due to the presence of water vapour and carbon dioxide in the air of the chamber which absorb heat and emit it in the infrared band, part of the heat emitted by visitors through radiation is also used to raise the air temperature, while the rest is absorbed by the walls of the chamber, which behave, to all intents and purposes, as a black body. Nevertheless, given the high heat capacity of the rock, the temperature of the latter shows practically no change when the number of people making up a group of visitors is not too high. Furthermore, the increase in the enthalpy of the air, when the air temperature is raised, is dissipated on the surface of the chamber through convection and radiation. Thus, it follows that the convection and radiation phenomena of the air in the chamber will play an extremely important role with respect to the dissipation of the heat generated by visitors and the recovery time after visits and, for this reason, they are studied in somewhat greater detail below.

NATURAL CONVECTION

Given the small temperature gradients involved, natural convection (convection in its strict sense, plus conduction), occurs as a laminar flow.

The amount of heat transferred between the air and the walls of the chamber through natural convection and over a given time unit is supplied by the following equation (Mc Adams, 1964):

$$\frac{dq}{dt} = K\left(\frac{\Delta\theta}{L}\right)^{0.25} . A . \Delta\theta \qquad (1)$$

where $\Delta\theta$ is the temperature difference between the surface of the rock and the air, L is the characteristic dimension (height for vertical surfaces, length of one side for square horizontal surfaces) and A is the area of contact. On the other hand, if $\Delta\theta$ is expressed in ^oC, A in m^2 and dq/dt in watts, coefficient K has a value of 1.47 watts.$m^{-7/4}$ $^oC^{-5/4}$ for vertical surfaces, 1.37 watts.$m^{-7/4}$$^oC^{-5/4}$ for ceiling and 0.610 watts.$m^{-7/4}$$^oC^{-5/4}$ for the floor. It will be observed that equation (1) is not greatly affected by the geometrical form, since the characteristic dimension is raised to the power of 0.25, as a result of which the Hall of Paintings, despite its irregular shape, may, for practical purposes, be substituted by a parallelepiped with an equivalent rectangularly-shaped surface area and the same volume.

ABSORPTION AND EMISSION THROUGH RADIATION

We have already pointed out that the presence of water vapour and carbon dioxide in the air means that the latter absorbs heat and emits it in the infrared band. The heat emission through radiation of a gas per time unit is supplied by the following equation (Mc Adams, 1964):

$$\frac{1}{A}\frac{dq}{dt} = \sigma\left[\varepsilon_G\,(4 + a + b - c)/4\right]\,(T_G^4 - T_P^4) \qquad (2)$$

where σ is the Stefan-Boltzmann's constant, ε_G is the emissive power of the gas, T_G its absolute temperature and T_P the average absolute temperature of the walls.

Likewise, a, b and c are parameters that depend on the type of emitting gas and the characteristics of the system; in the case that concerns us here, they should be obtained as a weighted average of the values corresponding to the two emitting gases involved.

In the particular case of the Hall of Paintings of Altamira Cave, the value of c, obtained as a weighted average of the values corresponding to water vapour and carbon dioxide is 0.50. Similarly, the values of a and b were obtained from the graphs contained in Mc Adams bibliography (1964). This procedure is rather imprecise but this is not too important since expression (2) is not too sensitive to variations in a and b, even when these have relatively high values. Thus, the average weighted values of a and b prove to be 0.42 and - 0.31 respectively. Equally, the values of ε_G can also be obtained from the graphs, in accordance with the temperature and pressure of the gas and the geometrical characteristics of the chamber. The value obtained in this way for the mixture of water vapour and carbon dioxide to be found in the Hall of Paintings proved to be 0.22. In fact, the values for ε_G depend, as noted above, on the partial pressure of the gas and its temperature; however, within the fluctuations of these two variables normally observed inside the Hall of Paintings, these variations of ε_G are extremely small, ranging between 0.21 and 0.23. Onthe other hand, since these gases are simultaneously present in the air of the chamber, the total emissive power drops slightly since each gas partially absorbs some of the radiation emitted by the other. Nevertheless, in the temperature and pressure conditions that concern us here, the necessary correction is absolutely negligible sinceit affects only the third decimal place. We have therefore taken the average value to be as follows: $\varepsilon_G = 0.22$, which, for practical purposes, we can assume to be constant.

TEMPERATURE VARIATIONS

We have already mentioned that some of the heat emitted by visitors is used to increase the enthalpy of the air, while some is radiated directly onto the walls of the chamber. At the same time, the excess enthalpy of the air is dissipated on the walls through both convection and radiation. Initially, the balance between the production and loss of calorific energy during visiting periods favours production, as a result of which a rise in temperature occurs, although if the visit is sufficiently prolonged, an equilibrium must finally be reached between production and loss, the average temperature then remaining constant. At each moment, the equation for the energy balance may be expressed as follows:

$$mc_P\frac{dT}{dt} = n\frac{dH}{dt} - \frac{KA}{L^{0.25}}(T_G - T_P)^{1.25} + A\,\sigma\,\varepsilon_G(4 + a + b - c)\,T_P^3\,(T_G - T_P) \qquad (3)$$

where m is the air mass and c_p is the specific heat, n the number of visitors and dH/dt the increase in the enthalpy of the air per time unit due to the presence of one visitor; the remaining quantities have been defined above. On the other hand, the term $T_G^4 - T_P^4$ has been has been substituted by $4T_P^3\,(T_G - T_P)$ due to the small temperature gradient involved.

To determine the equilibrium temperature, it is sufficient to set the left-hand side of equation (3) to zero and determine the corresponding value of T_G. In practice, the duration of visits is not, as a rule, sufficient to allow this equilibrium to be reached. To determine the air temperature at any moment during the course of a visit, equation (3) has to be solved numerically.

Simiarly, to evaluate the temperature at any time after a visit has taken place, one has

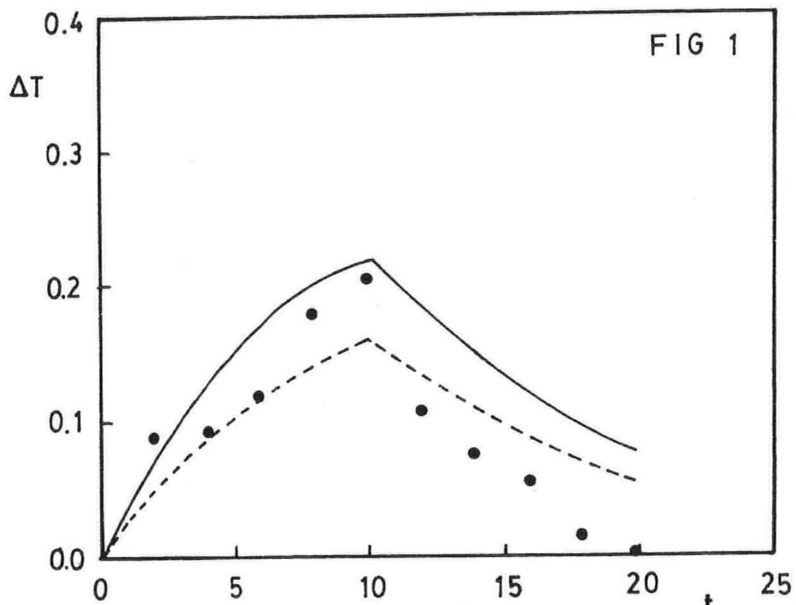

Fig.1. Variations of temperature differences between air and wall, ΔT in ^{o}C, as a function of the time t, in minutes, during a visit of a group of 5 with a guide.

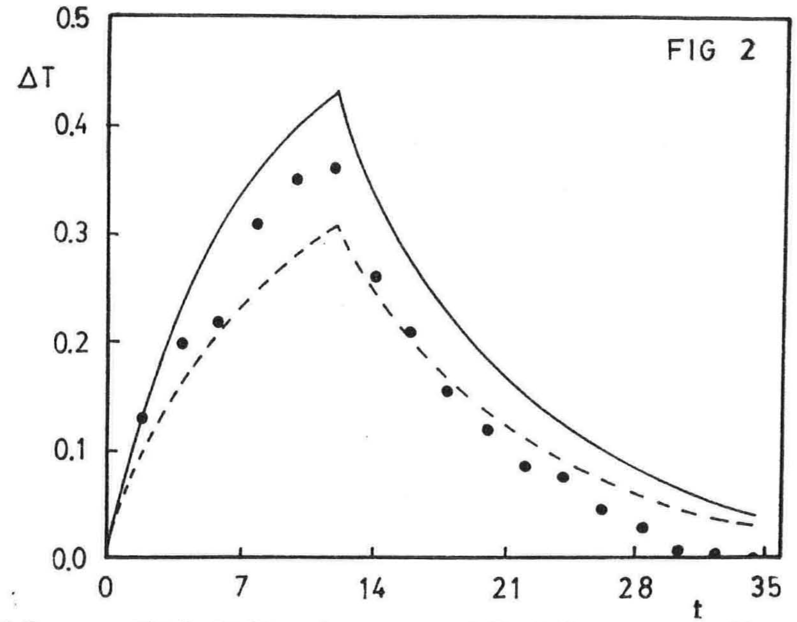

Fig.2. As Fig.1 for a group of 10 visitors with a guide

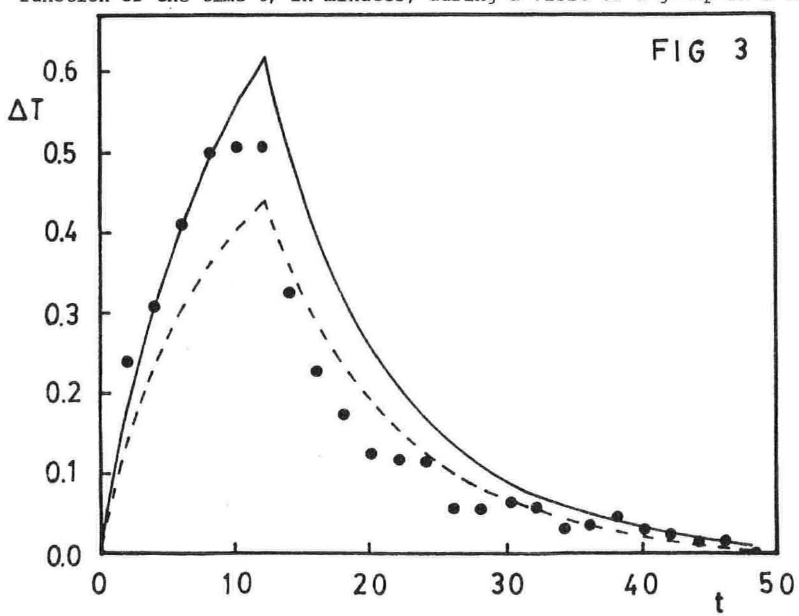

Fig.3. As Fig.1 for a group of 15 visitors with a guide

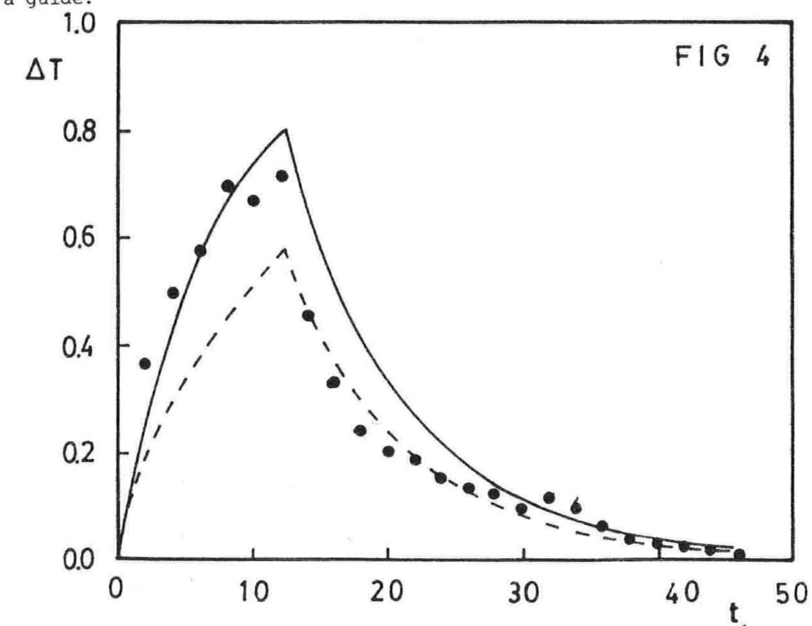

Fig.4. As Fig.1 for a group of 20 visitors with a guide

Continuous line: theoretical curve assuming that a human body emits 116 watts
Discontinuous line: curve assuming that it emits 82 watts
Points: experimental results.

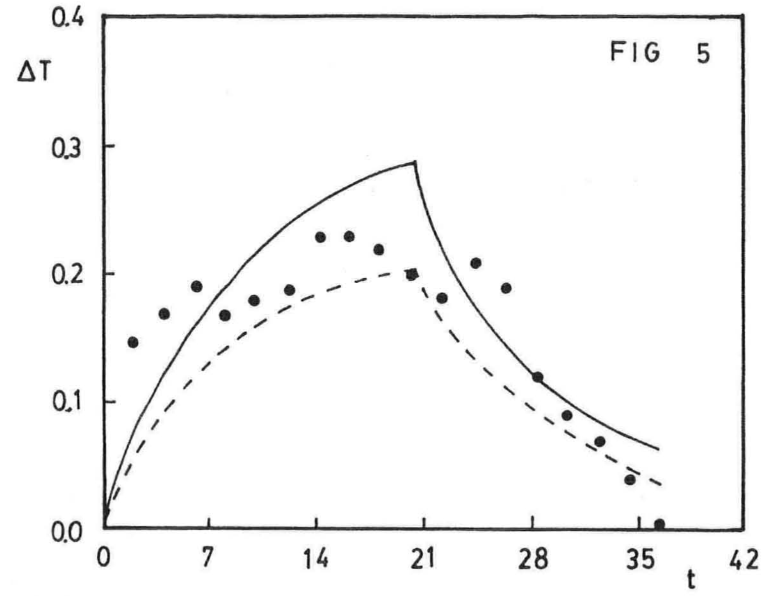

Fig.5. As Fig.1 for two consecutive groups of 5 visitors with a guide

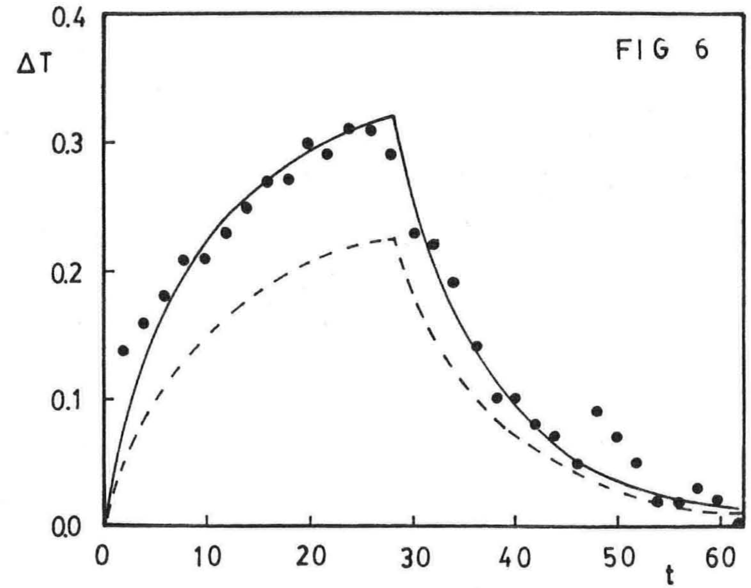

Fig.6. As Fig.1 for three consecutive groups of 5 visitors with a guide

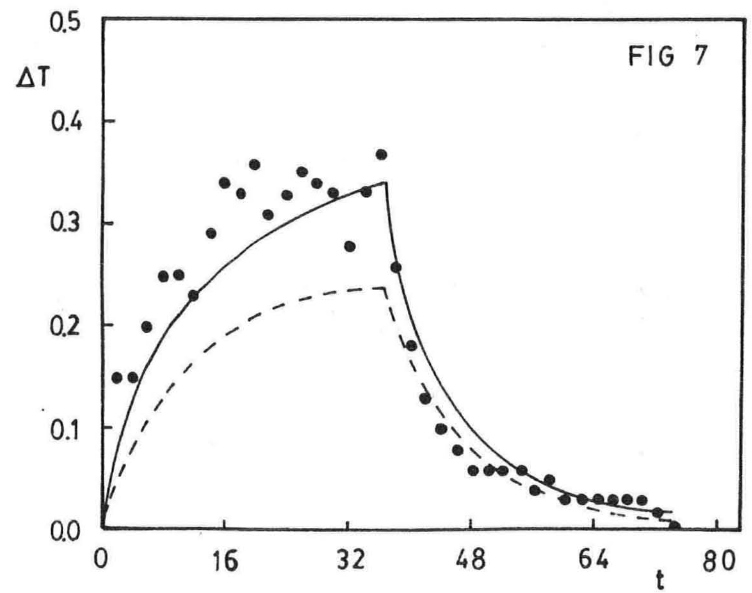

Fig.7. As Fig.1. for four consecutive groups of 5 visitors with a guide

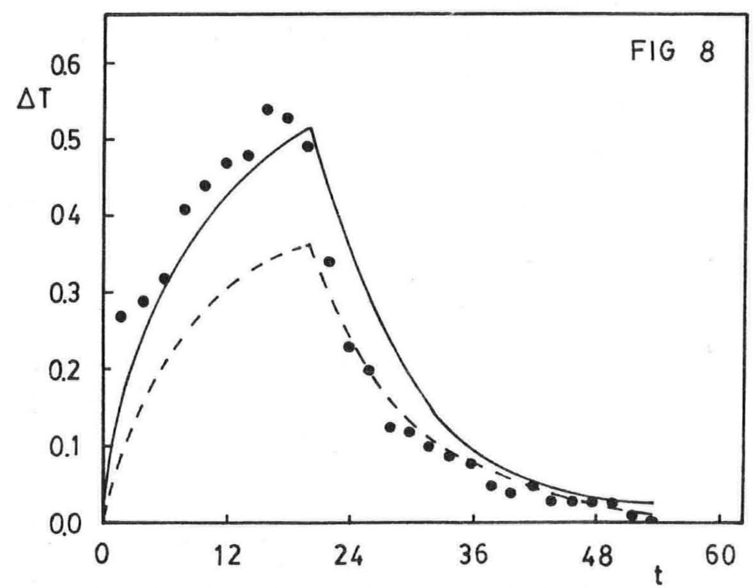

Fig.8. As Fig.1 for 2 consecutive groups of 10 visitors with a guide

Continuous line: theoretical curve assuming that a human body emits 116 watts
Discontinuous line: curve assuming that it emits 82 watts
Points: experimental results

to make the first term of the second member of equation (3) equal to zero and integrate. The result is as follows:

$$t = \left(\frac{4mc_p}{CT_p^3}\right)\left[\ln\left(\frac{\Delta T}{\Delta T_{max}}\right)^{0.25} - \ln\left(\frac{B\ (\Delta T)^{0.25} + CT_p}{B\ (\Delta T_{max})^{0.25} + T_p^3}\right)\right] \quad (4)$$

where $B = K.A/L^{0.25}$, $C = A_c(4 + a + b - c)$; t is the time elapsed since the end of the visit, T_{max} is the increase in temperature at the end of the visit and T is the remaining increase in temperature at moment t. The remaining magnitudes have already been defined above.

The time required for the air temperature to return to its former level prior to a visit is obtained from equation (4) by merely making $T = 0$. However, if this condition is applied, the time would be infinite and, for this reason, we make $T = 0.1°C$ since this is the experimental measurement error.

EXPERIMENTAL RESULTS AND DISCUSSION

Temperature variations in the Hall of Paintings due to the presence of visitors were measured by means of a series of thermocouples located at different points and levels. Measurements were taken every two minutes using a data logger during and after visits until the temperatures returned to their initial levels prior to the entrance of visitors. These data were used to determine the average temperature as a function of time from the commencement of a visit until such time as the temperature returned to its initial level after the end of the visit, this moment being defined as the point when all the probes begin to systematically record the temperature that prevailed before the visit.

The measurements were taken throughout the course of one year, with many groups of visitors, consisting of a variable number of persons, of which the most interesting are: groups of 5 visitors (between one and four consecutive groups). groups of 10 (one or two consecutive groups), groups of 15 and groups of 20. in addition, each group was accompanied by a guide.

Figs. 1 to 8 show the curves for variations in the average temperature of the air in the Hall of Paintings during visits (ascending curve) and after visits (descending curve), for the different types of groups and it will be observed that, as a rule, the agreement between the theoretical and experimental results is very satisfactory. On the ascending curve, the experimental points generally coincide very well with the curve corresponding to an emission of 116 watts per person. Nevertheless on the downward curve, the experimental points frequently lie below this theoretical curve. This is because the visitors have a tendency to concentrate in certain places of special interest to tourists, thereby producing local temperature increases well above the average. Consequently, the heat is not distributed uniformly as predicted by the theory and, at the end of the visits, the warm areas lose their heat through convection and radiation more quickly with the result that, overall, the average temperature falls more rapidly than forecast by the theory. This fact is particularly notable in the case of small groups, as is natural, since, when large groups of persons are concerned, their increased size causes the heat to be distributed more uniformly.

It will also be noted that consecutive groups with a small number of visitors (Figs. 5 to 8) cause an increase in the air temperature considerably less than a single group with the same number of visitors (Figs. 2 to 4). Notable variations in ambient temperature may cause appreciable variations in rock temperature (as has been experimentally verified by means of radiation thermometer measurements). These, together with surface moisture variations, may lead to contraction and expansion of painted surfaces with resultant loosening of the surface layers and consequent risk of damage to the paintings (Cendrero et al, 1976). Thus for a given number of visitors, consecutive groups with small numbers should be preferred instead of larger groups more spaced in time, in order to ensure a better conservation of polychromed surfaces.

In summary, the temperature variations that take place in the Hall of Paintings of Altamira Cave due to the presence of visitors can be accurately described by means of the theoretical model used, which can be applied to all formats of visits. It is concluded that ambient thermal variations in the chamber are fundamentally determined by convection and radiation processes, the latter being the most important in quantitative terms, while a preponderant role is played by the presence of carbon dioxide and water vapour in appreciable concentrations in the air of the chamber, which, due to its form, is thermally very sensitive to the presence of visitors.

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LIMESTONE AND VOLCANIC CAVES OF THE FIJI ISLANDS

by the late Tim Gilbert
(contributed by Mrs J.Gilbert)

Abstract

The small limestone areas in the Fiji Islands contain many caves, one with a surveyed length of 1500m. There are lava caves in the south of Taveuni Island, the most extensive being 920 m long.

GEOGRAPHY

The Fiji Group is an archipelago of 320 islands, situated in the South Pacific Ocean about 1800 km north of New Zealand (Fig. 1). The larger islands are rugged and hilly, rising to 1200 m in places, with minimal coastal lowland strips. The population of 647,000 people consists mainly of native Fijian islanders and fourth generation Indian immigrants. These friendly people live in towns and villages on the coast, and along the main river valleys.

The climate is mild and equable, the normal temperature range being 16 - 32°C. The S.E. tradewinds bring a rainfall of about 3000 mm per year to the windward areas of the three largest islands. These have a natural covering of tropical rainforest. The smaller islands, and also the leeward sides of the larger islands, have a rainfall of 1800 mm per year. The natural vegetation is normally tropical grasslands, although limestone areas are densely forested.

Viti Levu Island is circuited by coastal roads: Queens Road around the south and west coasts, and Kings Road around the north and east coasts. A few roads penetrate inland, along the main river valleys. Away from these roads, travel is on foot, with a guide. There are no roads in the central highland area, some 3000 km^2. Travel to the other inhabited islands is by the small inter-island trading vessels. There are also regular flights to Vanua Levu, Taveuni, and Lakeba Islands.

Viti Levu Island has a wide range of rock types, plutonic, volcanic, sedimentary, and metamorphic. Many of the sedimentary and fragmental volcanic sequences have interbedded limestone units, which commonly contain coral. The islands of the Lau Group are mainly single volcanoes, most of them with overlying limestone. Some islands, mainly in the south of the group, are wholly limestone, the presumed volcanic edifice below not yet exposed by erosion. Vanua Levu, and most of the other islands of Fiji, are mainly volcanic and limestone is rare.

CAVE EXPLORATION

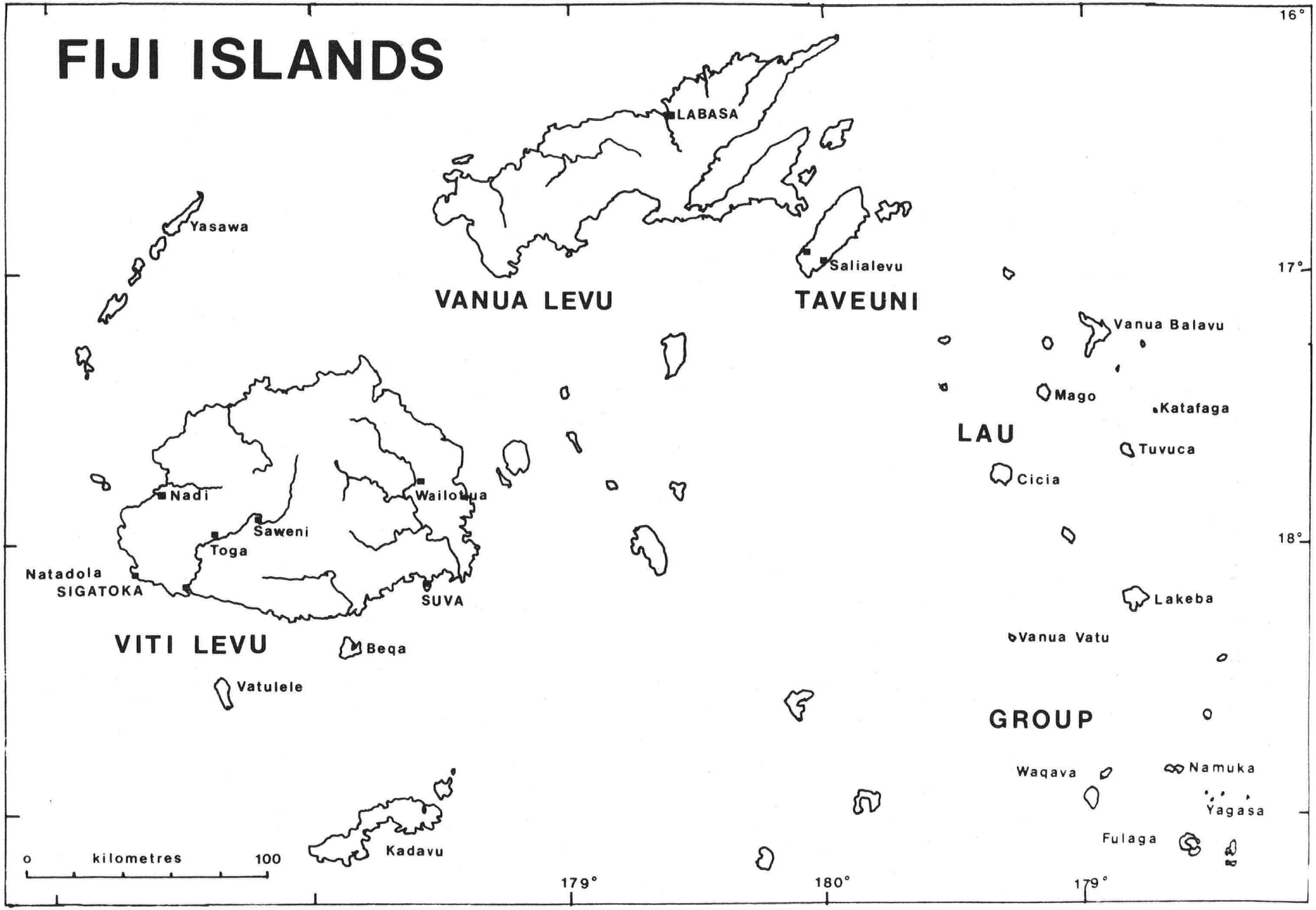
The small scattered limestone outcrops of the main island, Viti Levu, contain a surprisingly large number of caves. The entrances are often in uncultivated land belonging to a nearby Fijian village. Most of the caves described have been systematically explored and surveyed by the author (now deceased) while he was resident in Suva between 1969 and 1973. Some caves were explored solo, and some had probably not been entered before, i.e. Udit Cave and Quaia Cave. On one occasion the author, accompanied by an Indian student, spent three days in the bush whilst exploring a remote limestone area in Eastern Vitu Levu, sleeping in a cave at night. The only other recorded cave explorations in Viti Levu are those of caves in the Sigatoka Valley by Watling and Pernetta (1977), Sawyer and Andrews (1901) and Rodda, a resident geologist. Fijian villagers are frequently unwilling to enter caves, because of their traditional beliefs.

The account of caves in the Lau Group of Islands is extracted from descriptions of incomplete explorations by Sawyer and Andrews (1901) and Ladd and Hoffmeister (1945). There may be undiscovered volcanic caves in the uninhabited S.E. side of Taveuni Island, in addition to those in southern Taveuni, which are described for the first time in this article.

CAVE BIOLOGY

Caves provide protection and food for a variety of creatures. Most noticeable to the nose as well as to the eye are the bats. Nearly every cave described contains small insectivorous bats (the Sheath Tailed Bat, *Emballanura semicaudata)*. The large fruit bats do not live in caves, unlike the smaller Long Tailed Fruit Bat, *Notopteris macdonaldi*, at Saweni Cave. Guano is thick on the floor of many caves and makes a good fertiliser.

A small bird, the White Rumped Swiftlet (*Collocallia spodiopygia)* uses a similar echo-sounding method to bats to find its way about in the dark. It builds its nests on the cave walls, and is reputed to alight nowhere else. Spiders and cockroaches are found on the walls. Spiders found 70 m beyond the entrance in Saweni Cave, Viti Levu Lisland, have been identified as members of the genus *Loxosceles* . This genus is known to be indigenous to the African and American tropics (Watling and Pernetta, 1977). In the streams, prawns, crabs and eels are easily visible. The caves in Namuka-i-Lau and Vatulele Islands are famous for their red prawns. Many animals are only temporary and involuntary cave dwellers. Toads, for instance, are often washed in by floods.



FIJI ISLANDS
LABASA
Yasawa
Salialevu
VANUA LEVU
TAVEUNI
Vanua Balavu
Mago
Katafaga
LAU
Tuvuca
Cicia
Nadi
Wailotua
Saweni
Toga
Natadola
SIGATOKA
SUVA
VITI LEVU
Beqa
Lakeba
Vanua Vatu
Vatulele
GROUP
Waqava
Namuka
Yagasa
Fulaga
Kadavu
0
kilometres
100
179°
180°
179°
16°
17°
18°

FIGURE 1

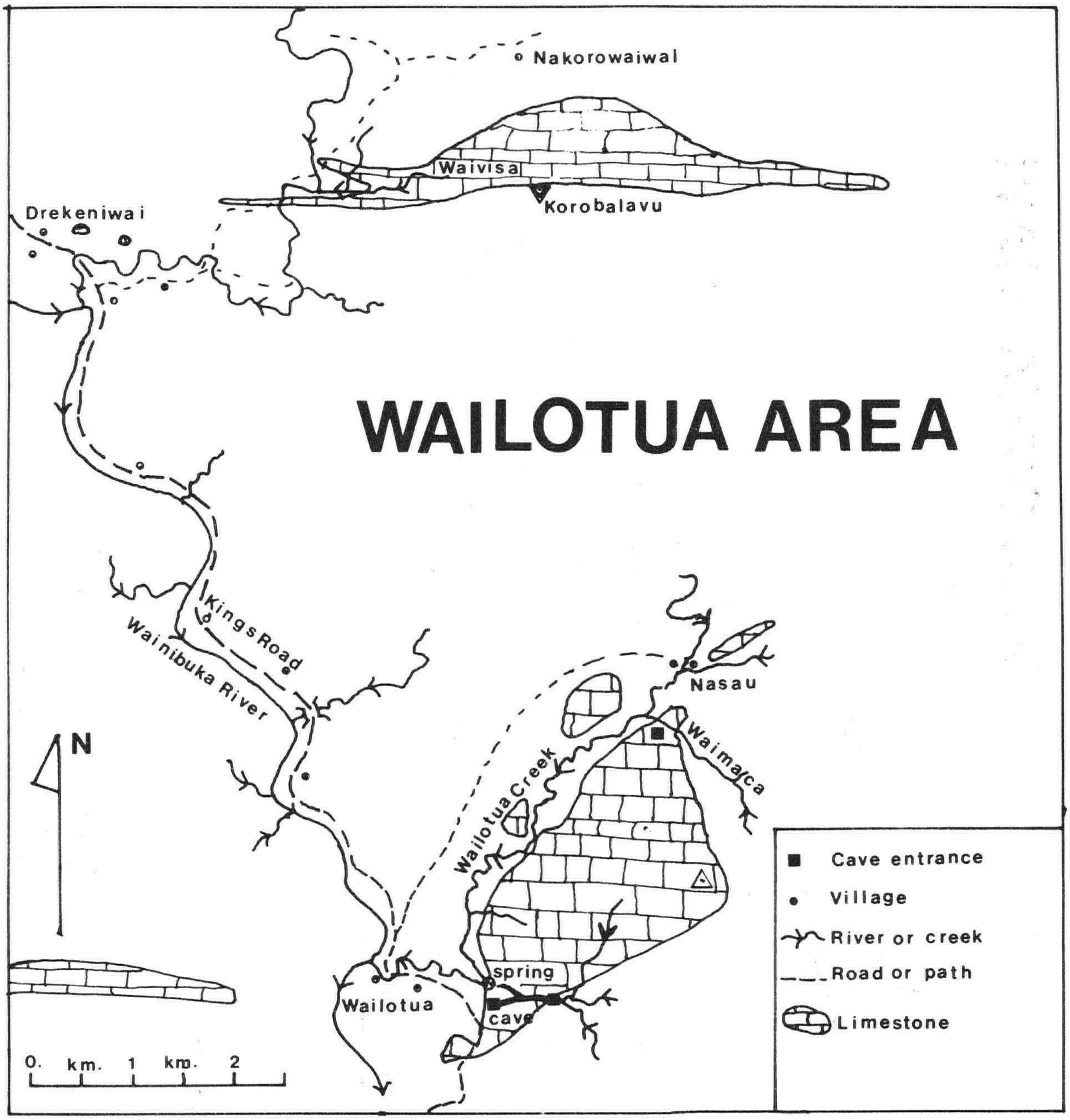


FIGURE 2

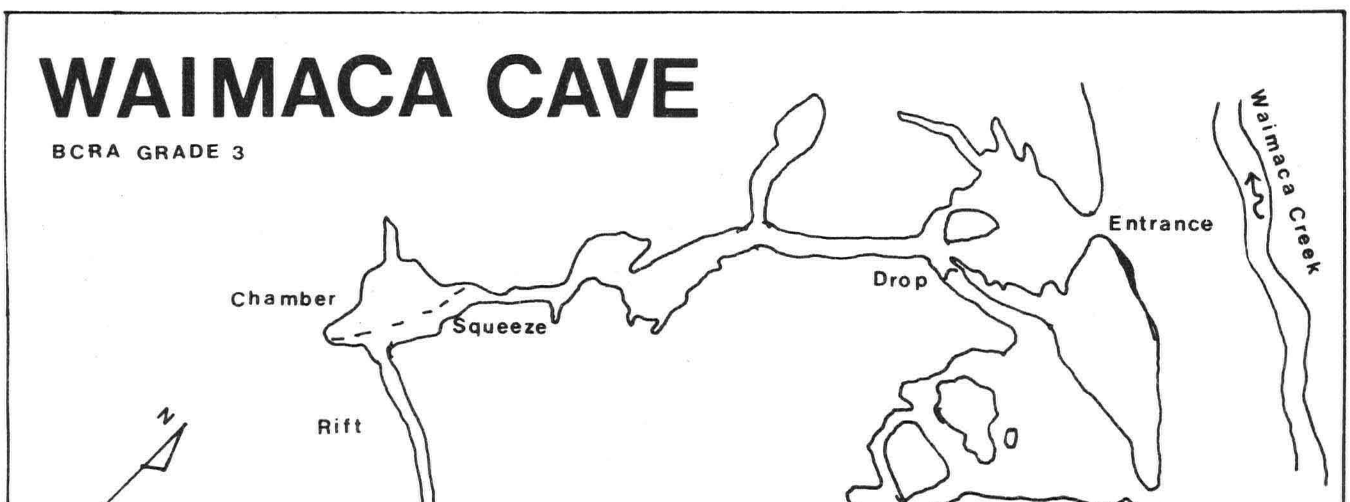
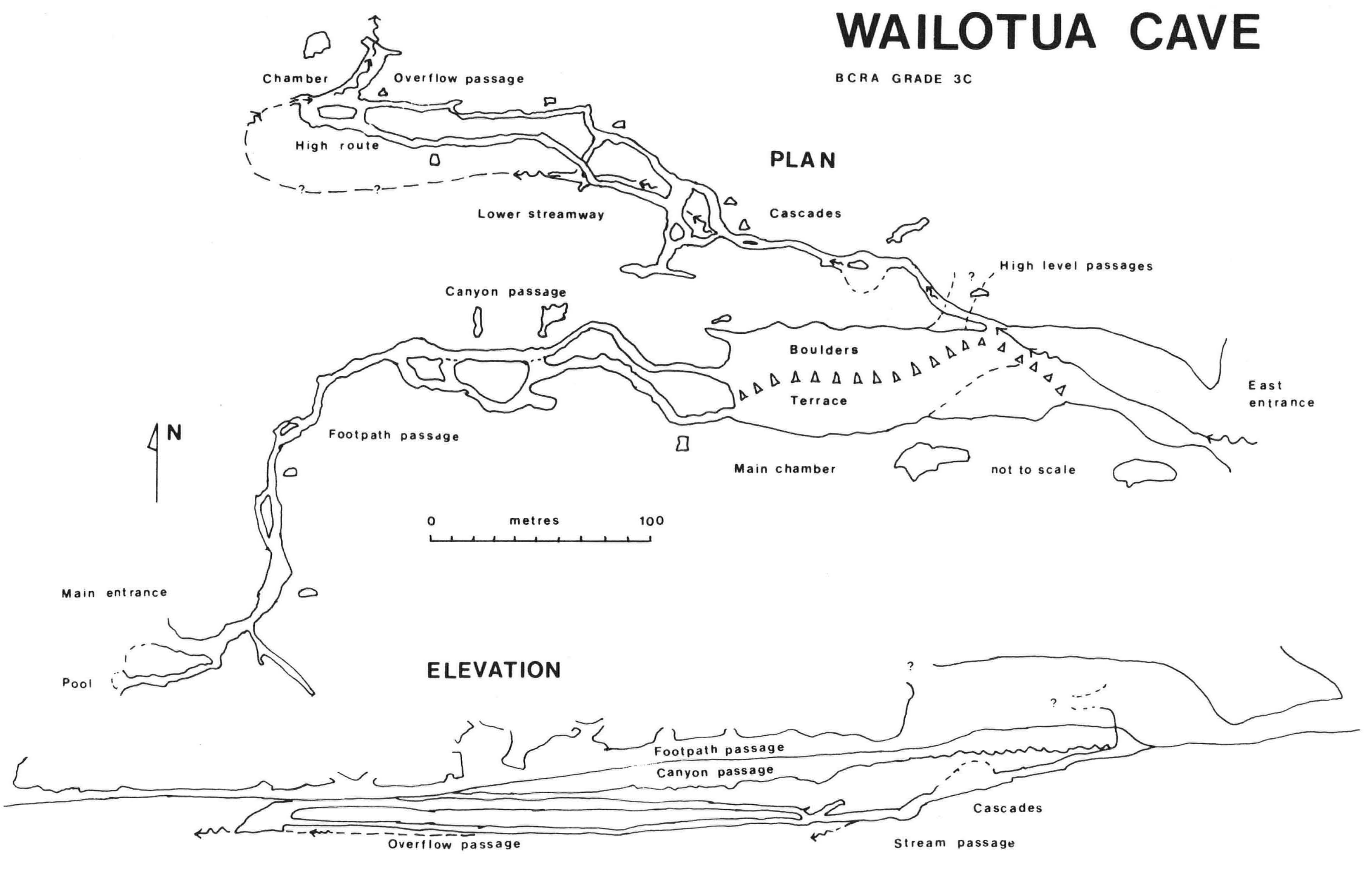


FIGURE 3



WAILOTUA CAVE
BCRA GRADE 3C
PLAN
Chamber
Overflow passage
High route
Lower streamway
Cascades
High level passages
Canyon passage
Boulders
Terrace
East
entrance
N
Footpath passage
Main chamber
not to scale
0
metres
100
Main entrance
Pool
ELEVATION
Footpath passage
Canyon passage
Cascades
Overflow passage
Stream passage

FIGURE 4

It is not known if any solely cave-dwelling species live in Fiji, but there are reports of cave adaptations. Prawns of a new species and genus (*Mesocaris lauensis*), with modified eyestalks and ocular pigment reduced, are recorded from Waqava Island in the Lau Group (Edmonson, 1935). White spiders are reported from Volivoli Cave in Viti Levu (Sawyer and Andrews, 1901).

CAVES OF WESTERN AND NORTHERN VITI LEVU AND ADJACENT ISLANDS

a) Western and Northern Viti Levu.

There is very little limestone in this area; what there is occurs mostly as thin elongate lenses. The patches of limestone southeast of Nadi, of Eocene and possibly Oligocene age, are the oldest fossiliferous rocks known in Fiji. Bartholomew (1960) stated that "Caves and natural arches occur at a number of localities.... There are a few sink holes in places but generally these are small; however, there is almost a "classic" example in the limestone beside the track leading to Koromba summit". (17 km southeast of Nadi). Bartholomew's Plate VI shows a cave in the mass of limestone 3 km southeast of Lolobalavu trigonometrical point (Nadi).

b) Yasawa Islands.

There is a well-known cave on Sawa-i-Lau, an island just off the southern coast of Yasawa. The cave, which is regularly visited by tourists, can be entered in two ways; from the top, by walking around the cliff-face, or by diving through a submerged opening at sea level. The light from this opening is visible inside the main chamber. There are some "paintings" on the wall which have not been satisfactorily interpreted. Derrick (1965) reported a legend about a young chief who regularly dived through with food for his illicit betrothed, who was hiding inside.

CAVES OF EASTERN VITI LEVU

There are some small scattered outcrops of limestone in the area around Wailotua Village in Eastern Viti Levu (Fig. 2). The terrain is hilly and densely forested, travel is difficult away from the roads. Caves near the villages of Wailotua, Nasau, Drekeniwai, and Nakorowaiwai were explored. The more remote limestone outcrops were not visited. In relation to Wailotua Village these are situated at: 2 km west : 15 km west at Korosuli Village and 9 km east-north-east.

a) Nakorowaiwai.

The area near the abandoned village of Nakorowaiwai is typical jagged and densely forested limestone country. It is essential to get a guide. At one point the Waivisa Creek (Fig. 2) flows through a large tunnel about 30 m long. A few metres downstream from the tunnel a tributary enters Waivisa on the left. This leads after about 100 m to a cave entrance. This can be penetrated for about 60 m to the foot of an underground waterfall about 20 m high, with sheer walls and a strong draught. Upstream of the tunnel in Waivisa Creek there is a short high cave, beyond which the source of the stream is revealed - a circular pool about 20 m in diameter surrounded by wooded slopes.

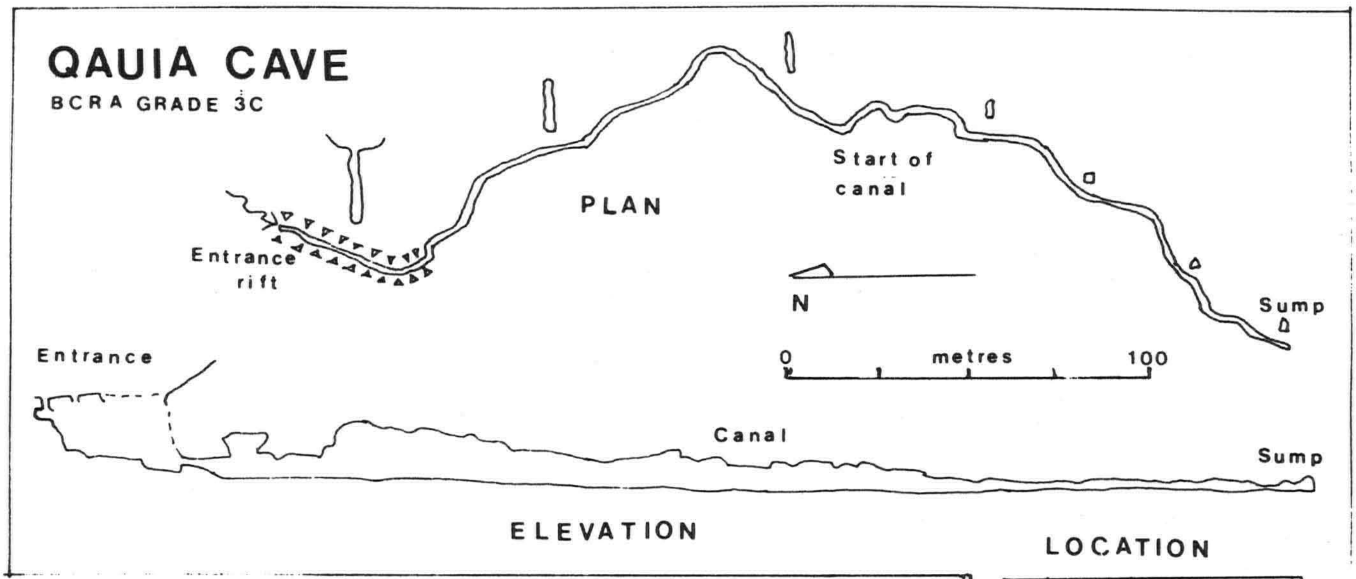
In the main valley above the pool, there are a number of depressions in the alluvial floor, some with small streams flowing along the bottom. East of Korobalavu Peak and near a manganese deposit, is an impressive rift in the face of a cliff. At one point access can be gained to about 100 m of small cave passage with a small impenetrable stream. Further along the surface, a rope is necessary to descend to a chamber. From the chamber a number of holes in the floor drop down into a narrow rift with a stream. Possibly the stream is the one emerging in the waterfall described earlier, near Waivisa.

These are the only caves so far entered, in this area, but the villagers have reported many others.

b) Wailotua.

The cave entrance (Fig. 4) is situated next to Wailotua Village Number 1, about 15 km west of Korovou (Tailevu) on Kings Road. The villagers will take visitors to the main chamber for a charge. The approach is decorated with ginger plants, and there is a path from the main entrance to the main chamber. There is a dry mud floor but it is clear that at one time water used to flow through these passages. The canyon passage is at a lower level, its height varies between 3 m and 15 m. There are some flowstone formations in the entrance passages. The footpath leads to the vast main chamber, where fires are sometimes lit in the centre of the flat terrace. Below the terrace, which is floored with hard mud, the chamber floor is a jumble of large boulders. Beyond the chamber lies the eastern entrance, where a stream flows into the cave.

There are some high level passages leading off the main chamber, but these could not be surveyed because the bamboo ladder leading to them was dangerously rotten. The main stream flows into a passage in the side of the main chamber, down an exciting series of cascades and waterfalls. The deepest is about 6 m, and no ropes are needed by an agile person. The stream disappears under the passage wall, and beyond this the passage is dry, though it evidently acts as an overflow in flood conditions because there are fresh gravel banks, waterworn rocks, and sticks in the roof. The dry passage continues, mostly just sufficiently high and wide to walk through, and opens dramatically into the wall of a large chamber. A mud slope leads down to a stream, which disappears under the rock at the far end. It is presumed to re-emerge 100 m away at the same level, at some springs at the sharp bend in Wailotua Creek (Fig. 2), where some water flows through a pile of boulders on the river bank, and cold water can be felt welling up from the river bed. There is also part of the lower streamway accessible, and a high level parallel route.



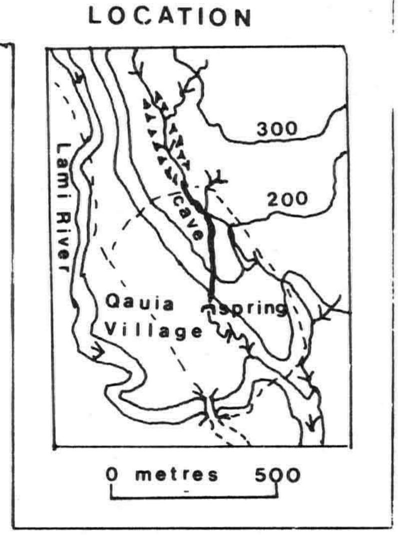


FIGURE 5

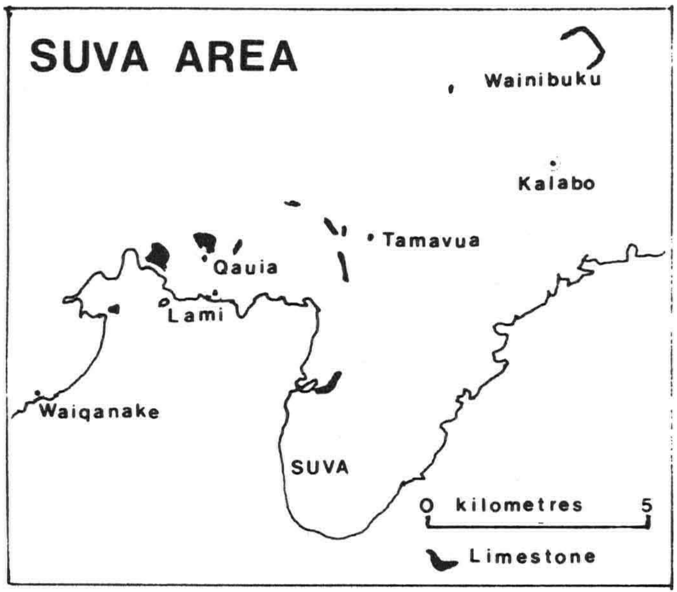


FIGURE 6

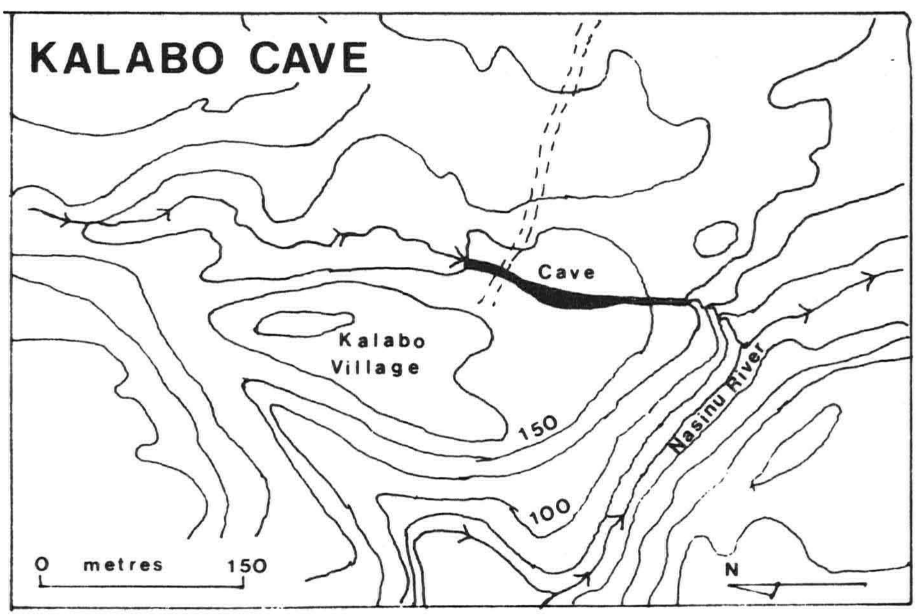


FIGURE 7

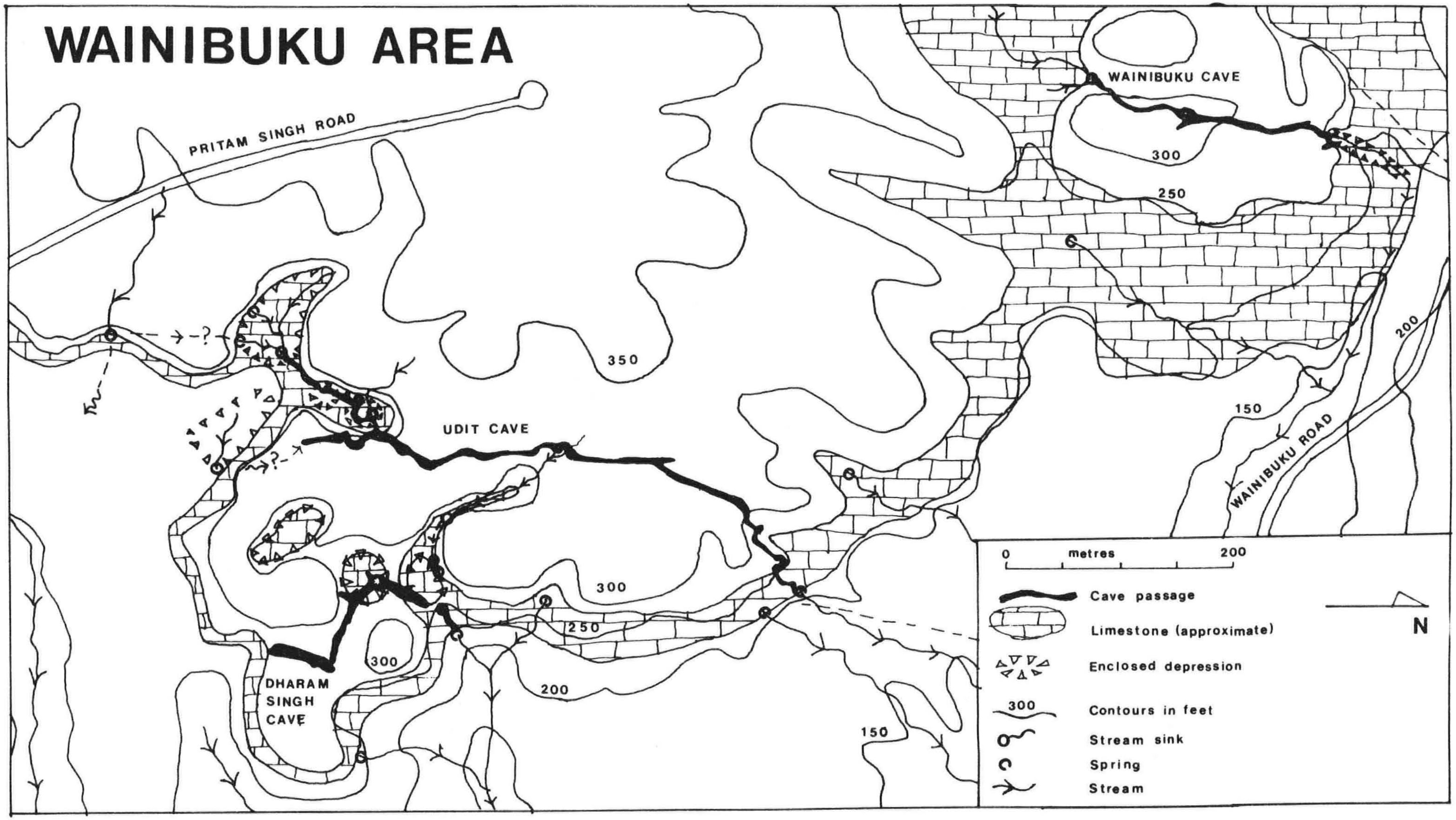

WAINIBUKU AREA
PRITAM SINGH ROAD
WAINIBUKU CAVE
UDIT CAVE
DHARAM
SINGH
CAVE
WAINIBUKU ROAD
350
300
250
200
150
0
metres
200
N
Cave passage
Limestone (approximate)
Enclosed depression
Contours in feet
Stream sink
Spring
Stream

FIGURE 8

There is potential for further exploration in this cave. Surveyed length - about 1500 m (the longest in Fiji).

c) Nasau.

The area of limestone in which Wailotua Cave is formed extends 8 km eastwards, and contains several other caves. Two were visited at Nasau Village (Fig. 3). These two caves (found to be linked inside) appear to be old springs. The water table has dropped below the level of the caves, and below the stream bed they face onto (Waimaca means "dry stream"). It is clear that water rises considerably in the caves in rainy conditions, but there is no stream course in them. The entrance chambers have much guano on the floor. The fluted columns around the entrance are impressive. Near the end of the caves, a tight squeeze gives access to a Rift Passage, containing many stalactite columns. Length 100 m.

CAVES OF SOUTH EASTERN VITI LEVU

Within a 15 km radius of Suva, the capital of the Fiji Islands, there are a number of very small areas of exposed limestone (Fig. 6). This is a thin band of reef limestone which occurs in the Suva Marl Series. Most of the land in the area is either cultivated or built-on. There are caves over 300 m long near Quaia Village, and near Wainibuku Creek, in addition to the many smaller caves in the area.

d) Quaia.

A stream runs onto the Lami limestone about 2 km north of the cave entrance passing through several short shallow caves. It then cuts a deep trench and goes permanently underground (Fig. 5). It is clear that the stream once flowed on the surface, at the level which now forms the top of the entrance rift. A 10 m ladder is needed to descend the rift, and beyond is a series of pools and cascades (Plate 1). Shafts of daylight are still visible, coming from the surface and casting complex shadows over the sheer walls of the rift. Beyond the daylight zone, the stream follows a level meandering rift passage, decorated with some calcite formations. Further on, the water is deeper and swimming is necessary. The cave ends in a sump with a small muddy chamber above it. The water resurges at a row of small springs at the base of the ridge behind Quaia Village (Fig. 5). According to the survey, the sump at the end of the cave comes very close to one of the springs. It may be possible to create a bottom entrance by digging. The cave, 365 m long, is formed along a fault line.

e) Other Caves in Lami and Suva.

1) A small cave occurs on Cave Island Only 15 m long, it zigzags from side to side.

2) Two small caves occur on the shore at Lami.

3) There is a small cave off Edinburgh Drive in Suva, near the CWM Hospital.

4) Nauluvatu; a cave at least 50 m long occurs in the lower part of the village. The entrance is used as a rubbish dump, hindering access. The cave contains several large dry chambers.

5) A small cave occurs in the cliffs on the east side of Tamavua River.

6) There is an underground cavern near Waiqanake Village (Fig. 6).

f) Kalabo.

A stream has cut a massive tunnel right through the ridge on which Kalabo Village is situated (Fig. 7). It cuts through the whole of this isolated limestone band, for the flat roof is marl, and in the lower half of the cave the stream flows through basalt. The passage is mostly 5 m wide and 15 m high, for the entire length of 150 m.

g) Wainibuku Creek Area.

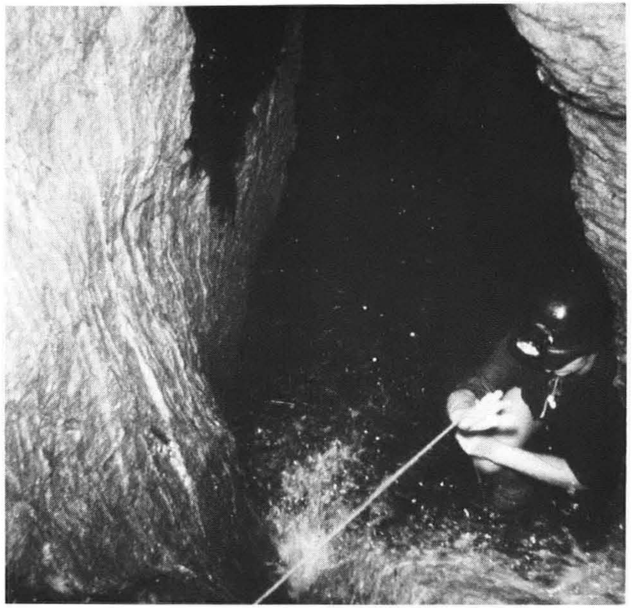
This limestone area is about 11 km northeast of Suva (Fig. 6). The limestone is roughly horizontal with a maximum thickness of 25 to 30 m, wedging out to the south, so that it is absent on Pritam Singh Road (Fig. 8). It is exposed in the face of a prominent escarpment, in some enclosed depressions in the higher ground, and in flatter areas further north. It is overlain by marl (Plate 2).

This small karst contains a rich variety of features: sinking streams, several distinct types of cave, enclosed depressions, potholes, natural arches, and miniature canyons.

1) Udit Cave (Fig. 8): Inside the lower, northern, entrance a 6 m climbable cascade leads to 100 m of low, crawling passage. Beyond this the cave continues as a fine boulder strewn tunnel mostly 6 m high and wide to its end in a stalactite grotto. The one junction is not easily found - a small stream enters through a low passage at floor level and this can be followed up through the base of two climbable potholes and then through a crawl to the sink. The total passage length is 790 m.

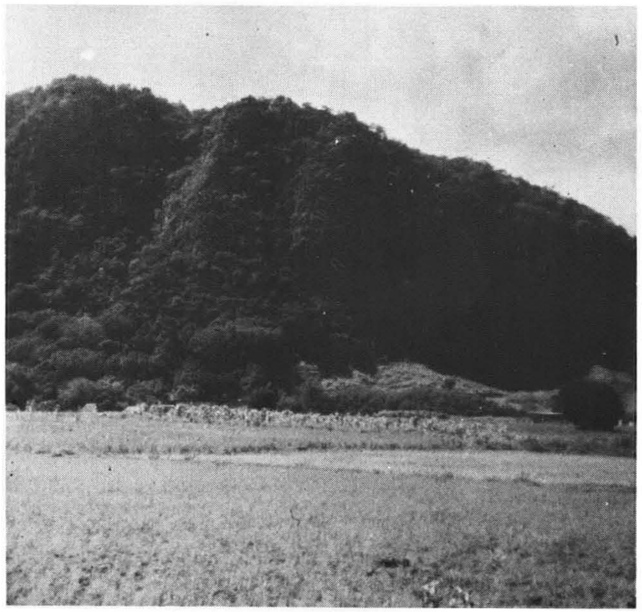
2) Wainibuku Cave (Fig. 8): The stream enters the cave after cutting a narrow channel in the limestone for one kilometre. Its basin, several square kilometres in extent, probably used to drain on the surface, through the col to the east of the top entrance. The initial 75 m of stream passage is 2 m wide by 6 m high, with deep water. The cave becomes much larger at a junction with a short dry passage, and is inhabited by many bats, cockroaches, and swiftlets. The stream continues through a number of pools, in a passage 4 m wide by 15 m high. It emerges from the northern entrance into a circular pool. Nearby are the entrances to two short dry caves. Below the pool, the stream flows through a miniature canyon, with an arch, deep pools, and cascades. This is presumably a former continuation of the cave where the roof has collapsed. The length of the cave is 180 m.

3) Dharam Singh Cave (Fig. 8): The small southern entrance gives access to a large downward sloping chamber, 55 m long by 9 m wide and 6 m high, which is crossed by a tiny stream. An insignificant hole leads into a horizontal passage, about 3 m high with a flat muddy floor. Daylight is reached after 50 m, where the roof has collapsed. Beyond is a large chamber 43 m long with a collapse hole in the roof. Length 200 m.

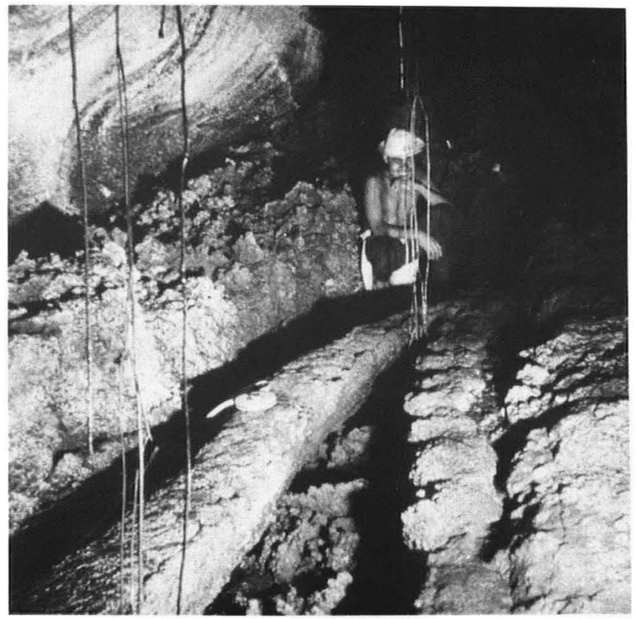


1. Cascade in Quaia Cave, S.E.Viti Levu, Fiji.

2. Marlstone overlying limestone in the Wainibuku area, S.E.Viti Levu.



3. Limestone outcrop in the Sigatoka River valley, southern Viti Levu.



4. Lava tube with clinkery floor and roots hanging through the roof, Waimaqere Cave, Taveuni.

CAVES OF SOUTHERN VITI LEVU

There is very little exposed limestone in the southern coastal area of Viti Levu, between Sigatoka and the Suva area (Fig. 1). The 45 m long Matalima Cave occurs in a thin limestone lens near Nabukelevu Village, 12 km north of the Queens Road. Small caves in volcanic rock are reported near Rukua Village on the west coast of Beqa Island, and on Yanuca Island 10 km west of Beqa. Vatulele Island is almost entirely limestone. There are several caves near the northern tip of the island, northwest of Ekubu Village. These contain chambers with pools of brackish water, evidently connected with the sea, and inhabited by red prawns.

a) Sigatoka River Valley.

There are several limestone outcrops in the Sigatoka River Valley (Fig. 1). The valley is characterised by rolling hills, with natural grasslands, and cultivated areas with many villages. The limestone outcrops are densely forested, with cliffs cut by old river meanders (Plate 3). The largest mass of limestone in the islands, 6½ km long and 1½ km wide, is near Toga Village. There is a small resurgence cave in the cliff opposite Toga Village. Two kilometres to the west. A small stream emerges from a low arched entrance in the cliffs behind Sautabu Village. Beyond is a chamber about 350 m long and 30 m wide, with side passages leading off at a higher level. (Watling and Pernetta, 1977).

Thirteen kilometres up the Sigatoka Valley Road from Toga Village, a small limestone outcrop near Tuvu Village. This is a densely vegetated area of jagged pinnacles and rock depressions. There are a few small caves in the low cliffs facing the road. One contains a pile of human skulls.

Clunie has described Malua Cave, 2.5 km southeast of Saweni Village. It consists of two chambers in a limestone outcrop, and is of great historic and archaeological interest.

b) Saweni.

Saweni Cave (Fig. 9) is formed in an isolated band of limestone which encircles Talemalawe Peak, and contains other caves. The two bottom entrances are across the river, and about one kilometre from the village. The cave consists of an upper and a lower series of passages, which emerge at a common entrance higher up the hillside. The present stream, which is only a trickle in dry weather, has invaded the existing cave and cut the lower level passages much more recently. The chambers are impressive in size, but there are few formations in the cave except some wall moonmilk. There are considerable deposits of guano throughout the length of the cave. Archaeological excavations prove that the cave was used by man for hundreds of years, possibly as a centre for making shell ornaments. There are several burials in the cave floor. White-rumped swiftlets breed and roost in the cave, as do Long Tailed Fruit Bats and Sheath Tailed Bats. Barn Owls (*Tyto alba*) are often seen there, as they prey on the swiftlets and fruit bats. Surveyed length of Saweni Cave is 420 m.

CAVES OF SOUTHWEST VITI LEVU

Limestone of the Thuva Sedimentary Group stretches irregularly along the coastal hills between Sigatoka and Natadola Harbour (Fig. 1). Sink-holes are common but how many of these are drained by negotiable caves is not known. Some sink holes are usually lakes and therefore very poorly drained. Small caves occur at several locations. Natuata Cave, which is used as a burial chamber, is near Naevuevu Village, 8 km west of Sigatoka by road. There are several small caves on the coast to the southeast of Natadola Harbour : Cikeci Cave is an active sink in wet weather, situated about 800 m from Sanasana Village. Further along the Queens Road near Tau Village, about 40 km from Sigatoka, there are several caves in a limestone quarry.

a) Voli Voli.

The entrance to Volivoli Cave (Fig. 10) is in the floor of a dry valley near the escarpment overlooking Volivoli Village, 2 km southwest of Sigatoka. A stream clearly flows through this cave in wet weather, and through most of the cave it has cut a channel about ½ m wide with a floor of angular blocks. The main passage is small in places, but opens into large chambers with extensive mud deposits. The cave may continue beyond the low pebbly crawl, which marks the end of the survey. There are unconfirmed reports of a bottom entrance although water evidently backs up considerably in the chamber before the crawlway, suggesting constrictions further on. Surveyed length 195 m.

LAVA CAVES OF TAVEUNI ISLAND

Almost the whole island has experienced recent volcanic activity and most of it is covered by lava flows, with many cinder cones, one of which is known to have erupted only about 2000 years ago. Most of the known lava tubes are in the coconut plantations at the southern end of the island (Fig. 12); but there may be more in the uninhabited rain forest along the south-eastern side of the island.

a) Salialevu.

The cave entrance, a 5 m deep collapse hole, is about 30 minutes walk from Salialevu Village (Fig. 11). It is possible to walk all the way through the cave to the upper entrance, apart from one awkward pool, and climbs up some of the lava falls. The small stream has invaded the cave only relatively recently, and has had very little erosive effect on the original lava formations. Mud and gravel deposits obscure them in some places. Most of the walls are very smooth, but where the floor is unaffected by the stream it is commonly very rough and sharp, especially at the lava falls. There are lava terraces in the passage walls, and in some places a false floor divides the lava tube. Downstream of the main entrance, there are deep deposits of soft and putrid-smelling mud. It is probable that the passage is

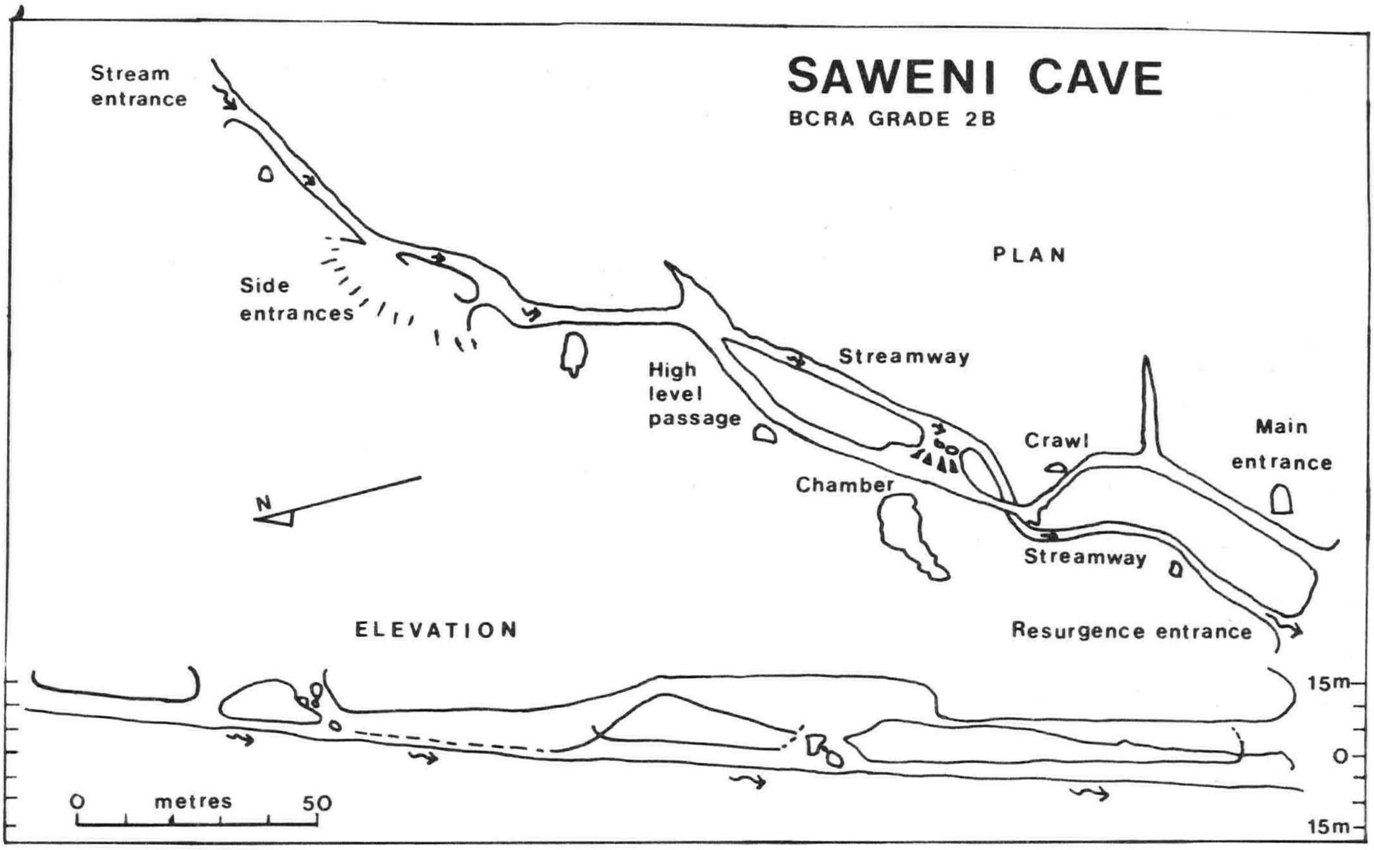


FIGURE 9

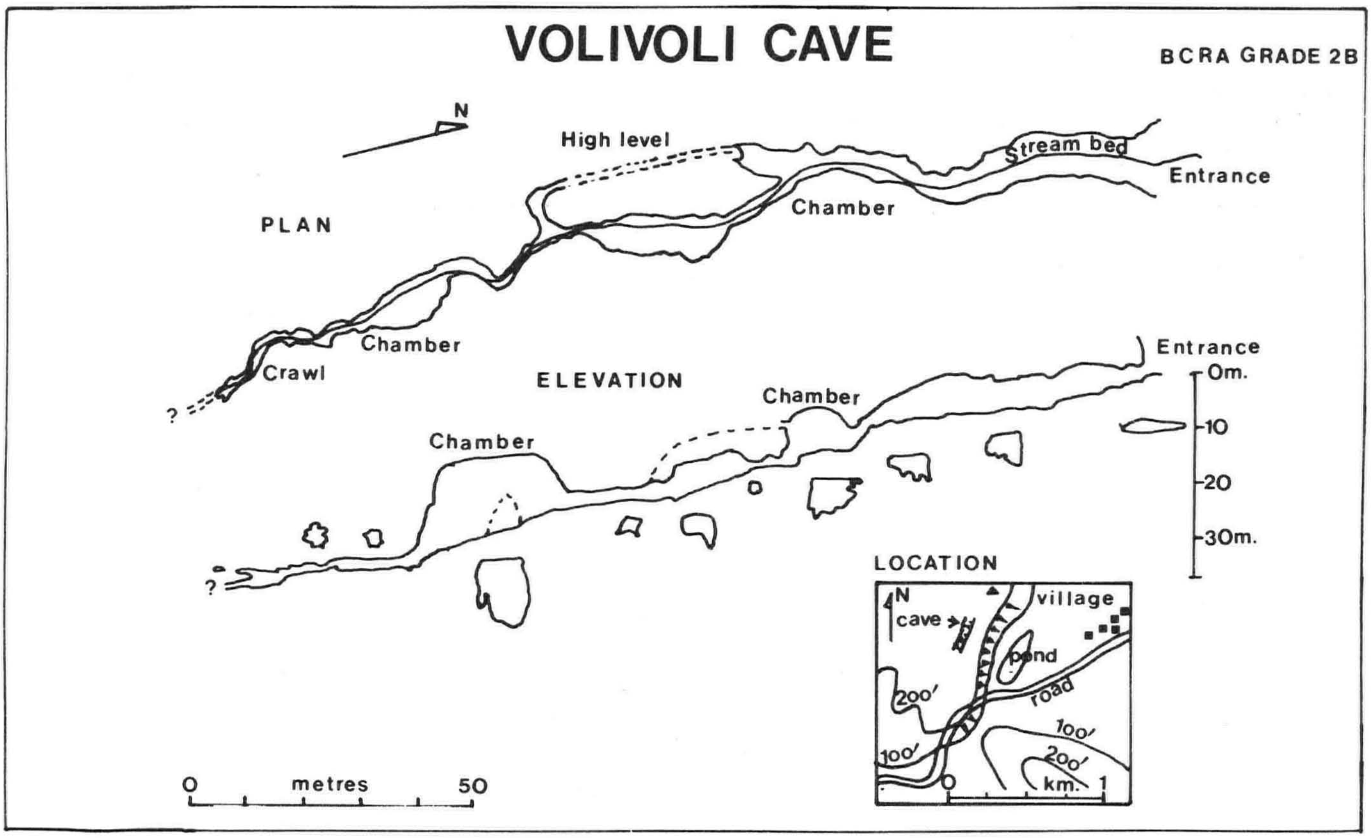
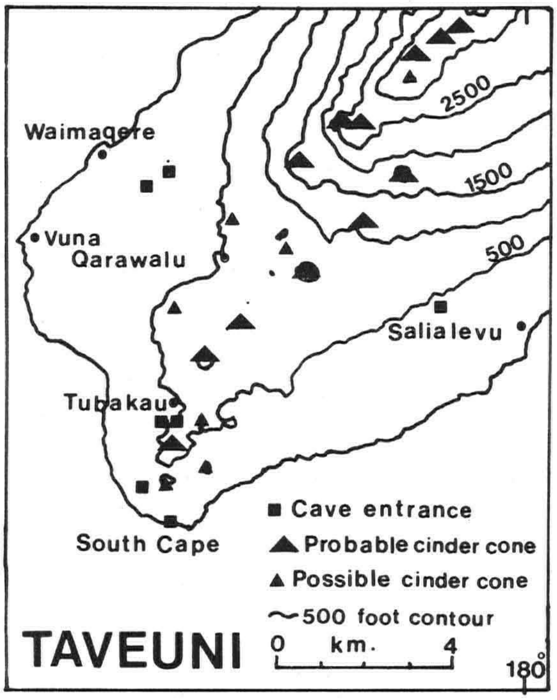


FIGURE 10



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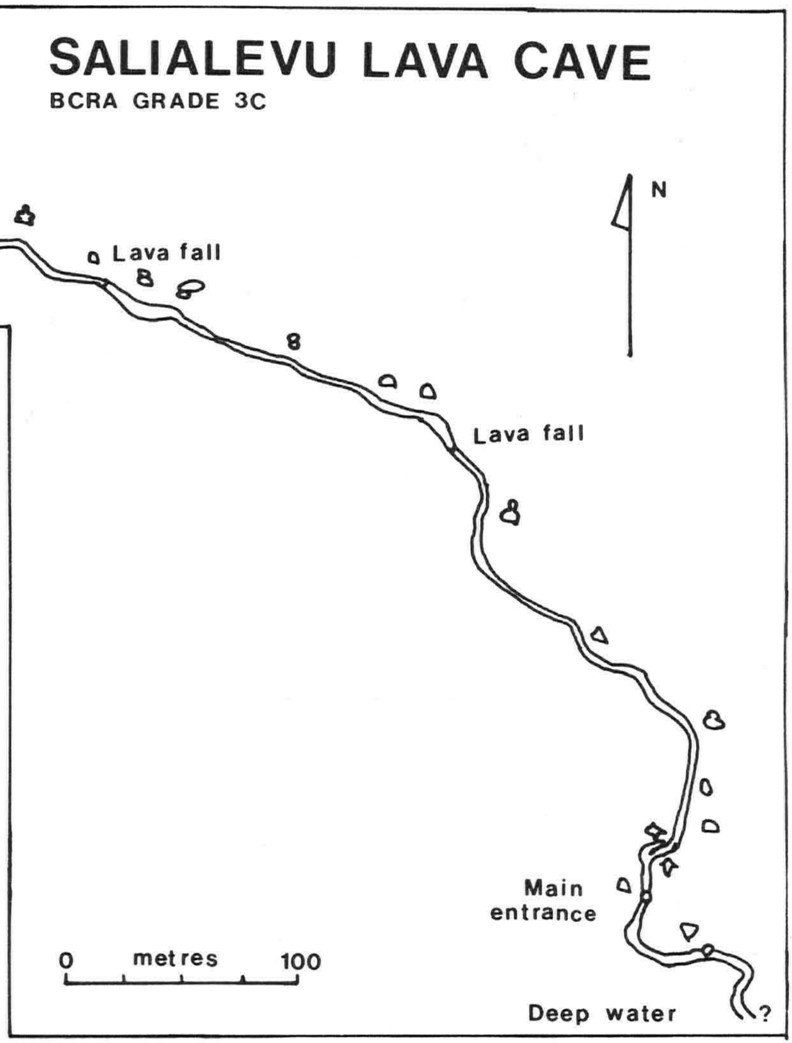

Figure 11

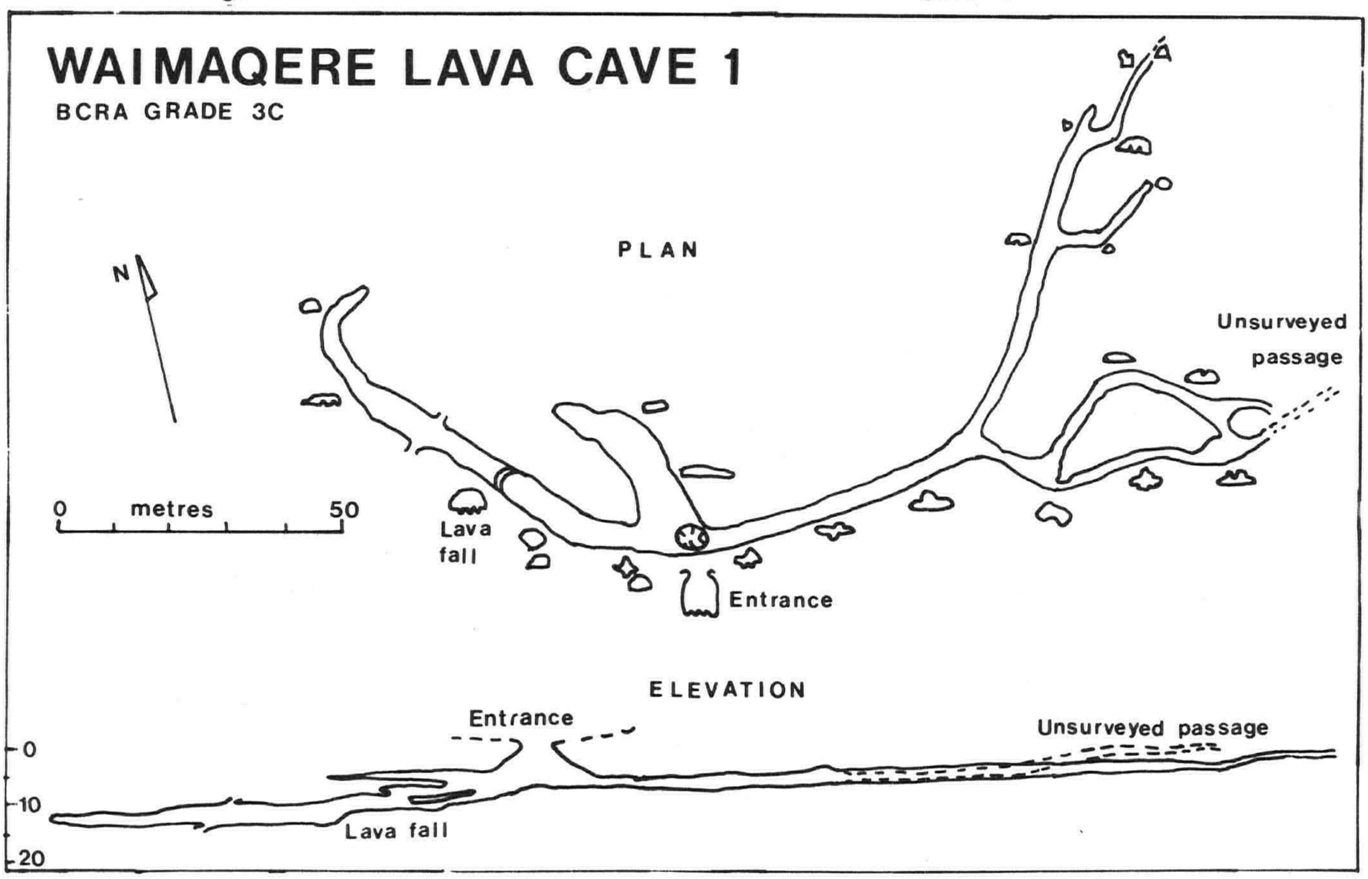

Figure 13

filled with mud or water beyond this point. Bats are only found close to the tunnel entrances, and small eels live in the stream. Most of this 920 m long cave could easily be developed as a tourist attraction. The estimated slope of the cave is 10°.

b) Waimaqere.

Both of the lava caves at Waimaqere are in the coconut plantation, about 30 minutes walk from the village. Cave Number 1 (Fig. 13) needs a 6 m ladder to enter the collapse hole entrance. The surveyed length is about 330 m, with another 100 m unsurveyed. Cave Number 2 has a constant slope of about 8° downwards from the walk-in entrance. It is a single lava tube, mostly 6 m high and 3 to 9 m wide, for the surveyed length of 180 m. Plant roots hang from the roof in places.

There are only a few drips of water entering these caves, so the lava formations are better preserved than in Salialevu Cave. These include lava falls, deep channels in the rough clinkery floor (Plate 4) which sometimes meet and join at junctions, lava terraces and false floors and ropy lava. Much of the rock is very rough and sharp. In some places there are small brownish coloured straw stalactites; in others, a grey-white deposit on the roof.

c) Soqulu.

The two collapse hole entrances to Soqulu Cave are a 30 minute walk uphill from the Soqulu Estate House, 12 km northeast of Waimaqere. The cave is a single lava tube with a floor of mud and boulders, and contains few interesting formations. The humped top of the lava flow it follows can be clearly seen on the surface. Like other lava tubes, it does not dip far below the surface, and roots can be seen in several places. There are piles of bones in the lower part of the cave. The estimated length of the cave is 165 m.

d) Other Locations.

Many smaller and less interesting lava tunnels have been found in southern Taveuni. One which may be long but has not been explored is Qara Tabu. This cave really is tabu; Gilbert was forbidden by the Tui Vuna to enter the cave. There are also practical difficulties; the entrance, near the South Cape, is at sea level in a cliff face and can only be entered by boat in good conditions.

Caves have been noted near the villages Qarawalu ("eight caves") and Tubakau (Fig.12). A cave with two chambers and passages leading off is reported near the end of the Vuna Road, about 1 km from the South Cape. It is best known locally as the cave down which an Indian was once thrown.

CAVES OF THE LAU GROUP OF ISLANDS

There is a greater area of limestone in these scattered islands than in the whole of the rest of Fiji (Fig. 1). Of the 36 largest islands, 15 are wholly limestone, four are solely volcanic, and 17 of composite nature. The limestone islands are quite distinctive in appearance. They often have cliffs undercut at sea level; the higher areas are covered in rocky pinnacles and depressions, entwined with tree roots; sometimes there is a central depression, draining underground to the coast. Much of the following information is obtained from Ladd and Hoffmeister's (1945) article, which also contains maps showing the locations of many caves. The islands are described from north to south.

a) Vanua Balavu Island.

Caves occur in the limestone islets at the northern end of Vanua Balavu, near Qilaqila. One islet is merely a hollow limestone shell containing a large chamber, 22 m high and 1 m deep in sea water (Sawyer and Andrews, 1901).

b) Mago Island.

There are many caves in the limestone rim of Mago Island (Sawyer and Andrews, 1901). To the northeast, there is an entrance in a large cliff face, 60 m above sea level. This leads to several well decorated chambers, 3 to 12 m long. Another cave in this area has a 35 m deep entrance shaft, connected by a series of large chambers, to a bottom entrance at the base of a cliff. To the north, a large shaft 35 m deep, joins a tortuous underground passage about 700 m long, which drains to the sea. In the northwest of the island, a small cave entrance gives access to a well decorated chamber, 30 m square and 10 m high. Several passages lead off : one is 300 m long with side passages (Sawyer and Andrews, 1901).

c) Lakeba Island.

The well known cave on Lakeba Island is near Nasaqalau, west of the airstrip. The cave passage is about 450 m long, 5 m wide and 15 m high. It has stalactites hanging from the roof, and a small stream in the flat mud floor. The first entrance is in the side of a wooded bluff, and the cave itself describes a rough arc through the limestone mass, to emerge at the second entrance (Derrick, 1965; Sawyer and Andrews, 1901).

d) Other Islands in the Lau Group.

Caves have been reported in other islands in the Lau Group. These are: Tuvuca (Rodda, 1981), Cicia, which is similar to Mago Island (Sawyer and Andrews, 1901), Vanua Vatu, Namuka-i-Lau, Yagasa (Sawyer and Andrews, 1901), Waqava (Ladd and Hoffmeister, 1945) and Fulaga.

CAVES OF OTHER ISLANDS IN FIJI

a) Vanua Levu Island.

Vanua Levu is the second largest island in the Fiji Group, but there is hardly any limestone, and most of the rock is of older volcanic origin. Small caves occur in coralline limestone outcrops in the Labasa area (Ibbotson, 1969).

b) Rotuma Island.

Rotuma, about 650 km to the north of Suva, is a young volcanic island and several lava tunnels are known to exist (Rodda, in Gilbert 1975).

c) Kadavu Islands.

The Kadavu Islands are mainly volcanic in origin, with very little limestone. A few small caves have been reported (Rodda, in Gilbert 1975).

ACKNOWLEDGMENTS

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