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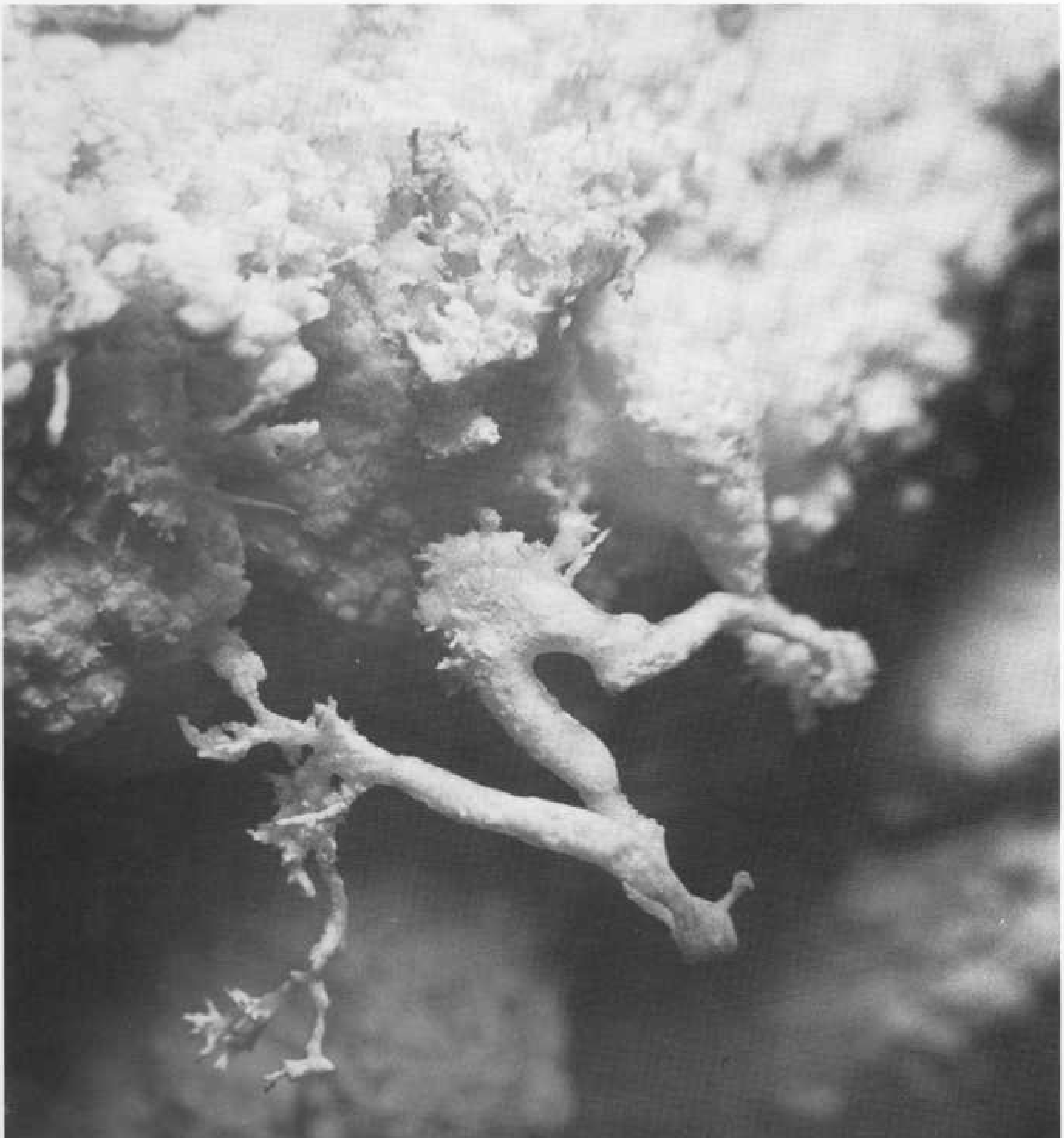
Helictite

JOURNAL OF AUSTRALASIAN CAVE RESEARCH



Mark Laurendet

Helictite, The Chifley Cave, Jenolan

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REVIEW

VERTICAL, by Alan Warild. The Speleological Research Council Ltd, Sydney, Australia 1988. pp VIII + 152: A4. Price $29.50.

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Forward, p IV. Acknowledgements, p V. Introduction, p VI-VII. Personal Equipment, p 1-16. Rigging Equipment p 17-34. Knots, p 35-41. Rigging Basics, p 42-59. Advanced Rigging, p 60-71. Descent, p 72-86. Ascent, p 87-109. Organisation, p 110-120. Disasters, p 121-128. Surveying, p 129-145. Equipment Suppliers, p 146. Bibliography, p 147. References, p 148-149. Index, 150-152. 331 line diagrams; 43 black and white photographs; 21 tables.

Vertical is a specialist book devoted to an esoteric pursuit: the exploration of deep caves. The author, Alan Warild, is a foremost expert in this field and his book is an outstanding documentation of vertical caving techniques. It is the most comprehensive and up to date English language publication presently available on cave exploration using lightweight single rope techniques.

Chapter 1 details personal equipment including clothing, harnesses, cowstails, helmets, lighting systems and other useful accoutrements. Pragmatic advice is given on selection of appropriate clothing, home sewing and improvised harnesses, the pros and cons of various commercially available lighting systems and solving problems associated with their use.

The next chapter is concerned with rigging equipment. Essential background information is provided on construction and properties of caving ropes, and detailed consideration is given to the placement of bolts considering their importance to the caving style expounded in this book. Notwithstanding, Warild's complete assessment of rigging equipment even embraces rope protectors and ladders.

The third chapter revises the basic knots a vertical caver should know. Additionally and more importantly, this section tabulates the results of knot strength tests done on caving ropes. Contrary to popular practise, some knots (particularly the butterfly knots) have been found to be relatively unsafe when used with thin ropes (9 mm or less). According to Warild's research the Figure-9 loop, Double Figure-8 and Double Fisherman's are the strongest knots to use.

In Chapter 4 the author discusses basic rigging characteristics for two distinctive caving styles: Alpine and American. Alpine style utilises thin ropes (generally 9 mm diameter) which must be rigged to avoid contact with the rock and water. This rigging style includes Y belays, deviations (redirections), rebelays and bolts. On the other hand, American style relies on a thick (11 mm+), abrasion resistant rope, minimal re-rigging and rope protection. Warild is admittedly a confirmed user of the Alpine approach although in practice there is often some degree of nexus between those two fundamental styles, depending on who is doing the rigging! Finally, some very useful hints are provided on rigging for comfort, and as the author explains, "[these hints] are usually learnt by experiencing uncomfortable rigging." They are small but often useful "tricks" which greatly contribute to user-friendly rigging.

The next chapter is devoted to advanced rigging: specialised techniques available to the caver pushing the front of exploration. These techniques include Ultralight rigging, Cord Technique, shock absorbent rigging, climbing (climbing platforms, climbing and scaling poles, aid climbing, belaying, lassos and grappling hooks), fixed rigging and pull-down rigging. The detailed explanation given to Ultralight and Cord Technique in particular, reflects Warild's unquestionable expertise in this area, having employed these techniques himself for solo descents of caves exceeding 1000 m depth. American, Alpine, Ultralight and Cord Technique rigging are compared on the basis of equipment weight and volume. Some important results of shock absorbing knots indicate that they are not reliable enough to be safe.

The following two chapters deal with descent and ascent techniques and equipment. Comprehensive treatment is given to the most commonly used mechanical descenders, and there are tables showing vital statistics relevant to the use of common commercially available ascenders and descenders. Both sit/stand and ropewalking prusik systems (as well as convertible) are examined, and again there is a useful tabulated appraisal of the various rigs. The procedures for crossing rebelays, deviations and knots (using a cowstail) are clearly described and figured. A miscellany of descent/ascent situations are dealt with, ranging from narrow, muddy pitches and diagonals, to big drops, long hair and tandem prusiking. I agree with Warild's opinion, that for Alpine style, the autostop bobbin is the most suitable abseiling device, and also that the Frog System is unequivocally the fastest and most efficient prusik system yet devised.

Chapter 8 is concerned with organisation - making it all work in a cave. Personal organisation, gear management and tackle lists directly contribute to caving efficiency, and therefore indirectly, to increased safety. Prospecting for new caves and exploration rigging are only briefly examined. Warild presents salient reasons for considering underground camping only as a last option. Lastly but most importantly he gives a conservation message which appropriately draws attention to bolts, because bolting is recognised as an essential component of Alpine caving technique. Without debating the ethics of bolting the author puts forward some very common sense solutions to minimise the so-called bolt problem.

The ninth chapter is pessimistically titled "Disasters". Potential hazards are given only superficial coverage, the topic of hypothermia is concluded with - "The chances of rewarming a severely hypothermic caver in a cave are very low and the situation should simply not be allowed to arise." I would quibble that a suitable reference here would be useful to readers. The inference nonetheless is that a basic First Aid knowledge is the responsibility of every caver. Somewhat more attention, however, is given to describing and clearly illustrating rope techniques for 'self'-rescue. Lifting or lowering an accident victim caught on-rope are complicated manoeuvres, suggesting to me that thorough practise beforehand is essential training for competence in emergency situations. Two points of interest for Alpine purists: bobbins can be substituted as effective pulleys and the autostop can be adapted to descend a taut rope.

The final chapter gives a thorough explanation of surveying for vertical cavers, since this is the only way to find out how deep a cave is! Using either tape and compass or topofil, Warild explains tactics and procedure for surveying with these instruments right through to computing and plotting.

My criticisms of Vertical are minor. Whilst this book purports to deliver a 'world view' of vertical caving, it unashamedly favours the European-derived Alpine style (versus American style) as the best method for exploring deep caves. A number of technical caving books have recently appeared on the market, such as Caving Practise and Equipment (Judson), Single Rope Techniques (Elliot) and On Rope (Padgett and Smith). Without lightly dismissing any of these publications I would contend that Vertical has taken contemporary caving literature one jump forward in the evolution of lightweight, self-sufficient and highly-efficient caving practises. But just as ladders will always have their niche in caving, so too, I believe, will American rigging style (perhaps inappropriately referred to in the Introduction as IRT - Indestructible Rope Technique).

This book is an encyclopaedic synthesis of information, but the large format and well structured presentation greatly facilitates its use as a reference and training manual. Indeed the layout of Vertical is very similar to that of its predecessor, Single Rope Techniques by Neil Montgomery. As authoritative and comprehensive as Warilds's monograph is, it is marked by succinctness and accuracy. I detected only occasional typographical errors but nothing which alters the intended context. The 331 line diagrams, 43 black and white photographs and 21 tables complement and clarify the detailed text. The author's wealth of experience and attention to detail has resulted in a precise documentation of 'little tricks' which otherwise can only be learnt through bitter experience! The book maintains a strong emphasis on safety and does not ignore cave conservation. I would unreservedly recommend this book as an essential reference for all cavers, from novice to expert to armchair, or for that matter, anyone using fixed ropes for personal safety.

Vertical is attractively packaged in glossy blackness. The cover design epitomises adventure and exploration, the photograph shows an Aussie caver 'hanging out' on the brink of a 310 m deep shaft in Nita Xongá, Mexico!

Stefan Eberhard

BOOK NOTICE

CURRENT TITLES IN SPELEOLOGY 1986, British Cave Research Association.

One of the most useful publications to arrive on my speleological shelves each year is Ray Mansfield's Current Titles in Speleology. It indexes, to a remarkable degree of depth, the speleological literature of the world.

It has, as many reader will know, bee published since 1969 by Tony Oldham. The British Cave Research Association has now taken over as publisher, and although their greater resources enable them to do a slightly better quality of production, the content remains as before.

Each issue lists all journals scanned, then lists general non-regional papers, followed by separate listings for each country. In turn, the listings are broadly classified under subject. It is a simple arrangement, but an easy one to use. The 1986 issue includes 4,679 items and it will doubtless grow as a wider range of publications reach the editor.

So, although a number of Australian publications have not been sent to the editor and so are not included, it does include a remarkable number of items from other journals - each year I discover a considerable number of things on Australian caves which were previously unknown to me!

It (and any back issues) are available from B.C.R.A. at 20 Woodland Ave., Westonzoyland, Bridgewater, Somerset. U.K. TA7 OLQ.

Elery Hamilton-Smith

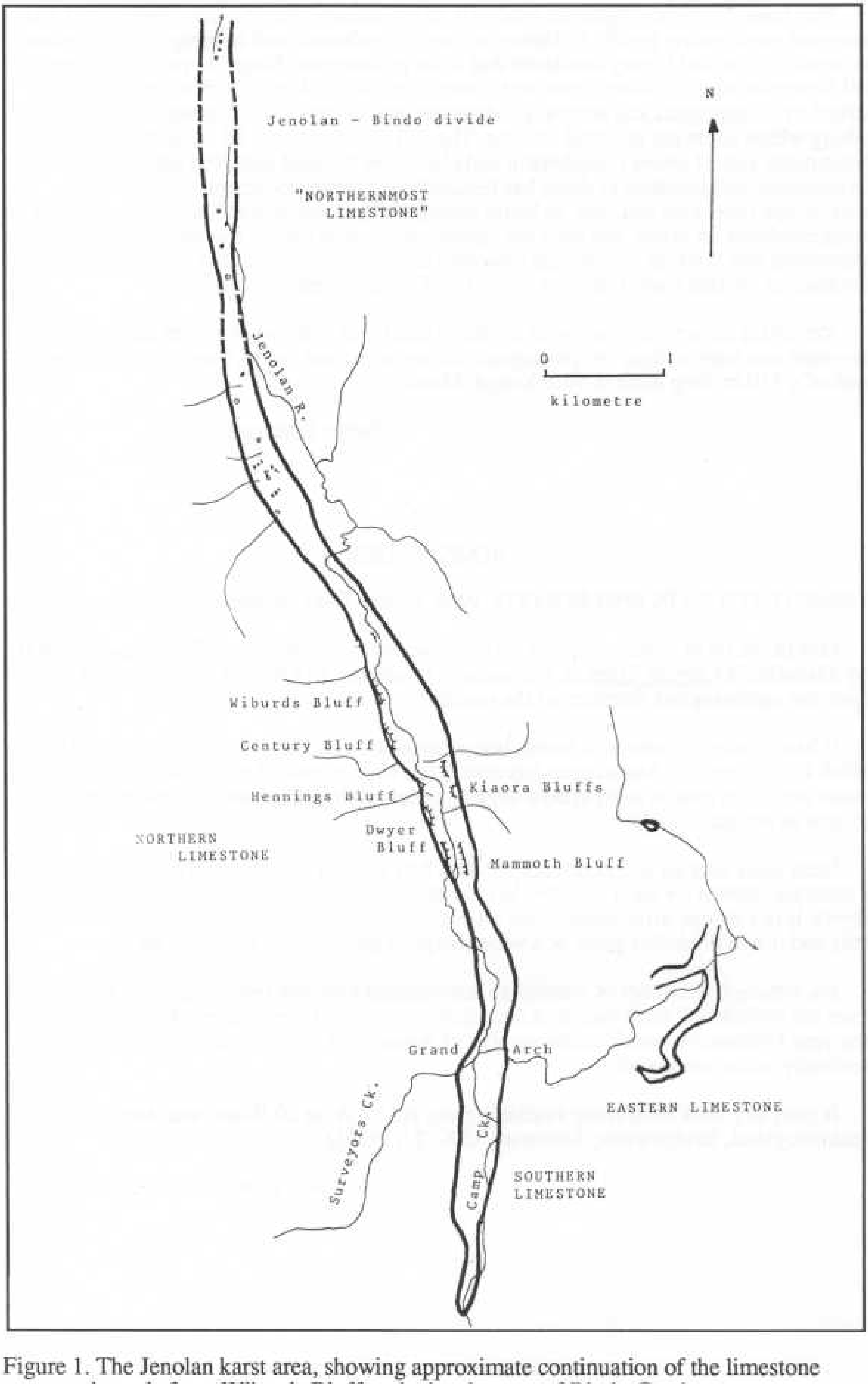

Figure 1. The Jenolan karst area, showing approximate continuation of the limestone northwards from Wiburds Bluff to the headwaters of Bindo Creek.

THE GEOMORPHOLOGY OF THE JENOLAN CAVES AREA

Kevin Kiernan

Abstract

The Jenolan Caves occur in a small impounded fluviokarst developed in limestone of late Silurian age. This paper reviews present knowledge of the geomorphology of Jenolan. The surface and underground geomorphology has been strongly influenced by the lithology and structure of the limestone and the non-carbonate rocks that surround the karst. There is evidence in the present geomorphology of the inheritance of influences from palaeo landscapes. Abundant surficial and cave sediments reflect slope gradients and climatic conditions that have existed in the past. Despite the very limited size of the limestone outcrop there is great variety in the karst, including many kilometres of underground passage and a range of cave morphologies and clastic and chemical sediments underground.

INTRODUCTION

The Jenolan karst area in New South Wales includes the most frequently visited limestone caves in Australia, and of all the karst areas in Australia it is probably the one of which the general public is most aware. Many of the caves have been comprehensively mapped for many years: Oliver Trickett (1898, 1899) compiled a map of the tourist sections of the Jenolan Caves in 1898, which was progressively upgraded until 1925. Subsequent mapping of extensions to the show caves has been on a piecemeal basis, but most of the wild caves were systematically mapped to a high standard in the 1960's and '70's (Dunkley & Anderson, 1972; Welch, 1976). Despite this, the area has received less scientific study than might have been expected from its fame and proximity to Sydney. Until recently official policy of the reserve management generally discouraged scientific investigation in the show caves. The compilation of a draft management plan for the Jenolan Caves Reserve in late 1987 provided the opportunity to review the limited geomorphological literature and knowledge available on the area. This paper reports upon that review and offers a few interpretations of some aspects of the Jenolan karst. It should be noted that while most of the locality names used in this report are in common use locally, not all have been formally accepted by the Geographical Names Board of NSW.

The geomorphology of Jenolan includes a variety of non-karstic phenomena that are significant in their own right and in some cases are also important because they have a systemic relationship with the karst. Because these features lie adjacent to and in some cases overlie the karst terrain an appreciation of them allows a greater insight into the karst itself. This report therefore reviews the overall geomorphology of the Jenolan area. It examines, firstly, its geological and physiographic framework. It then reviews the contribution to the present surface geomorphology made by structural and lithological influences; possible inherited topography from earlier landscapes; and the colluvial and alluvial landforms and sediments. It then reviews the present surface karst. A similar framework is then adopted for discussion of the underground geomorphology.

BEDROCK GEOLOGY

The Jenolan Caves Limestone is late Silurian in age. It overlies laminated cherts and andesites to the west and is overlain by silicic volcaniclastics to the east. The Siluro-Devonian sequence is unconformably overlain to the east by upper Devonian Lambie

Group sediments. Granitic plutons intrude NE and S of the caves. Permo-Triassic rocks occur at ~1150 m within 3 km of the caves and Upper Devonian rocks are overlain by Permian and Triassic sediments 15 km to the east.

Chalker (1971) regarded the limestone as being predominantly massive but more recent work has contradicted this view (Allan, 1986; Osborne, 1987a). Osborne (1987a) recognised the presence of three facies: thinly bedded; massive lime mudstone; and bedded stromatoporoidal calcirudite. The limestone consists of up to 96-99% $CaCO_3$ (Chalker, 1971).

The limestone belt is seldom more than 300 m wide and in places narrows to little over 100 m (figure 1). Most workers have proposed that continuous limestone extends for only 5 km along the Camp Creek Valley (the "Southern Limestone") and Jenolan River Valley (the "Northern Limestone"). Limestone extends a further 4 km up the Jenolan River Valley (which is known as McKeowns Valley) and occurs immediately north of the surface drainage divide between the southward flowing Jenolan River and the northward flowing Bindo Creek. A series of sinkholes and streamsinks in this area has been documented by Ernst Holland, Chief Guide at Jenolan, and by Stewart (1987). This limestone has been viewed as representing discrete lenticular bodies or "pods" (Chalker, 1971; Lishmund et al., 1987). However, Shannon (1976a) implied that the northernmost limestone may not necessarily be discontinuous and hydrological research by Kiernan (1988) showed that the limestone in at least the southern part of the area in question was continuous with the main limestone belt. More recently, geological mapping of the area was undertaken by Stewart (1987) who concluded that there was no evidence that the limestone occurred in "pods". Further outcrops of limestone occur 1.2-2.5 km east of the Grand Arch to either side of the Jenolan River (the "Eastern Limestone"), and along the course of Pheasants Nest Creek. Earlier interpretations of the geology regarded the "Eastern Limestone" as part of the Jenolan Caves Limestone, but structural, lithological, palaeontological and stratigraphic differences indicate this may not be the case (Allan, 1986).

The sequence has been variously interpreted as having the form of an anticline (Chand, 1963; Gulson, 1963); as a faulted anticline (Stanley, 1925; McClean, 1983); as a symmetrical anticline with overthrusting (Sussmilch and Stone, 1915); and as a syncline (Pratt, 1965; Chalker, 1971). More recently, Allan (1986) found that the limestone faces east. He argues that deformation occurred during at least two folding events and later high angle thrusting between Middle Devonian and Early Carboniferous time. Small faults with a displacement of 2-3 cm are numerous. Shannon (1976a) proposed that a number of small across-strike faults were present in McKeowns Valley, but Allan (1986) concluded that there was no evidence for these. The "Eastern Limestone" occurs on the limbs of a NE plunging anticline and exhibits asymmetric kinks and tight symmetric folds (Allan, 1986).

The geology of the area is therefore diverse and the structural and lithological relationships continue to stimulate research and debate. Exposures along the Five Mile Hill are utilised for education purposes.

SURFACE GEOMORPHOLOGY

The Jenolan Plateau is an irregular dissected erosion surface at ~1100-1200 m asl into which the Jenolan River has incised its valley. The distribution of Permian rocks near Hampton and on the Kanangra Range suggests that much of the plateau surface may be of at least Permian age. The highest summits are Mt. Edwards (1270 m), Mt. Whiteley (1250 m) and Mt. Wiburd (1226 m) on the southern side of the reserve; Kiaora Hill (1192 m) and an un-named summit (~1200 m) between Stockyard Creek and Terrace Creek in the north; and Oberon Hill (~1240 m) and a series of ridges to its NNW (>1200 m) in the east. The divide between the southward-flowing Jenolan River and northward-flowing tributaries of Bindo Creek lies at just over 1100 m. The river flows across of the eastern boundary of the Jenolan Caves Reserve at ~635 m east of the Grand Arch. As the reserve has a maximum width E-W of only ~4 km and a maximum length N-S of ~9 km this relative relief of ~635 m implies very steep slopes, and valley-side slopes of ~20°-30° are not unusual (figure 2).

Structural influences

The area exhibits some striking examples of the influence of bedrock structure upon landform evolution and the physiographic context in which karstification has taken place (Allan, 1986). The drainage pattern has been dictated by structure and is rectangular with a strong N-S and E-W grain. North of the Grand Arch McKeowns Valley has developed along the strike of the rocks and is met at right angles by most of its tributaries. A few hundred metres upstream of North Wiburds Bluff there is a sharp kink in its course that is probably the result of a fault. At the Playing Fields the valley turns from a NNW-SSE course to a N-S course in response to a change in the strike of the limestone. South of the Grand Arch the northward-flowing tributaries of the Jenolan River, Camp Creek and Surveyors Creek, also follow the strike and have a similar relationship with their tributaries. Unlike the Jenolan River at this point, Camp Creek follows the eastern side of the limestone body, however it crosses to the western margin of the outcrop at The Breach, possibly the site of a former arch. This appears to be a response to the local dip. Incision of the streams into the limestone has been retarded by resistant volcaniclastics. Immediately downstream of the Grand Arch the river turns sharply eastward, possibly in response to near recumbent folds that plunge towards the river from north and south, producing and E-W synclinal structure. The Jenolan Thrust Fault that forms an indented shallow arc from Oaky Camp to the western slopes of Mt. Inspiration has exerted a major influence on the evolution of valley systems in that area (Allan, 1986).

Lithological influences

The juxtaposition of eminences and depressions in the landscape has been influenced strongly by rock type. For instance, prominent ridges formed of quartz porphyry and altered ?dacitic crystal tuff overlook more subdued valleys formed in argillaceous rocks (Allan, 1986). The quartz porphyry also forms steep valley heads to the tributaries of Camp Creek.

The principal streams largely follow the belt of Jenolan Caves limestone and the cross profile of the valleys seems to be greatly influenced by lithology. The limestone crops out boldly in a number of areas towards the lower end of McKeowns Valley where a limestone gorge is developed. Immediately upstream of the gorge the floor of McKeowns Valley lies on non-carbonate rocks and is considerably broader; further upstream again the valley floor narrows through limestone but upstream again lies a broad alluviated valley with occasional limestone bluffs that overlook the valley floor. A dip slope on the limestone is present at Kiaora Bluff (Allan, 1986). The stream gradient steepens through the narrower reaches. Still further upstream the limestone is masked by alluvial or colluvial sediments of Quaternary age.

Inheritance

A number of topographic surfaces are present in the Jenolan Caves area and some of these have been interpreted as old erosion surfaces (Osborne, 1987a). They include saddles above the Grand Arch and also south of Lucas Rocks where there are remnant gravels that include clasts up to 30 cm in size. Benches occur at ~830 m near Carlotta Arch; at ~900-920 m in the vicinity of the Jenolan village; at ~1010 m at South Mammoth Bluff; at ~1020 m at Mammoth Bluff; and at ~990 m a short distance upstream of the kink in the river above North Wiburds Bluff. In the "Southern Limestone" downstream of Paradox Cave there is a suggestion of a bench on the western side of the valley at ~940 m and a number of degraded sinkholes and ephemeral springs occur along it. Well rounded

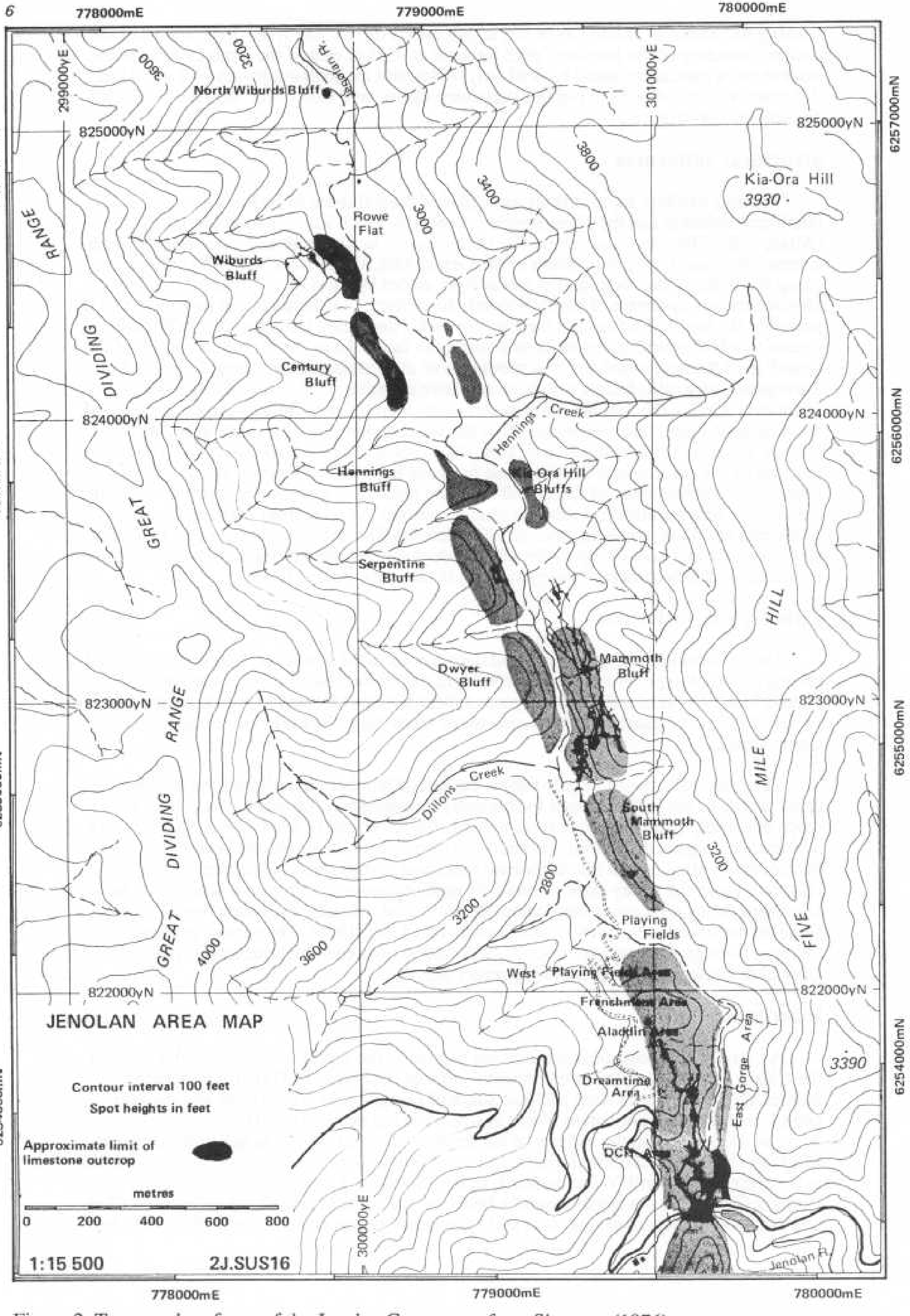

Figure 2. Topography of part of the Jenolan Caves area, from Shannon (1976).

gravels and cobbles occur in some of these localities. The benches appear to be remnants of former valley floors. However, they could conceivably be of ?Permo-Carboniferous glacial origin (Allan, 1986). They are associated with indurated conglomerates and ferruginous sediments. The discovery of a 1 m diameter stalagmite in the wallaby enclosure (E. Holland, pers. comm.) and of pool crystal in the garden of a house in the Jenolan village (J. Callaghan, pers. comm.) indicates the former presence of cave development well above the altitude of the present caves.

Surficial sediments

The Jenolan Caves area is centred at ~33°47'S, 150°05'E. Despite its moderately low latitude, the considerable relief and high elevation of the area has meant that the effect of climatic change during the Quaternary has almost certainly been considerable. Its elevation, steep slopes, predominant rock types, and its susceptibility to intense rainfall events and devegetation after fire or insect plague ensures that the surface environment remains geomorphically active today. A variety of landforms and surficial sediments exists (Stewart, 1987), the character of which has been conditioned by slope gradients and the climatic conditions that prevailed at the time of their deposition.

Colluvial landforms and sediments are widespread. They include diamicton slope mantles that are both matrix-supported and clast-supported. Some are of probable periglacial origin, including rudimentary *grezes litees* that may be the northernmost example yet recorded in Australia of this type of sediment. Slope deposits totally mask most of the limestone on the eastern side of McKeowns Valley upstream from North Wiburds Bluff. Possible mudflow deposits overlie terrace gravels in the Rowe Flat area and are probably Holocene in age. Similar deposits are exposed in the walls of gullies in the Eastern Limestone, and may have inhibited the sinking of streams to some extent. The gullies suggest that there has been a significant change in the balance between sediment supply and runoff since the sediments into which they have incised were first laid down. Screes derived from non carbonate rocks occur on slopes that may exceed 35° in some areas. Considerable overturning of the clasts, as shown by the distribution of lichen, emphasises their continuing instability.

Alluvial landforms and sediments are most strikingly represented by alluvial fans that extend from tributaries onto the main valley floors, and by river terraces that are widespread in upper McKeowns Valley. Only the lower terrace is now subject to flooding. Both the terraces and the alluvial fans have been incised by the present streams. For instance, the fan at the mouth of Pheasants Nest Creek is at least 6 m thick and a strath has been eroded across it by the Jenolan River. In McKeowns Valley the fans are of significance as sources of the water that drains through the cave systems, as are the coarse gravels and sands exposed in terraces formed along the Jenolan River itself (Shannon, 1976a). The coarse gravels that form the present bedload of the Jenolan River are being reworked from the fan and terrace gravels and are not being derived from bedrock at present. This reflects a change from predominantly mechanical to greater chemical weathering with climate amelioration during the Holocene, with silt now comprising a relatively greater proportion of the waterborne sediment. Such transitions in sediment calibre have had important implications for evolution of the caves into which sediments have been transported. Hence, in addition to having their own intrinsic value, proper management of these assets is also important to full and proper conservation of the geomorphic values of the caves.

Tufa deposits extend downslope onto the floor of the Camp Creek Valley in the Paradox Cave area of the "Southern Limestone", and tufa is also present on some limestone clifflines elsewhere.

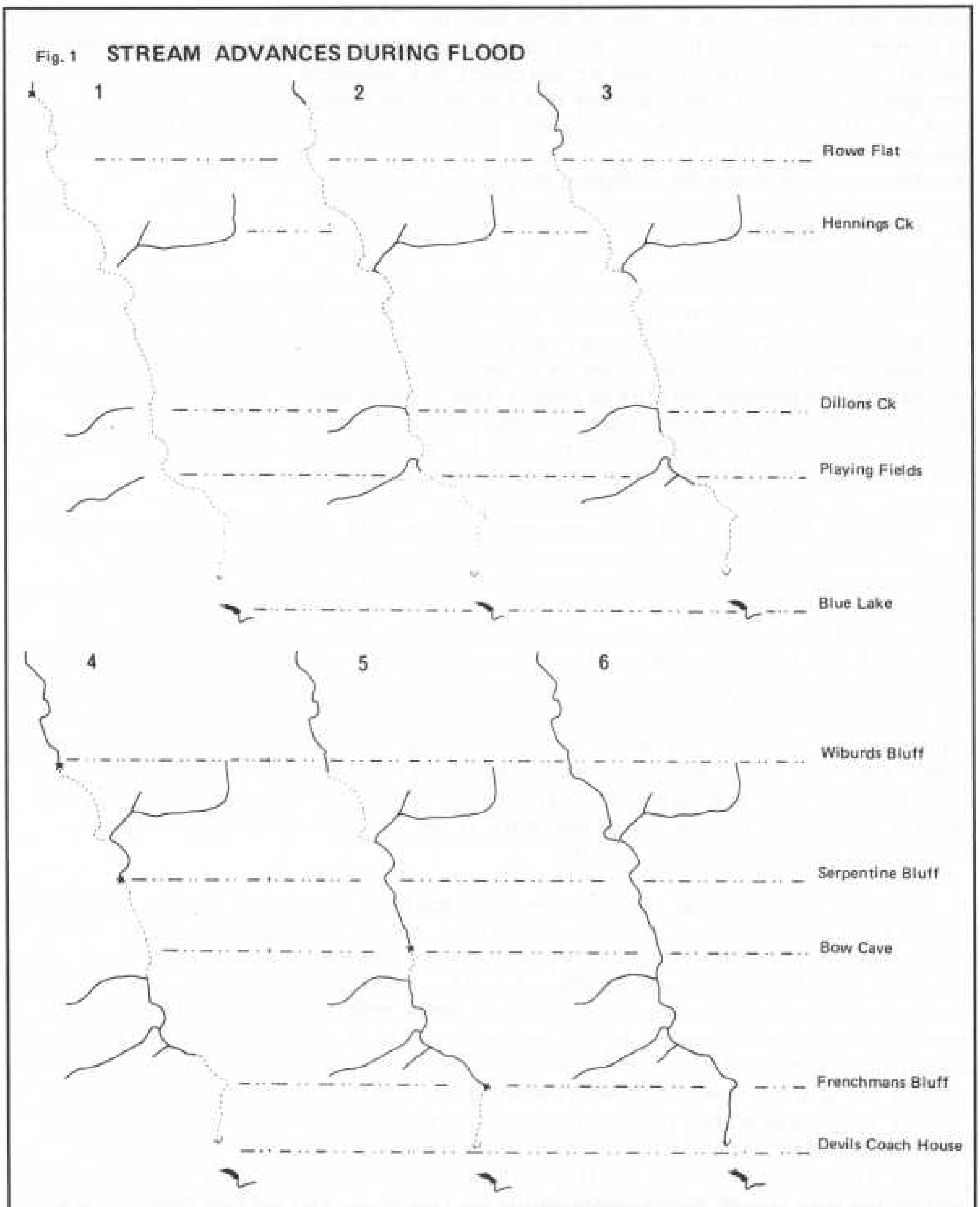

Figure 3. Stream advances during flood in the "Northern Limestone" at Jenolan, from Shannon (1976).

Surface karst

The Jenolan Caves lie in an impounded fluviokarst that is characterised by an impressively diverse array of surface karst landforms that constitute a major resource of the area. Where the limestone crops out it typically forms conspicuous bluffs, as exemplified at Lucas Rocks above the tourist caves south of the Grand Arch.

The largest enclosed depression is the sinuous blind valley of the Jenolan River which is closed at ~820 m to form a basin nearly 2 km in length but seldom more than ~100 m wide. The contours are also closed for 0.5 km up both the Camp Creek and

Surveyor Creek valleys. Generally sinkholes are not abundant although they may be very prominent locally. The best developed subsidence sinkholes occur on the margin of alluvial deposits, the largest probably being those that are developed in the "Three Dolines area" which lies just under 2 km NNW of Wiburds Bluff in the far northern extension of the limestone (Dunkley, 1972). Others are present on some of the alluvial fans and on the valley flats at the "Playing Fields" 1 km upstream from the Grand Arch. These latter hold water for some time after heavy rain, as do some of the very shallow dolines that occur immediately north of the Jenolan-Bindo divide (E. Holland, pers. comm.). Collapse sinkholes occur on some of the bluffs, the most striking being that which has breached the roof of the Devil's Coachouse.

The most prominent streamsinks are those of the Jenolan River at the Devil's Coachouse and Camp Creek at the Grand Arch. However, some streams progressively lose water into their bed, the most noteworthy example being the Jenolan River which reaches the Coachouse only after heavy rain. In the "Southern Limestone", a cave known as Heflan Trap reaches over 15 m below the bed of Camp Creek but does not usually contain water. There are a number of prominent streamsinks on the western side of the valley north of Wiburds Bluff. Dry valleys are therefore reasonably common. The principal resurgences immediately downstream of the Grand Arch have been inundated by the artificial Blue Lake, but small perched ephemeral springs, that are probably exsurgences, are present on the western side of Camp Creek in the "Southern Limestone", in the "Three Dolines area", in the Bindo Creek headwaters and elsewhere.

Small karst gorges are present along McKeowns Valley downstream of the playing fields in the "Northern Limestone", and at "The Breach", a short distance upstream of the Grand Arch in the "Southern Limestone". The latter may previously have been a natural arch. The most spectacular arches that exist today are the Devils Coachouse which reaches a height of 50 m, the Grand Arch which gives access to the tourist cave system, and the earlier Carlotta Arch, which appears to be genetically related to the possible terrace remnant at ~830 m near the Elder Cave sinkhole. Limestone cliff faces are present at some of the bluffs in McKeowns Valley and elsewhere, with the best example being in the gorge near False Frenchmans Cave.

Surface solution sculpture is prominent on many exposed outcrops, and is particularly well developed on Lucas Rocks and adjacent to the Six Foot Track above the Devils Coachouse where *rillenkarren* is the most common form. In striking contrast, solution sculpture in the "Eastern Limestone" emphasises more rounded shapes and linear karren is uncommon. This is probably the result of lithological factors, and these two areas therefore complement one another in presenting a range of karren forms developed on rocks of different lithology under a similar climatic and biotic environment.

Shallow caves are developed in calcareous conglomerates in some areas, notably near the eastern side of the wallaby enclosure at the southern end of the "Playing Fields".

UNDERGROUND GEOMORPHOLOGY

Approximately 320 cave entrances have been recorded at Jenolan. The greatest concentration of underground passage is the complex of tourist caves for which the area is best known. The tourist caves all represent part of a single cave system. The tourist cave complex is of considerable extent but has not yet been fully surveyed. A general map of the tourist caves was compiled by Oliver Trickett in 1925. Very detailed mapping is at present in progress. The recent exploration of a link between Imperial Cave and Spider Cave has considerably increased the length of surveyed passage, and exploration is continuing in other parts of the Jenolan complex. The possibility exists that before much longer there may have been a greater length of passage surveyed in the Jenolan tourist caves than in any other Australian cave system. The vast majority of the known caves are related to present or past drainage to what is now the site of Blue Lake, an artificial impoundment immediately downstream of the Grand Arch. The most extensive caves that have hitherto been explored beyond the area of the tourist cave complex are Mammoth Cave (3.5 km of passage) and Wiburds Lake Cave (2 km) in the "Northern Limestone". To date caves of only moderate size have been recorded from the extremities of the "Southern Limestone" and from "Eastern Limestone" although exploration of these areas has not been intensive.

Drainage

Most streams vanish underground almost immediately upon reaching the limestone, except where alluvial deposits form aquicludes and temporarily inhibit sinking. The major underground watercourse is the Jenolan Underground River. The northernmost known tributary of the Underground River sinks ~1.6 km upstream from North Wiburds Bluff, the water re-emerging in Mammoth Cave as Lower River and flowing thence to Imperial Cave and Blue Lake (Kiernan, 1988). The failure of this water to regain the surface between the streamsink and Mammoth Cave renders virtually untenable any suggestion that the limestone that occurs in these two areas is discontinuous. Indeed, the demonstrated continuity of underground drainage in the area of McKeowns Valley where the mantled limestone outcrop appears most discontinuous, and the absence of any known resurgences further north in the valley that could account for the known streamsinks there, makes it likely that water from as far north as the sinkhole terrain north of the Jenolan-Bindo divide may flow directly to the Underground River.

Drainage from Wiburds Lake Cave has also been shown to reach Lower River (Shannon, 1972a). Two smaller streams are also known in the Northern Limestone. The northernmost is Central River in Mammoth Cave, which has been shown both by chemical characteristics and fluorescein testing to have a different origin from Lower River (Shannon, 1972b,1976a; Handel and James, 1977; Kiernan, 1988). It is presumed to join the Underground River further to the south. A small tributary stream also drains into Imperial Cave through sumps 7 and 6, and probably originates, like Central River, from local runoff beneath the bed of the Jenolan River. The alluvial sediments along McKeowns Valley probably contribute much of the base flow (Shannon, 1976). Relative advances of tributary streams and the Jenolan River along their surface courses in McKeowns Valley under flood conditions (figure 3) are a fascinating feature of the area with important implications for understanding the karst hydrology (Shannon, 1976; Dunkley, 1976).

In the "Southern Limestone", the bed of Camp Creek is often dry for much of its course. The principal underground stream south of the Grand Arch is the River Styx in River Cave, which resurges around the pipes on the southern side of the Surveyor Creek drain through the Grand Arch at the upstream end of Blue Lake. Water also enters the caves on the south side of the Grand Arch from a streamsink on the margin of the Camp Creek channel at the upstream entrance to the Grand Arch. This follows an independent route via the Pool of Cerberus and the dye was not seen in any of the pools in River Cave, at the Cerberus Cave junction, or below the bridge in Lucas Cave (Shannon, 1976b). Diving in the Barralong Cave (an extension of River Cave) has recently led to the exploration of further cave in that area and has re-opened the prospect of further significant discoveries in the "Southern Limestone".

The caves of Jenolan exhibit considerable variety of form and striking contrasts are evident north and south of the Grand Arch, the caves to the north showing a greater range of vertical development in comparison to their horizontal development, and the converse situation applying south of the Arch.

Structural influences

A variety of structural elements have influenced the development of the underground landscape. McLean (1983) proposed the recognition of eastern and western structural domains, based upon predominating joint sets. He suggested that the largest chambers at Jenolan were in the eastern domain where the predominant joints were an orthogonal set that dips predominantly to the E and W with lesser influence by a horizontal joint set and a N-S vertical set. In contrast, he saw the N-S vertical joints as dominant in the west. He attributed apparent deviation from this at the Grand Arch and Devils Coachouse to greater flow volumes and proposed that the larger cavities developed closer to the ground surface. These suggestions have not been totally endorsed by later workers but raise important questions for detailed scrutiny.

The greater vertical than cross-sectional development of the caves on the northern side of the Grand Arch compared to those on the southern side was suggested by McLean (1983) to be attributable to major control by N-S trending vertical joints, with E-W dipping joints also affecting chamber shape. Control by vertical joints is evident in Shawl Cave and in the Confectionery Shop in Imperial Cave. Around Ridleys Short Cut control is exerted by E-W orthogonal joints and meanders have been produced by these between Bone Box and Ridleys Short Cut. Bedding and possible cleavage can be observed in Nellies Grotto, Imperial Cave, with small scale faulting observable in the Short Cut and elsewhere. Shear fractures that may be foliations are present in the roof of Mons Meg Chamber in River Cave.

McLean (1983) claimed that the Mafeking Branch had developed primarily under the influence of vertically dipping N-S joints, Lucas Cave under the influence of moderately E-W dipping orthogonal joints, and River Cave a combination of the two. Other noteworthy structural features on the south side are a dyke near the divergence of the high and low levels 40 m from the balcony in Lucas Cave, and a fault exposed at the western end of the Exhibition Bridge in Lucas Cave and in Wiburds Lake Cave (Shannon, 1976a).

Fault control is evident in the Wilkinson Branch of Chifley Cave (Osborne, 1987), in 22 Passage in Wiburds Lake Cave and possibly the Forty Foot in Mammoth Cave (Shannon, 1976a). Fault control has also been claimed to be responsible for the form of Spider Cave further to the north (Cox and Welch, 1984) but work by T.L. Allan (cited in Osborne, 1987a) suggests that parts of Spider Cave are probably controlled by a dyke. Dykes are also exposed in and exert a significant influence upon Wiburds Lake Cave (Shannon, 1976) and Hennings Cave (Welch, 1976). The interface between the limestone and shale is exposed in Contact Cave and in Waterfall Passage in Mammoth Cave where it has exerted a dominant control on its morphology.

Lithological influences

The karst forms are confined to the limestones with only very minor incursions into the neighbouring rocks, as at Contact Cave. At Caves House the limestone is ~235 m thick, with 10 m of cross bedded calcarenite at the base; then 50 m of finely bedded micrite; ~5 m of pebbly limestone with dark mudchips; >150 m of rudaceous limestone; ~10 m of shaley limestone; and ~10 m of cleaved mudstone (Allan, 1986). Osborne (1987a) has observed that most of the caves are developed along the strike of calcirudite facies that are probably equivalent to the rudaceous limestone described by Allan (1986).

Inheritance

As in the surface landscape, the underground landscape of Jenolan contains a number of enigmatic features, termed *palaeokarst*, that it has been suggested may represent a legacy inherited from an ancient phase (or phases) of karstification. Osborne (1984, 1987a,b) has argued that exposure and subsequent reburial of the limestone has led to the evolution of karst landforms during Permo-Carboniferous, Early Tertiary and Late Tertiary times and that early karst deposits have been exposed and truncated in the present caves at Jenolan.

Crystal-filled vugs are exposed in phreatic tubes for about 100 m in from the Showroom in Imperial Cave (long known by the guides as "old Crystal") (McLean, 1983) and imply the development of 1 m diameter cavities prior to the development of the tube. Crystalline deposits and a breccia vein intersect at the far end of the upper branch of Imperial Cave, and crystalline material is overlain by sandstone in the entrance area of Lucas Cave. The crystalline deposits do not appear to have been deformed as has the limestone and were probably deposited in nothephreatic conditions in view of the difficulty in achieving supersaturation in phreatic water (Osborne, 1984).

There are laminated sediments in a number of areas between the sinkhole in Imperial Cave and River Cave. The laminates are present on the eastern wall of Katies Bower, in the Grand Arch on the large rock below Imperial Cave and on the wall behind it and also between the Arch Dig and Lucas Cave, above the tourist path 30 m inside the downstream entrance of the Devils Coachouse, and near the junction in River Cave. They are highly lithified graded beds that sharply intersect the bedding of the Jenolan Caves Limestone, sometimes have an anastomosing form and are tectonically undeformed. Laminated dolomitic sediments occur in Imperial, Cerberus, and River caves in an unconformable relationship to the limestone. Near the entrance to Lucas Cave are horizontal laminates in a clearly unconformable relationship with the steeply dipping limestone. An unconformity is present in Arch Cave. Convoluted laminates occur in Katies Bower in Chifley Cave while at Olympia in River Cave the palaeokarst is faulted. There is slumping in the laminates in the Grand Arch near Lucas Cave. Vertical palaeokarst is associated with horizontal palaeokarst in the Oberon Grotto of Cerberus Cave (Osborne, 1987). However, interpretation of these laminates is complicated by the presence of dolomitic laminates that are conformable with the limestone and are possibly of primary origin in Jubilee, Cerberus, River and Ribbon caves (Osborne, 1987a). Near the downstream sump in the tourist section of Imperial Cave purple shale is present in a bellhole and laminated sediments that appear to be conformable with the limestone exert a major influence on the form of the cave.

Lithified angular block breccias in Lucas Cave and in the roof of Katies Bower contain clasts up to 1 m across, with the boundary between the limestone and the breccia suggesting they may be palaeokarst rather than syngenetic. In the upper branch of Imperial Cave breccia is intersected by crystalline palaeokarst that is probably calcite. One possible origin of a curious structure in a limestone wall adjacent to Carlotta Arch is that it is an ancient recrystallised stalagmite (Osborne, 1987a).

Dolomitic palaeokarst present in the Oberon Grotto and near the second bridge in Cerberus Cave and forms roof pendants near the Pool of Cerberus. There is a crystal vug in dolomite in the Oberon Grotto. Dolomitic palaeokarst is also present in River Cave in the Mossy Rock-Furze Bush area and at the Olympia Steps the horizontal palaeokarst is unconformable with the steeply dipping limestone. Osborne (1987a) observes that many occurrences of aragonite speleothems at Jenolan are associated with dolomitic palaeokarst, as in Ribbon Cave. He attributes the dolomitic palaeokarst to seawater having flooded pre-existing karst when the Sydney Basin sequences were being deposited during the Permian. Osborne (1987a) has recorded phosphatic and reaction rims on some ancient cave sediments, as near the Olympia ladder in River Cave, and argues that some Early Tertiary cave sediments were lateritised later in the Tertiary.

The present caves

Less contentious than the palaeokarst are those underground karst features that are clearly the product of the same phase of karstification as is responsible for the cave systems as we presently know them. However, it may be difficult to differentiate between a filled cave, palaeokarst and relict karst (Osborne, 1987b)

To the north of the Grand Arch there is abundant evidence of cave development in varying hydrological contexts. Phreatic speleogens are visible in the roof in many areas with a small phreatic tube present at the Whales Throat in Jubilee Cave and there is a probable bathyphreatic loop between Imperial Cave and Blue Lake that reaches a depth of -23 m. Other noteworthy phreatic speleogens include spongework near the Duckunder in the left hand branch of Jubilee Cave; the phreatic morphology of the eastern wall near Katies Bower in Chifley Cave and pendants in the upper branch of Imperial Cave that are possibly the result of secondary solution. Epiphreatic speleogens are evident at sites such as the approach to Ridleys Short Cut (McLean, 1983). Keyhole passages are present between Lucinda Cave and Katies Bower in Chifley Cave, and also further north in Mammoth Cave below the Skull and Crossbones. Vadose speleogens are widespread with a readily accessible vadose canyon at the Flitch of Bacon and a well developed sinuous passage in Serpentine Cave and on the route to Ice Pick Lake in Mammoth Cave. Paragenetic speleogens produced by erosion above a gravel fill are present in the Railway Tunnel of Mammoth Cave, Serpentine Cave and McKeowns Hole.

The easily accessible Grand Arch and Devils Coachouse exhibit a variety of speleogens that are well suited to interpretation. Ceiling half tubes, anastomoses and roof pendants are also present in the Grand Arch. The upstream entrance of both the Grand Arch and Devils Coachouse exhibit epiphreatic roof profiles, while channel incuts are present on the northern wall of the western part of the Grand Arch, and around the southern entrance to the Coachouse. Wall scallops are easily accessible in the Grand Arch. The downstream entrance of the Grand Arch is primarily of collapse origin, as are the daylight holes and other areas of the Devils Coachouse where joint control of the cave geometry is very obvious. It has been suggested on the basis of likely incision rates that Carlotta Arch, which lies 60 m above Blue Lake, probably dates from the Tertiary.

On the south side of the Grand Arch, Lucas Cave contains high domed chambers that form part of a series of phreatic loops and also contains areas of collapse where joint systems exert the predominant control on cave geometry. The former includes the Cathedral Chamber which is 50 m high; the latter includes the Exhibition Chamber which is 75 m X 43 m X 9 m high (Dunlop, 1979). In the absence of a suitable map the origin of the caves has not yet been fully resolved. Mons Meg Chamber in River Cave has variously been argued to be almost exclusively vadose (McLean, 1983) and the top of a phreatic loop with later channel incuts (Osborne, 1987a). Good examples of speleogens related to the hydrological conditions that existed during evolution of the caves are phreatic loops in the area around the Cathedral Chamber and the Slide in Lucas Cave and on the southern side of the Grand Arch; ceiling pockets in Queen Esthers Chamber of River Cave, north of Mons Meg, in the Persian Chamber of Orient Cave and at the Egyptian Colonnade also in Orient Cave; dolomitic roof pendants near the Pool of Cerberus and other pendants in Paradox Cave; vadose shafts that intersect the epiphreatic roof of Cerberus Cave; the keyhole passage at the southern end of the Cathedral in Lucas Cave; and channel incuts near the Reflection Pool in River Cave.

Cave sediments

The cave sediments at Jenolan include a variety of speleothems that are primarily but not entirely formed of calcium carbonate, and also include clastic deposits that range from entrance facies that include aeolian contributions, through breakdown facies to alluvial deposits.

The speleothems include an abundance of the common dripstone forms such as stalactites, stalagmites and columns. In the Exhibition Chamber of Lucas Cave primary (straw) stalactites are restricted to areas where no collapse has occurred, while secondary stalactites occur at the Home of the Fairies. Primary stalactites are also present in Mafeking Cave. Flowstone is also common, impressive examples including the 60 m long Queens Canopy and the Home of the Fairies in Exhibition Chamber, Lucas Cave. Flowstone commonly forms false floors, as in Nettle Cave. Well developed gours are present at the Crystal Cities, Imperial Cave. A possible shield is present in Alladin Cave. Among the larger shawls are those in Mons Meg Chamber in River Cave, and the Angels

Wing in the Temple of Baal. Cryptalgal stalagmites ("craybacks") are well developed in Nettle Cave, and more rudimentary examples are present in Paradox Cave in the "Southern Limestone". Initially regarded as phototropic (Cox, 1984) they appear to rather be the result of wind-blown traces of drip water. Cave coral is well developed in the Indian Chamber of Orient Cave. Coralline overgrowth on flowstone is present in the southern section of some of the northern tourist caves, as in the Lucinda Chamber of Chifley Cave.

Excellent displays of helictites occur in a number of caves, including Orient Cave and Cerberus Cave at its upstream end. Heligmites are prominent at the Pincushion in Jubilee Cave, in the Sydney Smith Cavern and in the Whit Temples area in River Cave. Pool crystal is present in the Sydney Smith Cavern, calcite variously occurring at Jenolan as Dog Tooth Spar, Nail Head Spar and Hopper Crystal (E. Holland, pers. comm.). The presence of "old crystal" in Imperial Cave has already been noted, together with its subaqueous origin. Good displays of intact speleothems remain in the Chevalier and Loubens extensions of Glass Cave, in Barralong Cave and elsewhere.

Most of the speleothems consist of calcite but aragonite speleothems of both coralloidal and acicular form occur in association with dolomitic rocks in Ribbon Cave, at the Pincushion in Jubilee Cave and elsewhere, probably because magnesium concentrations are highest there (Osborne, 1987). Other minerals known to be present in the caves include dolomite, nitrates, mondmilch, phosphates (Mingaye, 1899), limonite, hematite, and goethite. Cerussite, azurite and malachite occur in association with electrical cables that contain lead and copper. Siderite, pyrolusite, psilomelane, pyrite, gypsum, epsomite, hydroxylapatite and leucophosphile may also be present (E. Holland, pers. comm.). Speleothems of ice occasionally form in the Devils Coachouse and Grand Arch.

The clastic deposits exhibit considerable variety. Sandy entrance facies that are reddish in colour and contain angular limestone clasts are present in some cave entrances. Among the vertebrate remains that have been reported from the caves of Jenolan are *Thylacinus cynocephalus* from Jersey Cave; *Sarcophilus harrisii* from Imperial Cave; *Macropus giganteus; Ratus fuscipes; Petrogale pencillata; Miniopteris sp.*; and *Homo sapiens* washed into Cerberus Cave. Bones of Pleistocene age have been reported from Imperial Cave and a small cave above the guides office.

The gravels vary in lithology and calibre according to the predominating rock types in the present and former catchments of the cave streams. The clasts are generally well sorted and well rounded. Highly cemented conglomerates are present in Dreamtime Cave (Osborne, 1987a). Conglomerate fills are also present in The Verandah and Peter Lambert caves (Welch, 1976). Differences in clast calibre are evident in different parts of the caves. For instance, on the northern side the coarse cobbles and boulders occur to very high levels, reaching almost to the old entrance of Elder Cave and being prominent high in the Coachouse, in Arch Cave, and further north in Dreamtime (Osborne, 1987a). Such gravels predominate in Imperial and must have been deposited by high energy streams. They are well exposed in the descent to the Underground River and the passage to Chifley Cave in Imperial Cave; near Katies Bower in Chifley Cave; at Cooks Cavern, Victoria Bower and Alabaster Hall in Jubilee Cave, and in the Grand Arch near the entrance to Imperial Cave.

Fine gravels, sands, clays and silts occur in the Water Cavern of Jubilee Cave, where alternating beds of fine gravel and clay have inundated carbonate speleothems several metres above normal water level. A charcoal horizon is present in the sands at the Sinkhole in Imperial Cave. At Fairy Bower in Imperial Cave, flowstone overlies laminated clays with ferruginous cement, liesegang rings and botryoidal nodules. Carbonates also clearly postdate the clays and gravels at the Whales Throat in Jubilee Cave, at Molochs Grotto in the Temple of Baal and elsewhere. There has been secondary phreatic solution of the carbonates that overlie the gravel in Elder Cave (Osborne, 1987a). Remnants of finer fractions are scarce in Imperial Cave but the existence of "loose leaf" flowstone sheets around Model Cave and the Queen of Diamonds indicates that fine sediments were interbedded with the flowstone. Silts predominate over gravels in some areas as in the upper levels of the breakdown chamber beyond Sump 4 in Imperial Cave and in parts of Wiburds Lake Cave and Mammoth Cave (Shannon, 1976a; Osborne, 1987a). Mud speleothems are present in Wiburds Lake Cave (E. Holland, pers. comm.). The most recent silt deposits in some of the caves of the Northern Limestone may have been deposited in response to land management practices higher in the catchment of the Jenolan River. Downstream from the Pool of Cerberus in Cerberus Cave fine films of clay delineate floodlines up to 6 m above normal stream level.

On the south side of the Grand Arch, the principal occurrences of gravels, silts and clays are in areas such as the Red Cavern and Queen Esthers Chamber in River Cave, but they are also present elsewhere such as at the Giant Slide, Cathedral Cavern and Bone Cave in Lucas Cave. The boulders present in the high levels of Imperial Cave are in contrast to the much finer deposits presently being moved through the sumps in the Imperial Cave streamway, but are comparable to stranded boulders in the Devils Coachouse that are occasionally moved when the Jenolan River is in flood. Loose fine sandy deposits in some areas, including the Grand Arch, may be of aeolian origin (N. Michie, pers. comm.).

The most striking example of breakdown deposits occurs in the Exhibition Chamber of Lucas Cave and the Wilkinson Branch of Imperial Cave. It appears to be unstable at the entrance to Alabaster Hall in Jubilee Cave. Breakdown deposits associated with possible palaeokarst are widespread in the eastern part of the Grand Arch (Osborne, 1987a).

The cave deposits at Jenolan are varied and represent a very major asset of the areas in both scientific and scenic terms. There is diversity in the range of speleothems and in the minerals found in the caves. The variation in the calibre of the clastic deposits probably reflects changes in stream energy related primarily to past climatic changes. Detailed study of these deposits is likely to shed considerable light on the evolution of the Jenolan Caves and radiometric dating of the associated speleothems may permit numerical estimates of the age of various parts of the caves. Moreover, because the cave deposits cannot be fully understood without equally thorough examination of the surficial deposits above ground, proper study may well shed considerable light not only on the evolution of the caves but also that of the surrounding landscape.

SUMMARY

On a broad scale the geomorphological resources of the Jenolan Caves area are diverse and interesting phenomena that are by no means restricted to the karst. Within the karst terrain which is the best known attribute of the area there is also considerable geomorphic diversity which arises in large measure from interaction between a variety of influences. This karstic diversity is the more remarkable given the quite limited extent of the limestone. The density of karst features, particularly the caves around the Grand Arch, is also remarkable. Good prospects remain for further discoveries in a number of areas, including the area beyond Barralong Cave into the Southern Limestone, the area upstream of Mammoth Cave where the long theorised Woolly Rhinoceros system still awaits, and the area known as the Hairy Diprotodon between Mammoth Cave and the northern tourist caves. An adequate appreciation of the origin and character of the karst, including the evolution of the caves and the origin and age of the sediments within them, rests upon a full appreciation of the nature and impact of the non-karstic geomorphological context.

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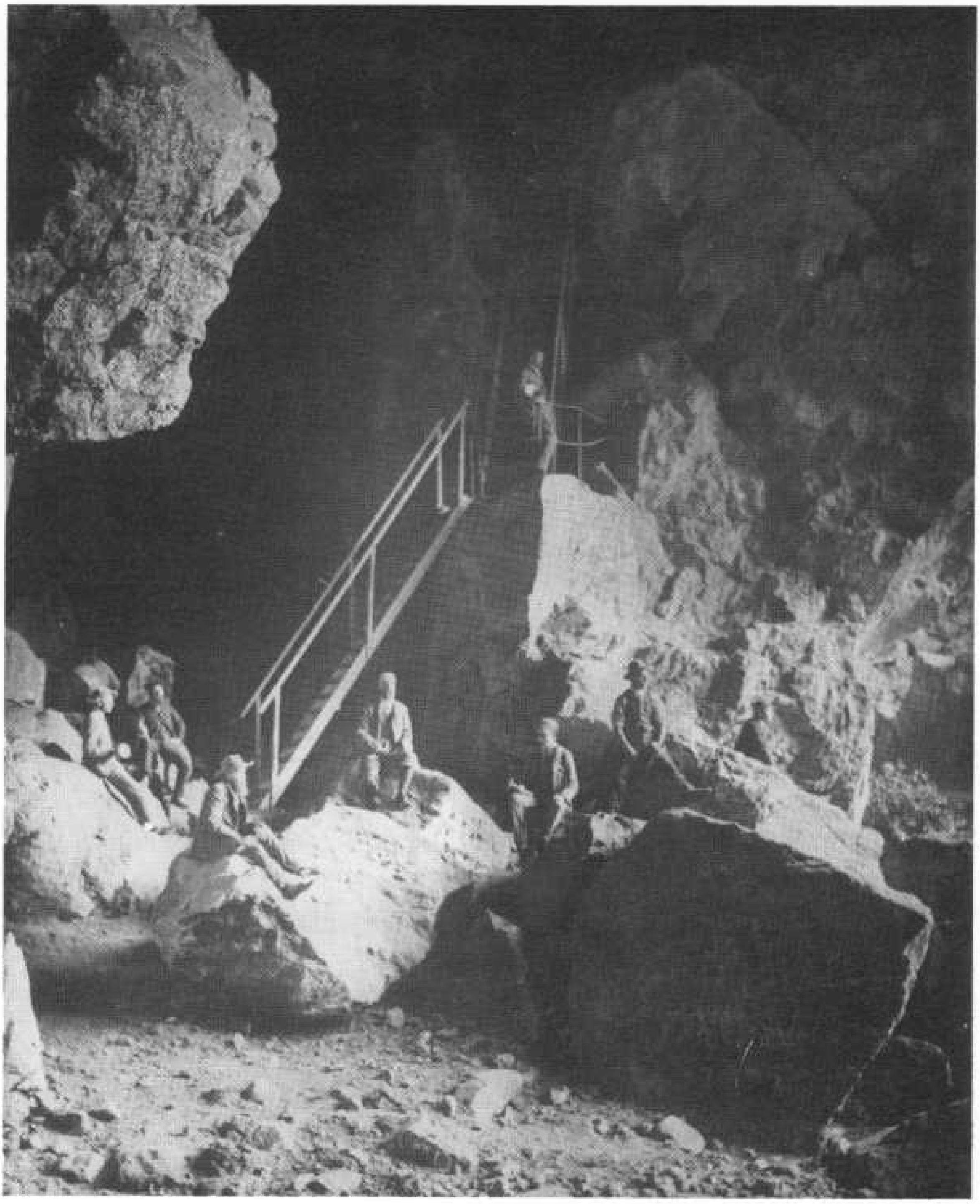

Plate 1

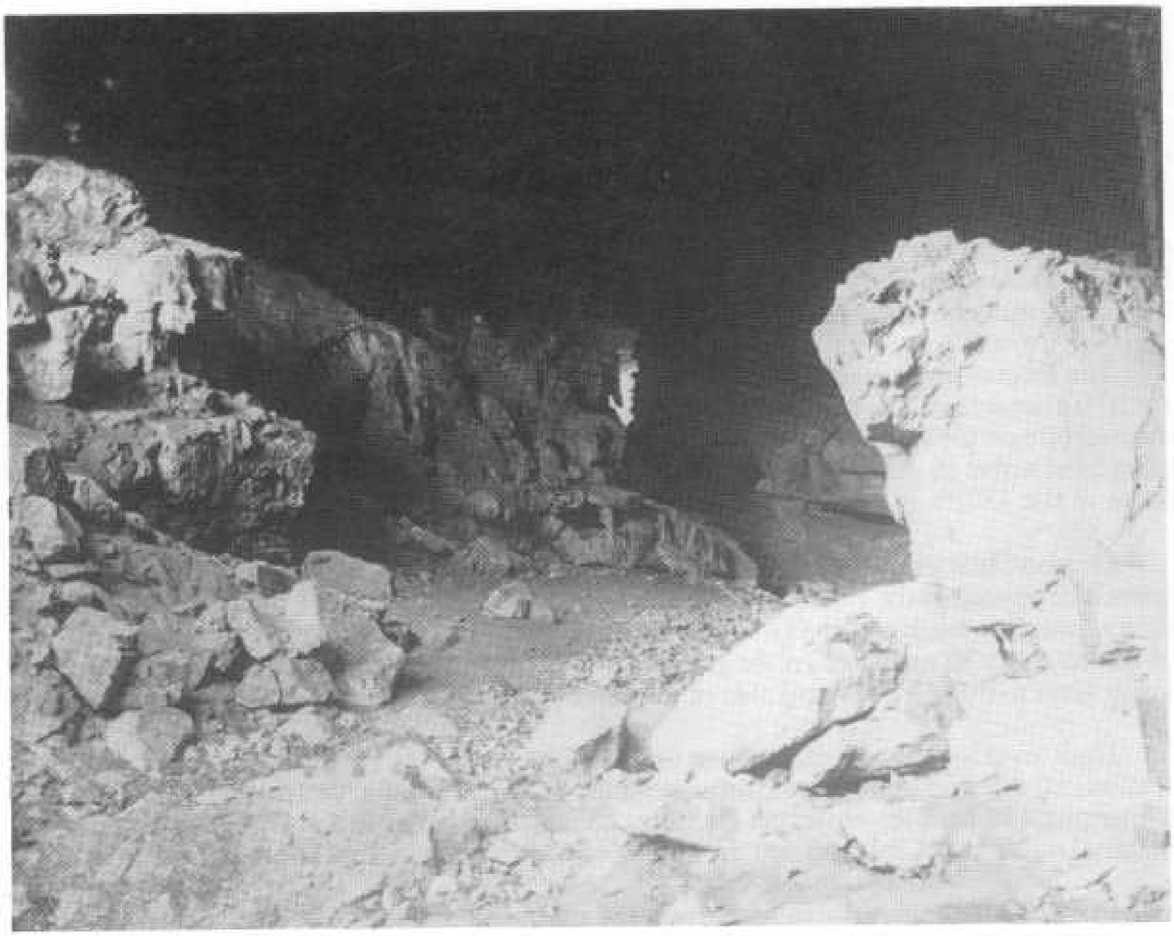

Plate 2

EVIDENCE FOR THE ORIGINAL ROUTE AND CONSEQUENCES OF THE CHANGED ROUTE OF THE GRAND ARCH STREAMWAY, JENOLAN, N.S.W.

Ernst Holland

It has always been assumed that the waters of Camp Creek flowed into the western end of the Grand Arch and out into what is now the Blue Lake at the eastern end of the Grand Arch. This assumption is based on the natural misconception that Camp Creek has been responsible for the development of the Grand Arch in its entirety. It is believed that the formation of the Grand Arch is in part due to the waters flowing from McKeowns Creek in the north. This is evident from vadose canyons in its roof and morphological evidence suggesting that the eastern end of the Grand Arch has been modified by collapse.

Observations made over a number of years while working at Jenolan, historical anecdotes and old photographs form the basis for this note. Map 1 shows the locations of Camp and McKeowns Creeks, the Grand Arch and associated caves. Ron Newbould (pers comm) started the inquiry when he read an unknown publication which contained some form of the following statement;

"If you spent the night sleeping on Mr Wilson's dance floor you could wake up with the sun shining into the Grand Arch and the running stream behind you".

As the sun fixes the position of the dance floor in its presumed position the stream mentioned must be against the north-west wall of the Arch.

Historical evidence lies in two photographs. The first (Plate 1), which dates from about 1870, was taken from the eastern end of the Grand Arch (see figure 1 for location). It indicates that the natural floor level was about three metres below an incut which is now only one metre above the present artificial floor.

The second photograph (Plate 2) was also taken from the eastern end of the Grand Arch. It shows there are no water worn rocks between Camp Rock on the north side and the rockpile on the south side. There is some evidence of an overflow channel which may have been active in very high flood flows. This photograph is also believed to have been taken in the 1870's.

Geomorphological evidence, in the form of scallops, incuts and the imbrication of the gravels deposited in the Flitch of Bacon, suggests that Camp Creek flowed through the narrow western section of the Grand Arch, then followed the northern wall into the Flitch of Bacon some 20 metres from the gate. The waters then abandon the cave flowing to a lower level to the left (western) side of the cave.

High level incuts occurring above the present ones show channel development with scallops all the way into Katies Bower in Chifley Cave. This suggests that even at this earlier phase of cave development the flow channel was similar to that which prevailed before the placing of the road and the cutting of the drainage channel for Camp Creek.

In 1978 a high intensity rainfall event (58 mm in 50 minutes) caused a sharp flood in Camp Creek. The rubbish grille blocked and water began running down the roadway and across into the Flitch of Bacon and thence down and out of the passage mentioned above.

Examination of the sediments in Flitch of Bacon revealed rubbish of a manufactured nature probably washed into the cave over the past 120 years. In 1984 a new sewage line for Caves House was cut through the Arch. In the vicinity of the incut the channel was cut through fill of recent origin. At the eastern end, the same channel runs into limestone bedrock at least one metre above the bottom of the channel at the incut end.

It is therefore suggested that the original course of Camp Creek was through the narrow western portal of the Grand Arch and down into the Flitch of Bacon Cave. Interference with the system has diverted the creek from north to south side, thus reducing the flow through the Imperial Cave river system and rising in favour of south side risings.There is a side passage off the main Imperial streamway that is filling up with recent sediments (Ron Allum, pers comm), This could possibly be the old connection through to the Flitch of Bacon Cave.

This may have significance for the deposition of gravel in the lower Imperial Riverway as the reduced flow would have less erosive power. The old Hydro Weir, and indeed the Blue Lake impoundment, may well have compounded sediment deposition by raising the water levels in the Imperial Riverway.

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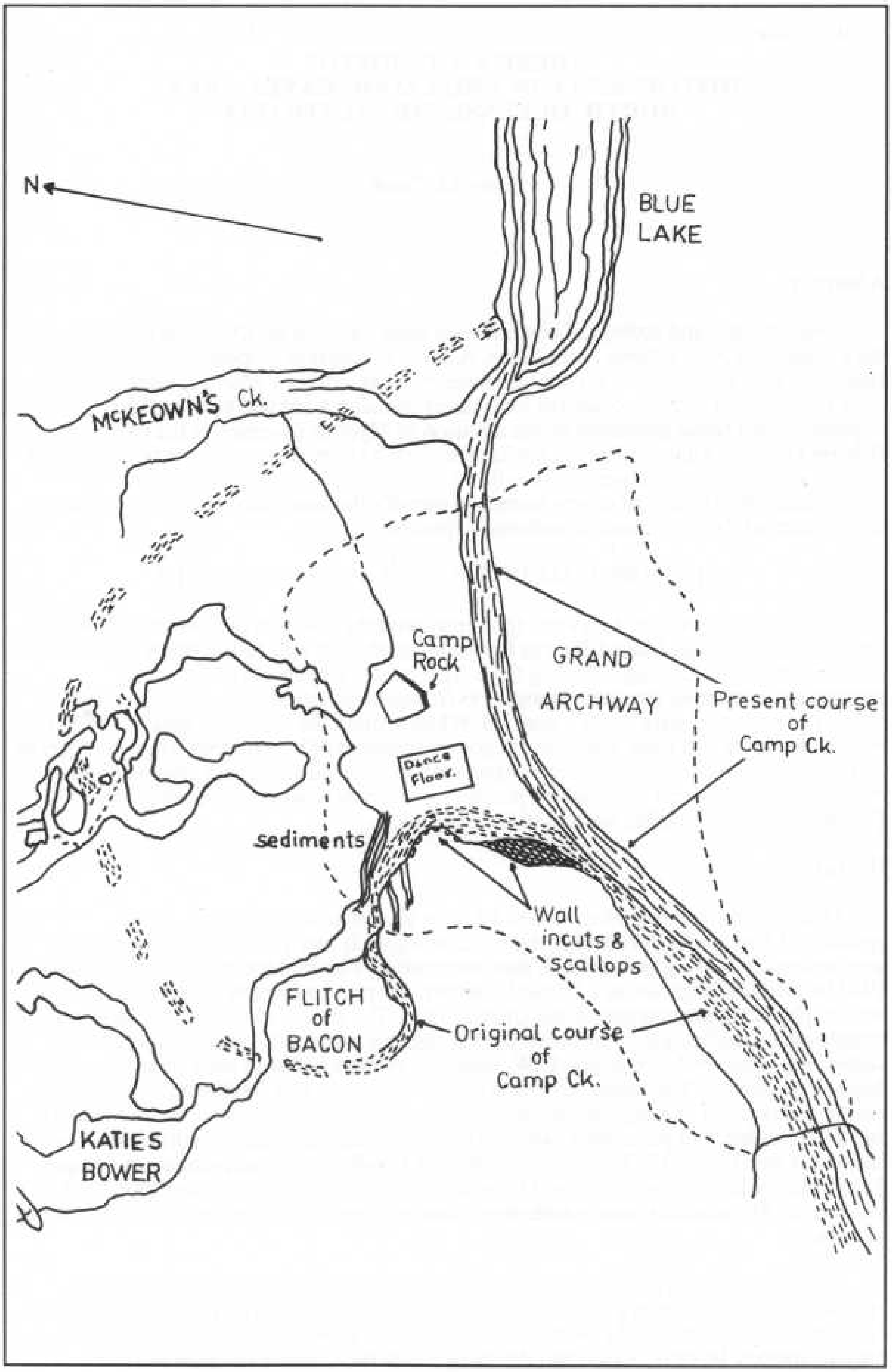

Figure 1. The Grand Archway, Jenolan Caves. Based on the survey by O Trickett.

WHERE'S THE HISTO? HISTOPLASMA IN CHILLAGOE CAVES AREA, NORTH QUEENSLAND, AUSTRALIA

Eileen M. Carol

Abstract

Ideal climatic and ecological conditions in many caves in the Chillagoe area suggest the existence of *Histoplasma capsulatum*. A study in progress proposes to identify those caves that may be reservoirs for the organism, thus presenting a potential health risk for cave visitors. Soil samples collected from caves containing bat and bird (swiftlet) populations are being processed by the Division of Mycotic Diseases, at the Center for Disease Control, Atlanta, Georgia. Preliminary results from 15 caves have been negative, thus a more precise technique will be utilized in further collections. Intradermal histoplasmin skin testing of cavers intends to identify the possibility of cave exploration as one source of *Histoplasma capsulatum* exposure.

HISTOPLASMA IN THE CHILLAGOE CAVES AREA

In the late 1970's, Dr. Anil Patel (presently with the Division of Specialized Health Services Tuberculosis Chest Clinic in Brisbane) conducted skin testing for histoplasmosis on members of the Chillagoe Caving Club. Test results were positive for many individuals, indicating previous exposure to *Histoplasma capsulatum*. However, the sources of exposure were never identified. While visiting the Chillagoe area in 1982, it became apparent that there were several possible sources of histoplasma: large numbers of surface birds and caves harbouring bat and swiftlet populations. These observations evolved into the present study which proposes to determine which cave sites in the Chillagoe area are possible sources of histoplasma.

History

Histoplasma was first identified in 1905, in the Panama Canal Zone, by the pathologist Samuel Taylor Darling during an autopsy. It was 1932 before the organism was isolated in a living person, and, then successfully cultured the following year. In 1943 its original diagnosis as a tropical disorder was proven incorrect during selective service physical examinations in the United States. The review of chest films showing intrathoracic calcification in the presence of a negative reaction to tuberculin produced suspicions of an unknown entity. C.W. Emmons in 1944 believed such changes were due to histoplasma. The following year a nationwide study was conducted on student nurses and resulted in a high degree of correlation between histoplasmin skin sensitivity and x-ray evidence of pulmonary calcification in tuberculosis negative individuals (Schwartz and Baum, 1957). Since most of these people were asymptomatic, a benign form of histoplasmosis was believed to exist. Serologic methods were developed and by 1952, over 30 epidemics were subsequently studied, identifying the typical pattern for the disease.

C. W. Emmons (1949), the first mycologist of the Public Health Service, first cultured histoplasma from 2 of 387 soil samples from a mound of dirt under the edge of a chicken house. Examinations conducted in 1120 small animals yielded histoplasma in only 10 species. In 1951, Ajello and Zeidberg established epidemiological evidence indicating chicken houses as favoured sites of *H. capsulatum*.

"Cave sickness" was described by Washburn (1948), from three separate outbreaks in individuals with the commonalty of visiting caves. However, the causative organism was not identified. Numerous cave associated occurrences have been reported in the United States since then (Hasenclever, Shacklette, Young and Gelderman, 1967; Sacks, Ajello, and Crockett, 1986). Lewis (1974) provides an extensive review of cases of histoplasmosis in cavers in the United States through 1974.

In contrast, by 1976 only eight cases of histoplasmosis had been diagnosed in Australia since the disease was first identified in 1953 (Ibister, Elliott, and Nogrady, 1976). Of these, five Australians had never left the country, and two were international visitors. The first cave related cases were associated with Church Cave (a bat nursery cave), N.S.W., in 1972. The inability to isolate the organism at that time resulted in an investigation that was conducted in the cave from 1977 to 1983 (Hunt, Hardin, Hibbins, Pritchard, Muir and Gardner, 1984). Samples were collected at different times of the year, utilising five different techniques and resulted in the isolation of *H. capsulatum* on only one occasion. Of the eight individuals visiting this cave during this period, only three contracted histoplasmosis.

Four extensive epidemiological surveys utilising histoplasmin skin testing have been conducted in Australia at Rockhampton, Sydney Eye Hospital, Brisbane Chest Clinic, and Royal North Shore Hospital in Sydney (Ibister et al, 1976). Though several thousand individuals have been tested, positive results were obtained in only fifteen individuals. To date, the actual incidence of histoplasmosis and source of the organism in Australia is unknown.

THE ORGANISM

Natural History

Histoplasma capsulatum, the organism causing histoplasmosis, has worldwide distribution. The fungus is dimorphic, allowing it to exist in a mycelial (thread-like) form on decaying organic matter in the environment. The infectious spores are inhaled by susceptible animals and enter a yeast-like phase.

The organism has been found throughout the United States with about 500,000 new cases identified each year (Schlaegel, 1977). Endemic in the central and southern portions of the country, where about 90% of cases originate (Hoff and Bigler, 1981). To date, no systemic studies have been performed in Australia to determine the occurrence of the organism. It seems likely that histoplasma does exist in the country, with isolated caving regions providing suitable environmental conditions.

Ecology

Suitable macro-climactic conditions, soil harbouring *H. capsulatum*, and animal feces are necessary for the proliferation of the organism. The ability to recover the organism from the soil in an endemic area is low, and the level of recovery from soil and guano in a given cave is influenced by micro-zoological cycles within the cave environment (Shacklette and Hasenclever, 1968). Though bats and 17 species of wild and domestic animals are known to be accidental hosts of *H. capsulatum*, only bats are considered to play a significant role in the epizootiology of the histoplasma (Emmons, Klite, Baer and Hill, 1966; Hoff and Bigler, 1981).

Bats

Emmons (1958) first reported the importance of bats in the ecology of *H. capsulatum* in urban areas in 1956. Bats are indirectly responsible for providing a suitable environment in which the fungus can grow. The organism has been isolated from bat guano shed by infected animals throughout the world (Di Salvo, 1971; Emmons et al, 1966).

The presence of the fungus in the organs of naturally infected bats was identified in 1962 (Hasenclever, 1972). Bats become infected via their respiratory tracts, the organism spreading from the pulmonary system to other organs, primarily the liver, spleen and the gastro-intestinal tract. It was found that as few as 100 viable mycelial cells could stimulate the natural defense mechanism (both humoral and cell mediated immune response), causing disseminated disease in 10% of the bats. If death occurred from this dissemination, it did so in 2-3 weeks (Di Salvo, Ajello, Palmer, and Winkler, 1969; Greer and McMurray, 1981). Because of their natural exposure, bats often have chronic controlled infection. This allows them to seed the organism into the environment. Acquiring the infection by inhalation of the fungus, bats are able to excrete the fungus through the gastro-intestinal tract. A short intestinal transit time (15 minutes) allows for active multiplication of the viable yeast cells and shedding in the feces (Hoff and Bigler, 1981). It is important to note that histoplasmosis cannot be contracted through bat feces or urine, the excreta acting only as nutrient for the growth of the organism (Carvajal-Zamora, 1977c; Shacklette, Hasenclever, and Miranda, 1967).

Natural histoplasmosis is found in most species of neotropical fruit eating bats (Di Salvo, 1971). Several authors identify other species of bats more likely to be infected (Di Salvo et al, 1969; Emmons et al, 1966; Greer and McMurray, 1981). Since no studies have been conducted to determine the occurrence of *H. capsulatum* in Australian bats, it is impossible to determine any actual threat from bats in caves, attics and trees.

Birds

Avian habitats are especially suitable for *H. capsulatum*. Readily accessible areas such as chicken coops, starling and grackle roosts have been identified as principle sources (Ajello, Hosty and Palmer, 1967). The presence of histoplasma in roost sites does increase exposure rate to histoplasmosis, especially when the site is disturbed (Chick, Compton, Pass, Mackey, Hernandez, Austin, Pitzer and Flanigan, 1981). In the parasitic phase, *H. capsulatum* prefers temperatures of 37°C (98.6°F). Because of high internal temperatures, it is unlikely that infection exists or has ever been documented in birds (Hoff and Bigler, 1981). Much of the endemic infection in the central United States is thought to be due to bird roosts.

Environmental Conditions

The habitat, rather than the species of bat or bird, may be the major factor in determining whether or not a bat or human becomes infected. Conditions influencing the growth and survival of the fungus include temperature, humidity, pH and composition of the soil (Di Salvo, Bigler, Ajello, Johnson and Palmer, 1970). Growth of the organism is due to the interrelationship of all factors.

Air

A relative humidity from 68-90% or more, pools of water in a cave, and an annual rainfall of 800-1250 mm encourage the growth of *H. capsulatum* (Di Salvo et al, 1970; Furcolow, 1958). Growth in the saprophytic (environmental) phase is optimal with a mean annual temperature of 22-29° C. Certain coastal regions of Queensland provide these optimal conditions.

Distribution of spores in the air occurs from the pattern of air currents. Only relatively small currents are needed to maintain the suspended particles of mycelium or spores of *H. capsulatum* and disburse them through the cave. The flapping of bat wings often provides this dispersal (Carvajal-Zamora, 1977b). Spores can remain suspended in the air for long periods, allowing for individuals to become infected when exposed to the cave atmosphere, even when bats are not present (Shacklette et al, 1967).

Water

Though a sufficient humidity is necessary for growth of histoplasma, flooding of caves decreases the number of soil particles as well as the number of *H. capsulatum* in the air, soil and water. Wet caves often inhibit spore dispersal and may actually account for low rates of histoplasmosis sensitivity (Di Salvo et al, 1970). However, it has been found that mycelia can remain viable for 180 days or longer at 20° C during flooding, and in fact remain in the mud until the water has receded. Following flooding and with a return to favourable growth conditions, the organism will flourish after a 2-3 month period (Shacklette et al, 1968; Hasenclever, 1972).

Soil

The pH, the humidity and the temperature of the soil were found to play a major role in supporting the organism. Carvajal-Zamora (1977a) found that a pH greater than 5, a relative humidity 90-96%, and a soil temperature between 23-25° C best supported *H. capsulatum*. Even in highly endemic areas, the fungus has been difficult to isolate from the soil. Depth of the sampling was found to be a significant factor, with greater depth (8-20 cm) yielding better results.

Contamination with either avian (bird) or chiroptera (bat) feces is necessary for colonization of the soil by *H. capsulatum*. Furthermore, an active insect population with formation of small tunnels tends to aerate the soil and optimise the growth of the organism (Carvajal-Zamora, 1977a). Consequently, mechanical disturbance of the soil containing the fungus is needed for infective particles to become airborne. The organism has a proclivity for sustaining itself. It was found that even after the source of excrement had been removed from one area for 5-6 years, the organism persisted and continued to be distributed randomly (Hasenclever and Piggot, 1974).

The interaction of nutrients from excreta of bats and birds, prolonged periods of medium temperature, a high humidity of the soil and the air, a certain soil texture, and bat presence produce an environment highly suitable for the growth of *H. capsulatum*. When humans interact with that environment, they expose themselves to the possibility of acquiring the disease.

THE DISEASE

Epidemiology

Histoplasmosis, an acute febrile respiratory disease, has been recognized for many years in cave visitors (Constantine, 1970; Di Salvo, 1971; Washburn, Touchy, and Davis, 1948). Man, as well as other animals (cat, dog, mouse, brown rat, skunk, opossum), are accidental hosts. Chickens may harbour the organisms for a few weeks, but, cannot maintain it, because of their high body temperature. Bats are more likely to be chronic carriers, harbouring the fungus for years. The majority of human infections have been traced to harbourages such as caves and trees where there is an intense exposure to fungi laden soil and guano.

Inhalation of spores from the soil is the usual route of infection, though spores can be inhaled from dust and contaminated clothing. Incubation is generally from four to twenty-one days (Hasenclever, Shacklette, Young, and Gelderman, 1967), but, can occur up to forty-four days (Sacks et al, 1986). Re-infection is possible, either from different histoplasma strains, or, from an overwhelmed immune system. Occasional exposures are believed to be necessary to maintain a protective level of acquired immunity. The disease cannot be passed from person to person.

Clinical Presentation

Histoplasmosis can take various forms. More common are the asymptomatic and benign acute respiratory types. Infrequently, serious chronic pulmonary and disseminated fatal conditions can develop (Wilcocks and Manson-Bahr, 1972). The primary cases are asymptomatic and benign respiratory infections. They resemble influenza, last from one to three weeks, and are followed by complete recovery.

There is usually a lesion at the site of infection which is likely to be pulmonary. Oropharyngeal lesions (mouth and throat) are not uncommon and had been identified in six of the Australian cases (Ibister et al, 1976).

Ocular Syndrome

It is not clear whether histoplasma actually causes the syndrome delineated as presumed ocular histoplasmosis syndrome. The first suspected cases occurred in the early 1940's in the United States. Subsequent studies followed with the development of the histoplasmin skin test. Following routine histoplasmin skin testing, individuals with a certain form of uveitis (inflammation of the pigmented and vascular layer of the eye) had a flare-up of their disease. Since other organisms provoked a similar response, histoplasma could not be identified as the sole causative agent even with circumstantial evidence (Schlaegel, 1977).

The ocular syndrome has not been associated with active histoplasmosis. Instead, it is more likely considered to be a hypersensitivity reaction, an immunological inflammatory reaction, induced by healed sub-clinical disease (Chessin, Hoffman and Sabath, 1988). This probable recurrence often develops months or years after the first episode of histoplasma infection. In fact, histoplasmin skin testing exacerbates the lesions and is used as a diagnostic tool.

This syndrome was first reported in Australia, in 1971, in a visiting American geologist (Hendrick and Thompson, 1971). Mention is made of the disorder because several cases have been reported from the Atherton Tableland area, supporting the evidence for *H. capsulatum* to exist in this area.

Diagnosis

There are three serologic tests (immunodiffusion, complementfixation, latex agglutination) that are in general use for diagnosis of histoplasmosis. Since they may not be extremely sensitive in diagnosing active disease all the time, culture from the primary site is considered the diagnostic gold standard. Chest x-ray is also beneficial in revealing the typical lesions which are often identified as "buckshot" in the lungs (Utz, 1972).

Skin testing does not identify active disease and may actually interfere with serologic (blood) testing if disease does exist (Chessin et al, 1988). Positive skin testing with a dilute filtrate of *H. capsulatum* does usually indicate past infection.

Treatment

Many patients with acute benign histoplasmosis recover spontaneously. Those who are seriously ill require treatment, generally with intravenous fungicidal Amphotericin B for a six week period. Corticosteroids may also be given to these individuals (Chessin et al, 1988).

PRESENT STUDY

The purpose of the study is two-fold. Primarily, it is intended to determine the presence of *H. capsulatum* in soil, guano, and bird dropping in caves and associated areas frequented by bats, swiftlets, and large groups of birds. Secondly, histoplasmin skin testing will be provided to determine previous exposure to histoplasma in the population of cave explorers.

HISTOPLASMOSIS STUDY RESULTS MAY 1986

CAVE	N°	COLLECTION SITE	RESULTS
CH193 KIWI Dumpy Tower	Al	Bat guano, rear of chamber	negative
	A2	few bats seen	negative
	A3		negative
CHI2 SPRING	A4	Pretties chamber	negative
Spring Tower	A5	Down passage from big boss (95° stalag & 25° pretties)	negative
	A6	30 m down joint from stalag boss in side passage toward entrance adjacent brig station	negative
	A7	South end of 2nd parallel, between 2 daylights, left of rockfall	negative
	A8	3rd parallel, cargo chamber. L side	negative
	A9	Opposite end of A8 in cargo chamber	negative
	A10	Track sample at boss	negative
CH26 CLAM (no swiftlets, few bats)	A11	Base of guano pile, along wall under nests	negative
	A12	Top of guano pile	negative
	A13	Small deposit near entrance passage	negative
CH223 PIONEER	A14	Near hole in track, damp floor with some decaying matter	negative
	A15	Damp earth floor with thin layer of guano	negative
CH312-Proj.31 JACK & NEWELL	A16	Main terminal chamber, swiftlet roost and nest site, no birds seen, very warm cave	negative
	A17	Bottom of terminal chamber, bottom of guano pile	negative
CH362 HERCULES	A18	Top of bird dropping pile below 15 swiftlet nests, fresh droppings, no nests in use at present	negative
CH374 CH322 SWIFTLET SCALLOPS	A19	Collected from bird dropping pile below 30 swiftlet nests. Nests in use, presence of bird ticks	negative
CRAWFORDS CHICKEN RANCH	A20	Dropping pile below battery hens One of the 2 large chicken farms in the area, 8 km from city centre	negative
COLLINS #1 CAVE SPRING CREEK STATION	A22	Bat guano pile, rear of cave, damp	negative
	A23	Shelf on wall, 1.7 m high, dry	negative
	A24	Dry floor with mold growing	negative
	A25	Base of large bat guano pile, damp on top and dry on bottom (cave contains many bats later in year, + maternity site, (6 bats at present, soil on cave floor)	negative

HISTOPLASMOSIS STUDY RESULTS MAY 1986

CAVE	N°	COLLECTION SITE	RESULTS
TWO-TEN CAVE SPRING CREEK STATION	A26	From small, damp, mouldy bat guano pile at rear of cave	negative
LONG SHOT SPRING CREEK STATION	A27	From small guano piles on floor, mould present, 75 m from end of cave	negative
	A28	small guano pile on floor, mould present, 25 m from end of cave	negative
BAYLISS UNDARRA SYSTEM	A29	All from passage, very small bat guano piles, 20 m from ""wall"	negative
	A30	10 m from "wall", high $C0_2$ in cave	negative
	A31	25 m from "wall", some mold	negative
DARCY CAVE UNDARRA SYSTEM	A32	20 m from terminal, taken 2 m from wall, damp floor, bat guano	negative
	A33	In passage, 3 m from wall, damp bat guano on floor	negative
NASTY CAVE UNDARRA SYSTEM	A35	45 m from entrance, from thin layer of fairly damp bat guano on floor	negative
	A36	20 m from end, from thin layer fairly damp bat guano on floor	negative
BAYLISS UNDARRA SYSTEM	A37	30 m from entrance, small amount of bat guano on damp floor	negative
	A38	85 m from entrance, damp floor	negative
	A39	160 m from entrance, damp floor	negative
	A40	250 m from entrance, damp floor	negative
	A41	325 m from entrance, duck under, fine layer of guano on damp floor	negative
	A42	25 m from duck under, fine & fairly dry layer of guano, in fog zone	negative
	A43	530 m from entrance, damp soil	negative
	A44	from thin layer of guano on damp soil, guano patch 10 cm across	negative

Samples were processed by the Division of Mycology, Center for Disease Control, Atlanta, Georgia, U.S. All samples were negative for *H. capsulatum*. However, *Microsporum gypseum* (a geophilic dermato-phyte that causes ringworm) was discovered in several of the sites.

Caves

In 1986, several members of the Chillagoe Caving Club offered assistance in collecting the necessary samples of soil, guano, and bird dropping. Caves included in the study were identified as potential sources due to their ecology of animal populations and climatic conditions. Bat and swiftlet populations are known to exist in several karst tower areas (Suicide, Walkunder, Ryan's Creek, Dumpy, Royal Arch, Markham and Spring). Increased temperatures and humidity in Tea Tree and the Undarra system also distinguished these as additional likely candidates, despite the scarcity of animal populations in them. The large number of birds in north Queensland suggests the possibility that surface sites frequented by large flocks (in trees and near old buildings) may also harbour *H. capsulatum*.

After the proper collection permits were obtained, arrangements were made with the head mycologist at the Center for Disease Control in Atlanta, Georgia, U.S.A. to process the specimens and provide soil import permits. Guidelines for obtaining the samples were established. Specimens were collected by using individual plastic spoons and placed in separate, sealed plastic bags. A rough sketch of all collection sites were made, the numbers correlating to the appropriate marked sample. The appendix provides the results from all collection sites.

Cave Visitors

Previous studies have identified a 71% reactivity rate of histoplasmin in cave explorers as compared to a 2% or lower rate in non cave exploring populations (Hoff and Bigler, 1981). Though positive skin testing to histoplasmin usually indicates previous exposure to the organism, cross reaction has occurred when presently infected with similarly structured fungi such as coccidiomycosis.

The unavailability of previous testing results, in addition to a growing population of cave visitors, necessitates identification of individuals previously exposed to histoplasma. In this way an indicator of the percentage of risk in this area can be estimated. Volunteers will be provided an opportunity for skin testing at no charge. Upon completion of a signed consent, individuals will be asked to complete a questionnaire reflecting their cave exploring history and health status. Reading of the skin test will be done 48 hours after an intradermal injection of 0.1 cc of a sterile filtrate of histoplasmin. A positive result will exist if the area of swelling (not redness) is greater than 10 mm in diameter.

Discussion

The initial negative test results indicate the difficulty in isolating *H. capsulatum* from the soil. Previous Australian investigators trying to isolate the organism noted similar negative results (Hunt et al., 1984). Due to the unavailability of respiratory air filters, and sentinel mice and bats for sacrifice and organ evaluation, continued soil sampling will be conducted. Air and soil temperature and humidity recordings will be taken to identify any correlation between certain climactic conditions and the presence of histoplasma. In addition, soil samples will be obtained at a lower depth in an attempt for better retrieval of the organism.

The necessary conditions for the maintenance of histoplasma appear contradictory at times. An increase in temperature and humidity promotes growth of the organism so the onset of the rainy season appears an ideal time for collection. However, heavy rainfall and consequent flooding may obliterate its existence temporarily. Conversely, a drier environment during the cooler winter season tends to promote aerosol distribution from soil disturbance. The most effective method of identifying the existence of *H. capsulatum* would seem to include the collection of soil samples from the same caves and sites during different seasons.

Though histoplasmosis is generally a very benign disease, individuals who are either very young, very old, or, whose immune system is compromised in some way are predisposed to more serious disease. Identifying those caving areas which present the greatest risk would be advantageous for individuals most at risk of serious disease. This continuing study intends to augment the meagre present knowledge regarding the ecology of *Histoplasma capsulatum* in Australia.

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