AUSTRALIAN NATURAL HISTORY

SPECIAL ISSUE–
AUSTRALIAN CAVES

JUNE 1975 VOLUME 18 NUMBER 6 $1*

"From time immemorial caves have attracted man. The unusual formations, the menacing narrowness and the dim insufficient light become, through the force of imagination, part of a mysterious, almost magical and sometimes sinister whole. There is a natural law in man which dictates that he should strive after knowledge, advance with inquiring mind into new territory, whether it be spiritual or material; and cave research is one element of man's desire to know and understand his environment.

Under the Earth's crust there exists an enormously great world where secrets await their unveiling, and speleology is a branch of science which opens up this world to provide revelations of chronological, geological and sociological importance. These underground wonders, however, belong to all men, and after the initial discovery and surveying of caves have been completed, the public at large is entitled to share in the beauties below, even if only to a limited extent."

—*W.L. Brennan*
NSW Department of Tourism

This special issue of AUSTRALIAN NATURAL HISTORY is devoted to various aspects of caves and caving—the field of speleology—in Australia.

AUSTRALIAN NATURAL HISTORY

JUNE 1975 VOLUME 18 NUMBER 6 PUBLISHED QUARTERLY BY THE AUSTRALIAN MUSEUM, 6-8 COLLEGE STREET, SYDNEY
PRESIDENT, MICHAEL PITMAN DIRECTOR, FRANK TALBOT

COVER: The Grand Fissure in Exit Cave, Tasmania. (Photo: A. Pavey)

ABOVE: A helictite in the 'Gem of the South' formation, Temple of Baal, Jenolan, NSW.

Annual Subscription: $4.50—Australia; $5—New Zealand and New Guinea; $6—other countries. Single copies: $1 ($1.33 posted Australia); $1.45—New Zealand and New Guinea; $1.70—other countries. Cheque or money order payable to The Australian Museum should be sent to The Secretary, The Australian Museum, PO Box A285, Sydney South 2001. Overseas subscribers please note that rates are to be paid in Australian currency.

Opinions expressed by the authors are their own and do not necessarily represent the policies or views of The Australian Museum.

LIME,

LIMESTONE AND THE FIRST CAVES

BY E.A. LANE

Photo Robert Stewart

Watercolour of Wombeyan Caves, painted in 1872 by Conrad Martens—from the original painting in The Dixson Galleries, Sydney.

The foundations of Sydney, and of Australia, began on January 26, 1788 when the first party of soldiers and convicts under Governor Arthur Phillip landed at Sydney Cove to establish a penal settlement.

Within a few months of its establishment, Sydney's buildings were being constructed of brick, suitable clay having been found close to the new town. However, the shortage of lime for mortar was desperate. Only by the slow and laborious process of collecting shells around the shore and burning them could a little lime be produced.

In October 1804, Governor Philip King despatched an expedition under the Lieutenant-Governor, Colonel William Paterson, to establish a settlement at Port Dalrymple, near the mouth of the River Tamar in the north of Van Dieman's Land (Tasmania).

In his first report to Governor King at the end of December 1804, Paterson told of the discovery, among other building materials, of abundant quantities of limestone in the area—"a boon hitherto denied the Territory". This first discovery of limestone in Australia was most important as lime could now be produced in Tasmania and shipped to Sydney. However, limestone had still to be discovered on the mainland, and a generation of explorers to come made a point of reporting all such occurrences.

The records tell us of the first limestone discoveries in Australia, but what were the first cave areas reported? Which was the first cave actually discovered? Despite considerable documentation, the evidence allows substantial room for speculation. The lines of exploration relevant to our investigation lie south and west of Sydney.

On March 3, 1818, a party of explorers led by the surgeon and explorer Charles Throsby and surveyor James Meehan, set out from Liverpool, near Sydney, in the hope of discovering an overland route to Jervis Bay. The young explorer, Hamilton Hume, not yet 21 years old, accompanied the party at the request of Governor Lachlan Macquarie because of his previous journeys of exploration to the Berrima

---

E.A. LANE, Director of Information Services, Australian Atomic Energy Commission, is a member of several speleological associations and Editor of *Helictite,* the Journal of Australasian Cave Research.

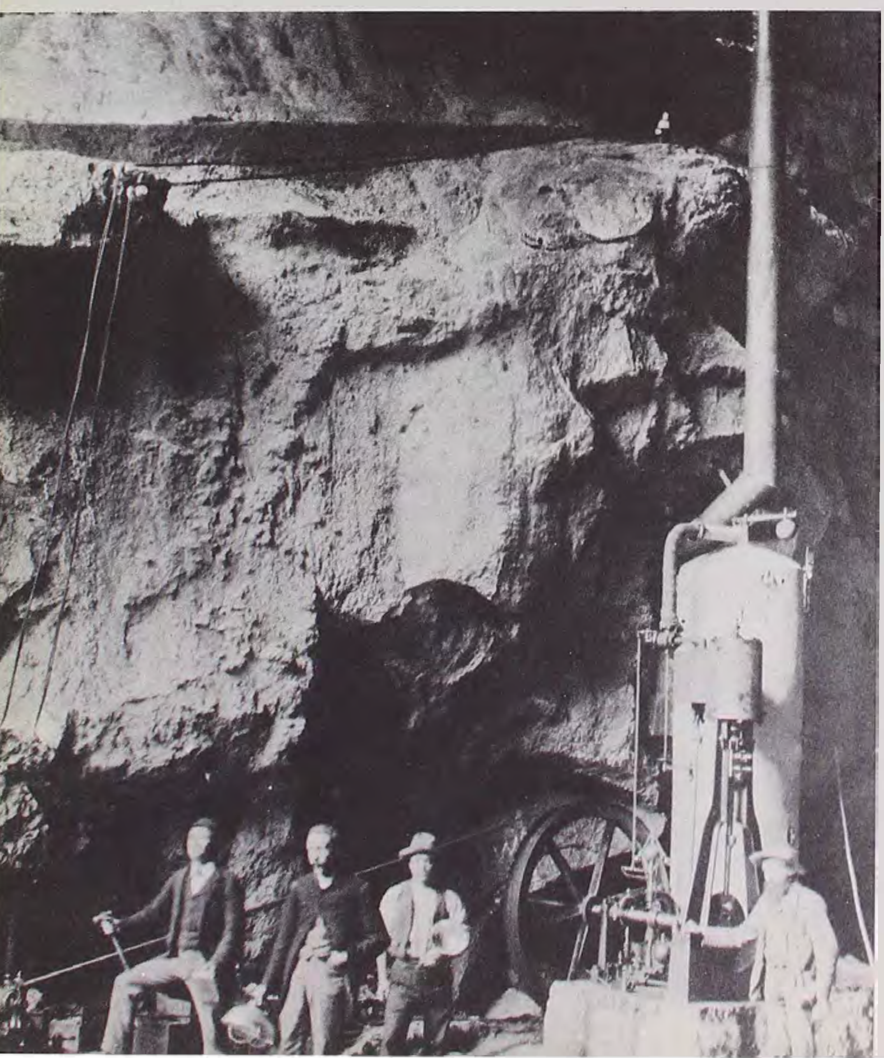
district and beyond. On March 25, finding themselves confronted with the gorges of the Shoalhaven River near Marulan, the expedition divided into two parties. Throsby went downstream and managed to find his way to Jervis Bay. Meehan and Hume worked upstream (south) along the high land west of the Shoalhaven.

It is uncertain whether the point of division reached by the explorers in this wild area of towering limestone cliffs and narrow ravines bordering the Shoalhaven River was in the vicinity of Jerrara Creek or Bungonia Creek. Suffice to say that they were in limestone country and the way had been opened for the early discovery of the Bungonia Caves.

In November 1820, Governor Macquarie issued an order permitting graziers to take their cattle to the Marulan district with tickets of occupation. However, because of delays, the earliest permits were not granted until 1822. Areas were soon occupied around the present township of Bungonia and along the heights flanking Bungonia Creek, the nearest property being only a short distance from the present Caves Reserve.

The first report of a cave exploration at Bungonia was made by the botanist and explorer, Allan Cunningham, while returning from a journey south of Lake George. He wrote in his journal under the date April 27, 1824 that, having been informed by a settler that a branch of the Shoalhaven River was nearby, he decided to visit the area especially as he would pass over "a curiously perforated Calcareous Country — the limestone extending N. Easterly to the great Ravines of the above-mentioned river."

Photograph of a steam-driven electric dynamo in the Grand Arch, Jenolan Caves, NSW, taken in 1886. This electric plant is believed to be one of the world's first permanent installations used for lighting caves.



Describing the visit, he said: "We found the land exceeding cavernous, orifices four feet diameter connected with capacious subterranean Excavations, appeared in every part of the Forestland, of whom some presented yawning fissures of apparently great depth, whilst others again had their apertures or mouth nearly closed up with earth". He continued that their local guide conducted the party to a large cavern. Being without lights, they did not venture far inside but were still able to see the abrupt and perpendicular chasm in what is now known as the Drum Cave.

Although first written record of the Bungonia Caves is dated April 27, 1824, the caves obviously were discovered before that, perhaps as early as 1819 or 1820. In May 1823, Captain Mark Currie, R.N., (army) Captain John Ovens and bushman Joseph Wild set out from Bong Bong near Moss Vale for the country south of Lake George. They crossed the Limestone Plains (the early name for the pastoral land near the Molonglo and Queanbeyan Rivers where outcrops of limestone occur) and finally discovered the Monaro Plains. On the return journey, they discovered 'London Bridge', south of the present town of Queanbeyan. Here Burra Creek has cut through a belt of exposed limestone to form "a natural bridge of one perfect Saxon arch".

In October 1824, an exploration party consisting of Hamilton Hume, retired sea captain William Hilton Hovell and six other men set out from Hume's station near the present town of Gunning to travel overland from the settled areas of New South Wales to Bass Strait.

They proceeded on a southwesterly course across the plains south of the present town of Yass, later naming them the M'Dougall's Plains from the family name of Lady Brisbane, wife of the Governor, though calling the area by The Aboriginal name "Yarrh" in their journal. They crossed the Murrumbidgee, noting frequent occurrences of large outcrops of fossiliferous limestone, continued southwest, rejoining the Murrumbidgee after some miles, this time noting high limestone cliffs on the opposite bank. (This area probably lies between Goodhope and Narrangullen.) They continued for some days on a zig-zag course, periodically mentioning limestone in their notes. By October 28, they reached what I believe to be the

Photo E A Lane

A lithograph, from an 1930 drawing by Major Thomas L. Mitchell, of the entrance to Cathedral Cave, Wellington, NSW.

Goodradigbee River valley, a few miles upstream (SSE) of its junction with the Murrumbidgee.

The journal of the expedition was subsequently edited by W. Bland and published in Sydney in 1831. The entry for October 28 notes that the party travelled thirteen miles along the valley. In a footnote, Bland added that "in their progress up this valley, there were observed several large and deep holes, apparently the outlets of some considerable subterranean cavities; rich, probably, in the organic remains of these regions." Two cave areas occurred in the valley in fairly close proximity—the Goodradigbee Caves (now drowned beneath the waters of Burrinjuck Dam) and the caves at Wee Jasper. There is no way of choosing between the two cave areas. One person could opt for the Goodradigbee Caves and another for the caves at Wee Jasper. In actual fact it is quite conceivable that the explorers observed cave entrances in both areas.

In May 1813, a party consisting of the free settler Gregory Blaxland, Army Lieutenant William Lawson and an Australian-born youth, William Charles Wentworth, found a way across the previously impenetrable barrier to the west of Sydney–the Blue Mountains. In November the same year. Governor Macquarie despatched Surveyor George William Evans to cross the Blue Mountains and to find a passage into the interior of New South Wales. Evans reached and named the Bathurst Plains and the Macquarie River, proceeding some sixty-five kilometres beyond the present city of Bathurst.

In May-June 1815, Evans led an expedition from Bathurst south to near the Abercrombie River, explored the middle reaches of the Belubula River, and discovered the Lachlan River. During this expedition he observed and recorded "lime rocks" and "lime cliffs" near the Belubula River and Mount Lewin. This was the first report of limestone on the Australian mainland.

Among a series of news items datelined Sydney, the *Sydney Gazette,* on October 6, 1821 published a paragraph as follows: "A cave, of considerable dimensions, has been recently discovered in the neighbourhood of Bathurst; and some very beautiful specimens of stalactites have been sent to town, which were procured in it. We hope shortly to be able to lay before our Readers a more particular description." Unfortunately, no further description appeared in the *Gazette,* leaving open the question—"What cave?" The leading historian of the Jenolan Caves, the late Ward L. Havard, believed this cave was "the great Abercrombie cavern", with a slight additional chance that it could be Jenolan as stockmen were in the vicinity of the Cox and Fish Rivers well before this date. On the other hand, it is equally possible that the discovery could have been the Cathedral Cave at Wellington as this country had also been opened up. Who can tell?

In his journal, *Journey Across the Blue Mountains, 1824,* René Primevère Lesson wrote that the discovery had been made of a cavern lying 16 miles north of Bathurst. "The way through it is covered with splendid thick stalactites of calcar[e]ous alabaster as white as sugar. The lime derived from it is very adhesive and consequently rated highly; only it is very expensive." A search of J.E. Carne and L.J. Jones' *The Limestone Deposits of New South Wales (1919)* reveals one cave area fitting Lesson's description—Benglen at The Limekilnes about twenty-six kilometres NNE of Bathurst on the Mount Horrible road. According to Carne and Jones, the caves were of limited extent and occurred in marble. The area has long been worked for ornamental stone, and whether the Benglen Cave still exists today or has been quarried I do not know. There is a possibility that Benglen is the cave referred to in the *Sydney Gazette* in 1821, despite the conflict of terms between "of considerable dimensions" and Carne and Jones' "of limited extent." However, the comparative size of a cave is often in the eye of the beholder.

The Wellington Valley was discovered and named in August, 1817 by Lieutenant John Oxley, the Surveyor-General of New South Wales, in company with the Deputy Surveyor-General, George Evans, botanist Allan Cunningham, the Colonial Botanist, Charles Frazer, and mineralogist William Parr. During a further expedition in 1818, Oxley noted the occurrence of limestone in the hills bounding the east side of the valley, claiming it as a valuable discovery. On his chart of the interior of New South Wales, published in 1820, Oxley noted this limestone as occurring a short distance west of the junction of the Macquarie and Bell Rivers. However, he did not similarly mark the Wellington Caves limestone on his map. The first settlement was set up in the valley in March 1823 under the command of Lieutenant Percy Simpson. The 'population' consisted mainly of convicts and their soldier guards. The stockade was positioned about three kilometres from the caves, between the caves and the present town of Wellington.

The earliest suggested discovery of the Wellington Caves by Europeans is published in a book, *Eumalga, or the White Chief*. The date of publication of the first edition is not known but the author, Robert Porter, was a long-time inhabitant of the district. The book tells of events allegedly occurring in the Wellington Stockade and surrounding country between 1822 and 1835. John Saville, a convict, arrived at the stockade in 1823, Porter wrote, and after being ill-treated, escaped and joined a group of blacks he had previously befriended. Later, Saville revealed himself to a prisoner named Dicky Taylor, acquainting him with "the secret of the now far-famed Wellington Caves", which Taylor communicated to the officer in charge of the settlement. The information was deemed of such importance that Taylor was rewarded with a ticket-of-leave. The introduction to the second edition, published in 1947, says that the story was told to Porter by Richard Taylor, who was a prisoner at the Wellington Stockade, and other old hands with whom the writer had come in contact during a long period of years.

On May 14, 1825, the painter and traveller, Augustus Earle, arrived in Sydney in the Brig *Cyprus*. In 1826, he visited the Blue Mountains, the Wellington Valley, the Hunter River, Port Stephens and Port Macquarie, returning with a portfolio of landscapes and sketches of Aborigines. These included the first known pictures of interiors and exteriors of the Wellington Caves.

After considerable travelling, Earle joined Charles Darwin aboard *H.M.S. Beagle* on October 28, 1831 as artist supernumerary. Later, the artist Conrad Martens joined the *Beagle* at Montevideo to replace Earle who was leaving Darwin's expedition because of ill health. Martens came to Sydney in 1835, remaining for the rest of his life. Apart from the coincidence of serving as successive artists on the *Beagle*, Martens became the second notable painter to depict Australian caves.

The earliest written, authenticated reference to the Wellington Caves is a letter written at Wellington by Hamilton Hume, on December 4, 1828 and carried by runner to Sydney. Hume was accompanying Captain Charles Sturt as second-in-command of an expedition down the unexplored Macquarie River. Hume wrote: "There is near this place a very large and beautiful cave". He then described what is now known as the Cathedral Cave.

The expedition leader, Captain Sturt, in his journal of the expedition, refers to "Moulong Plains, a military station intermediate between Bathurst and Wellington Valley." Sturt continued that "the accidental discovery of some caves at Moulong Plains led to the more critical examination of the whole formation, and cavities of considerable size were subsequently found in various parts of it, but more particularly in the neighbourhood of Wellington Valley." The caves in the Molong district are generally small but must be added, along with Wellington, to the earliest discoveries.

In 1830, George Ranken of Bathurst reported the discovery of fossil bones at the Wellington Caves and made the first collection of specimens. The cave concerned was probably the Breccia Cave, whose entrance was a small vertical shaft close to the entrance to the Cathedral Cave. A report of this momentous discovery appeared as a letter in the *Sydney Gazette* of May 25, 1830 over the signature 'L'. It was almost certainly written by the Rev. Dr. John Dunmore Lang who took a great interest in the bone collections.

Numerous other collections of fossil bones followed. Few bones were recovered intact, most being fragments only and mixed in utter confusion in a matrix of cave earth, clay, or as a breccia. The most important collection was made by Major Thomas L. Mitchell, the explorer and Surveyor General of New South Wales, also in 1830. Subsequent examination and study of these bone collections by people such as Professor Robert Jameson in Edinburgh and Professor Sir Richard Owen in London revealed many surprises.

Owen wrote to Mitchell in 1838 that the Wellington fossils were not referable to any known extra-Australian genus of mammals, nor were they referable to any existing species of Australian mammal. The greater number of specimens belonged to species either extinct or not yet discovered living in Australia. Owen was to work for another forty years on Wellington material, publishing a series of papers through to the 1880s.

For more than 140 years now, paleontologists have been studying fossil bones from the Wellington caves, ranging from the original collections of the 1830s through to collections made during the past few years. The list of discoveries consists of a bewildering array of extinct and existing marsupials together with monotremes, lizards, snakes, birds, rodents and dingoes. The few human bones found in the Wellington Caves to date have been unconnected with the fossils.

Despite their efforts there are still many mysteries to solve. We can assume, for example, that the Wellington Valley formerly supported a considerable population of animals, but no satisfactory explanation has been put forward as to why such a huge deposit of fossil bones should have accumulated within this small limestone hill.

Photo: NSW Government Printer

Pencil drawing of Burrangalong Cavern sketched in 1843 by Conrad Martens—from the original drawing in th[e] Dixson Library, Sydn[ey]

CLIMBING AND CRAWLING THROUG

BY ANDREW PAVEY AND NEIL MONTGOMERY

"A void so wide the far wall was not visible to a single lamp, and nothing but the jingling of the ladder disappearing into the gloom to betray the presence of a caver sweating away down below, while others of his kind froze above, paying out the lifeline and stethoscopically analysing his progress from its movements. Brief delays, slight jerkings, he is tiring. Finally a whistle blast, then two."
– Kevin Kiernan, *Southern Caver,* March 1972

In the gloom of the immense cavern the two explorers followed the stream on from below the crashing twenty-metre waterfall that had beaten them nine months previously. The steam continued for a mere sixty metres to a frothy, quiet, deep sump—Gollums Pool and the bottom of the cave. Thus, just twenty-five months after the discovery of a streamsink in the thick forests high in the Junee Valley above the small Tasmanian town of Maydena, the cave now named Khazad-dum had grudgingly revealed its record depth of 321 metres.

Early exploration parties were defeated by thundering, underground waterfalls, but in January 1970, a breakthrough into high-level passages occurred and the cave was 'pushed' to a depth of two hundred metres in the next two weeks. At this point, the nature of the cave changed into a meandering stream passage containing a number of short drops (no greater than ten metres). With large volumes of water crashing down on the explorers, exposure and exhaustion rapidly set in as the number of ladders and ropes required grew. Epic trips resulted: eighteen hours underground and the Australian depth record was broken at 256 metres with the foaming stream vanishing into the dark abyss below; then a marathon twenty-one hour assault and near disaster—ten metres down a waterfall and no end in sight, water splashing inside boots, parka, whistle.... The sodden bundle is hauled to safety by his comrades, and then, finally, nine months later, Gollums Pool.

The exploration of Australia's deepest cave was not yet complete. In January 1973, a dry entrance was found which descends into the final chamber via a series of deep shafts.

It is appropriate that Australia's first caving club—the Tasmanian Caverneering Club—was founded (in 1946) in the state now known to contain both our longest and deepest caves. One of the first trips to be held by the Club was to the Junee area where members explored the Junee resurgence and several small caves nearby. The trip was not without its excitement as the Club's founder, S.W. Carey, nearly foundered in the swollen Junee River after a party had reached the end of the cave where the river flowed from an underwater passage.

The formation of the first club was followed in 1948 by the founding of the Sydney University Speleological Society (SUSS). By 1956, eight clubs and societies had formed from around Australia and they banded together to form the Australian Speleological Federation (ASF) at an Inaugural Conference hosted by the Cave Exploration Group of South Australia (CEGSA). This conference was followed by a highly successful sixty-man expedition to the Nullarbor Plain in January, 1957.

Initially, no specialist equipment was available for the caver; he had to make do with gear intended for other pursuits. His ropes were of hemp or manila and his lights were household torches or carbide lamps. For clothing, the caver chose any old clothes or perhaps a pair of overalls. The helmet, essential for protection against falling rocks and bumping one's head against obstacles, was a miner's helmet of compressed cardboard. Sandshoes, or less commonly, boots, completed the outfit. Of this list, the only items that have withstood the test of time are the overalls and boots.

Since caves are often followed downward from the entrance, there arose an immediate need to have some safe technique for descending drops and, on the return trip, ascending them. Use of a rope and hauling party proved to be unsatisfactory although one of the deepest

A caver climbs a wire ladder on the 20-metre entrance pitch into Mammoth Cave, Jenolan, NSW.

ANDREW PAVEY has been a physics tutor at the University of NSW and is a past president of the University of NSW Speleological Society. NEIL MONTGOMERY graduated from Sydney University Teachers College and has been a member of the Sydney Speleological Society for the last ten years. Both are interested in single-rope

shafts on the mainland, the spectacular fifty-metre pitch in Drum Cave, Bungonia, was descended this way. In 1950, SUSS constructed three fifteen-metre wire ladders, an improvement on early wood and rope ladders. These could be rolled into small bundles and easily transported through a cave. Climbers on ladders were lifelined with a rope except on very short drops.

As easy finds became less common, cavers increasingly concentrated on pushing less obvious passages. It was this development which caused some major technical advances since these passages were often underwater, high in a cave roof, very constricted or almost filled with sediment. Descents of deep shafts, some carrying waterfalls, were equally challenging.

Early in 1952, two cavers from SUSS were exploring the Glass Cave at Jenolan when they noticed a hole some four metres up a vertical wall. Later that year, one of them, John Bonwick, read a French caving book, *Subterranean Climbers* by Pierre Chevalier, which told of his early exploration of a cave system under the Pyrenees in which he made repeated use of a 'scaling pole'. This scaling pole was constructed from short lengths of metal tubing which could be coupled together into a longer length when required. In 1953, Bonwick constructed a pole which was put to use on the hole in the Glass Cave. The cavers were elated to find a large extension to the cave which they explored over several succeeding weekends. They named it the Chevalier Extension, and it contains some of the finest calcite decorations known at Jenolan.

Late in 1952, a group from SUSS headed by Fred Stewart started underwater explorations at Jenolan Caves. Today's sophisticated cave divers would shudder at the primitive equipment they started with—a gas mask, a length of hose and a pair of foot bellows. Their first effort in the underground river of the Imperial Cave, Jenolan, forced a reappraisal of their gear and in 1953, Stewart managed to cover more than twelve metres until the hose ran out! The passage continued.

---

techniques and cave surveying and are presently in Europe to attempt the descent of the largest hole in the world—Gouffre Berger in the French alps.

A Pavey

P. Caffyn

Neil Montgomery climbs a single rope up a 60-metre shaft on an expedition to Papua.

Some of SUSS's leading diving enthusiasts formed the Sydney Speleological Society (SSS) in 1954. A Cave Diving Group formed in SSS soon after its founding. They trained rigorously and assembled modern equipment. Four years later in the Imperial Cave, divers passed four watertraps and found five hundred metres of passage ending in rockfall. The group dived frequently until the early 1960s when a near death caused their breakup. Little was then achieved until recent years when a new generation was attracted to the huge wonder-filled passages under the Nullarbor Plain.

In 1958, a small cave was found near Augusta in Western Australia. A rotting ladder near the entrance indicated that it had been previously explored, but a party from Perth, following an airdraught low in the chamber, tunnelled twelve metres through sandy soil to find themselves in a cavern with massive formations. Further exploration revealed beautiful helictites, a silent placid lake, and no sign of other explorers. The length of the cave, now named Easter Cave to commemorate its date of discovery, was increased many times by another party which succeeded in edging on their backs fifteen metres along a tiny water-filled passage with only sufficient airspace for eyes and nose (a technique aptly described as 'roof-sniffing').

After the successful trip of 1957, interest in the huge caves under the Nullarbor increased and a number of other groups had visited the area by 1962. Joe Jennings, in Canberra, made a careful examination of recent aerial photographs and identified 105 large depressions which might contain caves. The 1963-64 SUSS expedition, using these results, found Mullamullang Cave, and rapid exploration of its huge tunnels and rockpiles quickly promoted it to the longest cave in Australia at that time. Discoveries flowed on and in 1966 a CEGSA trip camped four kilometres underground for seven days and detailed mapping of the cave was continued. By the end of that year, the total surveyed length of the cave had grown to nearly ten kilometres.

Although Mullamullang still contains unsurveyed and unexplored passages, the focus of attention has switched to Tasmania. At Ida Bay, south of Hobart, near the Hastings Caves, two relatively short caves were known, one on each side of Marble Hill—Entrance Cave where Mystery Creek flowed into the hill, and Exit Cave two kilometres away, where the same stream flowed out into the D'Entrecasteaux River. After access was improved by cutting a new track, a quick breakthrough occurred

A. Pavey

Joe Jennings negotiates a narrow fissure in the Argyle Hole at Bungonia, NSW.

in 1966 in the large rockpile which had previously terminated Exit cave. Known passage rose rapidly and by 1970, over sixteen kilometres of passage had been surveyed. The elusive connection to Entrance Cave has yet to be found despite a prize of two dozen bottles of beer offered to the successful explorer!

As with most kinds of exploration, the cave explorer looks first at the obvious passages and it is often only years later that systematic checking of every nook and cranny is contemplated. The Victoria Cave at Naracoote, South Australia was first opened as a tourist cave late last century. Robert Sexton of CEGSA prepared the first survey of the cave and noted that it showed a conspicuous absence of fossil bone material. However, when a party led by Grant Gartell of CEGSA penetrated a constricted passage in August 1969, they found a silt-floored chamber scattered with what apeared to be rocks. Closer examination revealed that the 'rocks' were the remains of diprotodons, giant extinct kangaroos and marsupial lions—it was a huge animal graveyard!

By the end of the 1960s, the ASF comprised nineteen clubs, representing all states of Australia. With the increasing popularity of the sport, techniques and equipment had improved and some important changes had occurred. In 1965, the miner's light was introduced to Australian caving. It features a cell worn on the waist, with a cable connected to a light worn on the helmet. Another advance in industrial standards also benefited the cavers—the introduction of strong plastic and fibreglass helmets

to replace the compressed cardboard ones. It was also during the 1960s that synthetic ropes became readily obtainable, challenging and eventually ousting the conventional manila rope. Ladder construction had improved. A significant advance was that high-quality ladders had become commercially obtainable. The rungs were pressure-welded to the wire, making the ladder robust and durable.

Khazad-dum was, however, the last of the hard laddering trips. Around 1970, an upsurge of interest in vertical caving caused a greater consciousness of technical advances overseas and in particular of the swing there towards single-rope techniques. Instead of climbing shafts on ladders, cavers had turned to descending and ascending on a single rope. They abseiled down and prusiked out, two techniques originally developed for mountaineering many decades before. The saving in weight, and hence time, is enormous; ladder-and-tope is replaced by rope alone.

The development of single rope techniques has been parallelled by a renewed interest in caving overseas, particularly deep caving. Australians are looking to the close mountainous islands of Papua New Guinea and New Zealand, where much potential exists for the discovery and exploration of deep caves.

On home ground, however, laddering still remains the most common method used, except in our deepest caves. It can be expected that the ladder will continue to hold its place in this country, dominated as it is by shallow caves.

The rapid increase in awareness of caves and the techniques for exploring them has resulted in a plethora of publications on caves and caving. The growing practice of documenting discoveries will lead to increased systematic exploration which will in turn, using advanced techniques, reveal major extensions of known caves and a small number of new caves. Expeditions will follow up earlier iscoveries and produce comprehensive trip reports, club newsletters and books reporting on specific caves and cave areas, both within Australia and overseas.

It is unlikely that any extensive new cavernous limestone will be found in the densely populated southeastern sector of the continent. The remote 'frontier' cave areas in Tasmania and the far North of Australia can only be explored by 'expedition-style' trips and, with increasing affluence and leisure, these areas will be visited more frequently. Nevertheless the well known areas of easy access will always be popular and with continuing refinement of techniques and safety devices, more people will be inclined to try this speleosport.

FURTHER READING

Tolkien, J.R.R. *The Hobbit* and *The Lord of the Rings*, George Allen & Unwin Ltd., London, 1966.

A. Pavey

Cavers attempt to free-dive the water-trap separating the two sections of Na rangullen Cave. NSV

MINERAL DECORATIONS
NATURE'S CAVE ART

BY JULIA M. JAMES

Cave minerals are important economic resources, but in Australia they are mainly exploited for beauty as tourist attractions. Cave mineralogy is a young field but is rapidly growing with use of modern instruments which allow minute sampling, and miniature monitors using solid-state electronics can now continuously record the mineralising process as it occurs.

Carbonates are the major cave minerals. Among the three crystal species of calcium carbonate, calcite is commonest vaterite is very unstable and unknown in caves, and aragonite, which should be unstable in Australian cave conditions, is nevertheless widespread and exists in formations.

Calcite, the most common cave mineral, occurs in many different crystal forms, mainly rhombohedra and scalenohedra and less frequently, prisms. Their combination and twinning give many crystal shapes. Dog tooth spar crystals are scalenohedra combined with prisms. Size depends on conditions and well-formed large crystals may grow only under water. In most formations, crystals grow from thin water films as small modified shapes giving sheet- or rod-like forms, including the familiar stalactites, stalagmites and straws, but Australian caves also contain large numbers of exotic formations whose growth is more obscure.

Helictites are still called mysteries because their shape is difficult to explain in terms of normal calcite growth. They twist and turn in random directions and seemingly defy gravity by growing upwards. They commence as fine filaments with a narrow central canal, often less than 0.25mm diameter. Carbonate solution flows down this to the open end, sometimes forming a drop. The tip grows with continuous addition of crystal material. Solution dribbling down the sides may thicken the helictite which continues to grow as single crystal and it may become so thick that the original structure is lost. The capillary canals branch, dividing the helictite into twig-like structures. Blockage of the capillaries with faster precipitation causes changes in direction, often as sharp bends.

One inconspicuous but widespread formation on cave surfaces is cave coral. Clusters of nodules stand out on short stalks and vary in shape and size depending on conditions of growth. Phototropic cave coral grows in entrances and areas illuminated by artificial light. Photosynthetic algae grow on lighted surfaces and, removing carbon dioxide from carbonate solutions seeping down walls and formations precipitate calcite. The algae need light for photosynthesis; therefore cave coral accumulates towards the light giving the impression, in a cave entrance, that a mighty out-breath blew the formations crooked.

Low-humidity cave coral exists in drier caves and unlit entrances. It is dry, rugged, and robust in structure with minute crystals that suggest formation from thin films of carbonate solutions seeping down. High-humidity coral grows in active caves. Splashes from drips cover the coral with thin carbonate solutions. Where carbon dioxide is most easily lost, as on the curved tips of nodules, carbonate is readily deposited, but little precipitates from thick films between nodules.

Cave pearls, occurring in small basins, are common in Australian caves, but usually in small numbers except for the remarkable river of pearls in Giants Causeway Cave, Chillagoe, Queensland. These are roughly spherical and their surfaces are reflective when wet. Their analysis reveals a nucleus of dust or rock layered with calcite or aragonite. Rotation is not necessary to obtain the uniform deposits of the pearl. They occur in still pools fed by falling drops with insufficient energy to move them. Possibly the crystals that grow under the pearl increase in size to lift the pearl and allow solutions to deposit underneath them.

Pendulites are another strange formation in Australian caves and were first discovered in the Easter Cave, Western Australia. They commence as stalactites or straws, but if the cave becomes partly submerged in slow moving streams, their tips dip below the water. Dog tooth spar then grows on the tips, forming crystal balls. If mud is then washed in, the

Two cavers admire Vivienne's Needle, a large stalagmite with its head in a cloud of straws, in the Peter Lambert Passages, Waitomo, New Zeala

A. Parry

JULIA JAMES, a lecturer in inorganic chemistry at the University of Sydney, is Director of the Speleological Research council and a member of the Sydney Speleological Society. Her major research project is on the mineralogy of the Bungonia Caves, NSW.

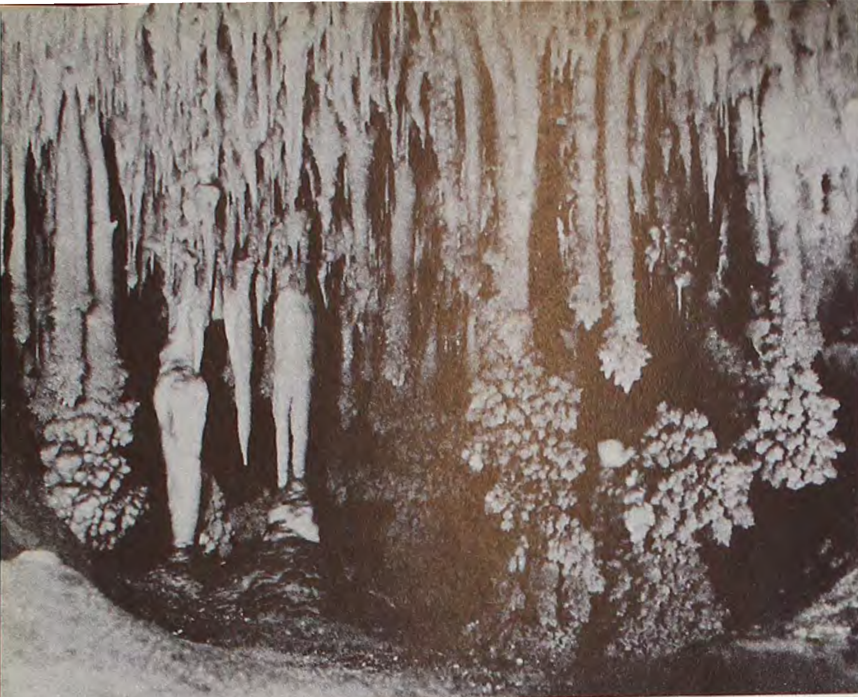


Photo: By Courtesy of NSW Dept. of Tourism

forest of stalactites with their tips covered in dogtooth spar and cave coral.

ball becomes coated forming mud pendulites.

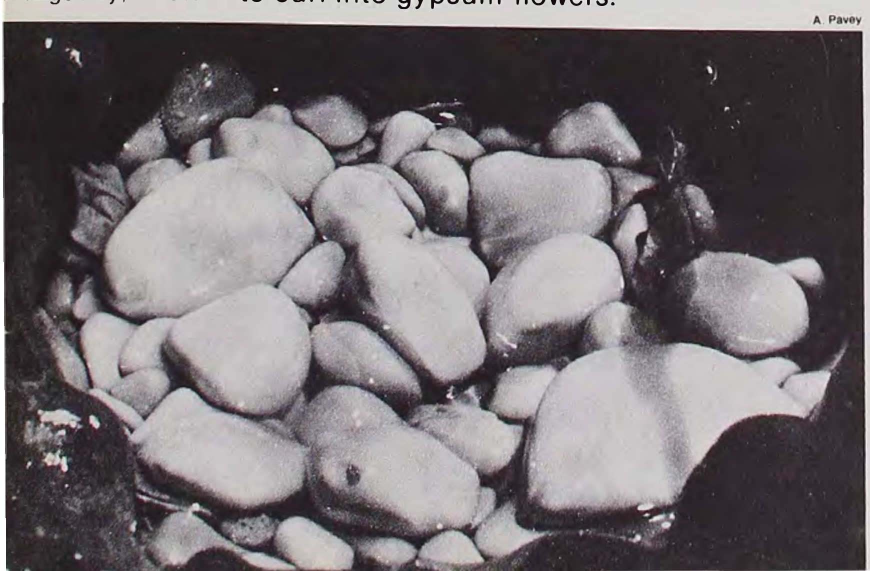
Magnesium and calcium magnesium carbonates are rare in caves even when dolomite is the parent rock. They include magnesite, hydromagnesite, nesquenhonite, huntite and small amounts of dolomite.

The attractively coloured hydrated copper carbonates, blue azurite and green malachite, are found in caving areas with copper mines Iron carbonate, as siderite, is found where heat and pressure have changed limestone into marble, though it is rare in caves.

Sulphate minerals are widespread in Australia, but in caves are restricted to the drier passages where growth of calcite formations is inhibited. The major sulphate is gypsum, which is usually colourless, but sometimes has pale colour from impurities. Forms include crystal groups, rosettes, crusts, curving clusters, flowers and snowy white fibres.

Porous limestone, as found on the Nullarbor Plain, favours gypsum formations. The ground water solutions containing calcium sulphate evaporate in the porous cave walls, forming crusts. Further deposition behind these crusts forces them into the cave as curved crystals. More rapid growth on one side causes them to curl into gypsum flowers.

A Pavey

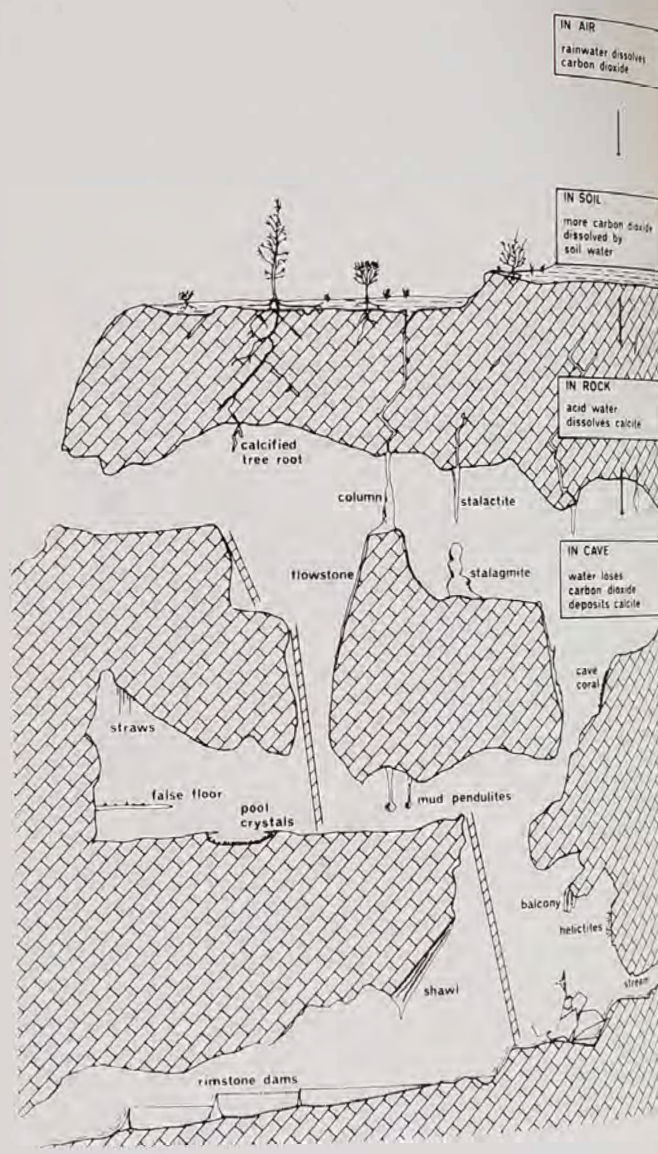


A pocket of cave pearls
n Eagles Nest Cave,
rrangobilly, NSW.

Halide minerals in Australian caves include halite (sodium chloride or common salt), which is found in many caves on the Nullarbor Plain. The growth of these formations is similar to that of gypsum deposits. Delicate glassy crystal fibres may form curving bundles resembling flowers, sparkling crusts on walls, or small stalactites and stalagmites.

Cave phosphates contain many minerals, some rare. The phosphate comes from two main sources, animal bones and bat guano. It reacts with calcium carbonate in the walls clay fills and sulphide-charged ground waters to produce a range of minerals, many of which

Julia James



The chemical formation of a variety of calcite speleothems.

are intermediate in nature and decompose. The making of nitrate from fresh bat guano requires particular bacterial action. These bacteria remove ammonia from bat urine and convert it to nitrite then nitrate, which reacts with wall rocks to produce calcium nitrate. Bat guano is mined in many Australian caves, not to extract the chemicals, but to use directly as fertiliser.

A Pavey

Halite and gypsum flowers and fibres in Mullamullang Cave, Nullabor Plain, Western Australia.

Haematite and goethite both iron oxide minerals, stain their surroundings red-brown, and in many eastern Australian caves, manganese dioxide covers cobbles, formations and walls with soot-like layers. Both manganese and iron oxides and hydroxides can be deposited by bacteria, but are usually precipitated chemically by highly oxygenated and alkaline cave waters. The only common Australian cave sulphide is pyrite. The detection of hydrogen sulphide gas in Odyssey Cave, Bungonia, New South Wales led to a detailed investigation by the writer, of the evolution of carbonate, oxide, and sulphide iron minerals in that cave. The minerals are forming in a slow-moving lake in an atmosphere with several percent carbon dioxide. These studies aim at understanding depositional conditions for specific minerals in the cave for maximum production of metal ores. In providing a model for the origin of iron minerals of the Precambrian period, when the Earth's atmosphere may have carried several percent carbon dioxide.

Theoretical and practical studies of the evolution of cave minerals will hopefully lead to new methods of extracting low-grade ores and the discovery of new ore bodies, and cataloguing of cave minerals in their special environments goes on; — but, though few mysteries now remain, the most widely studied and most fascinating aspect of cave minerals is their growth into objects of beauty and fanciful imagination that always delight those who visit the Earth's caverns.

FURTHER READING

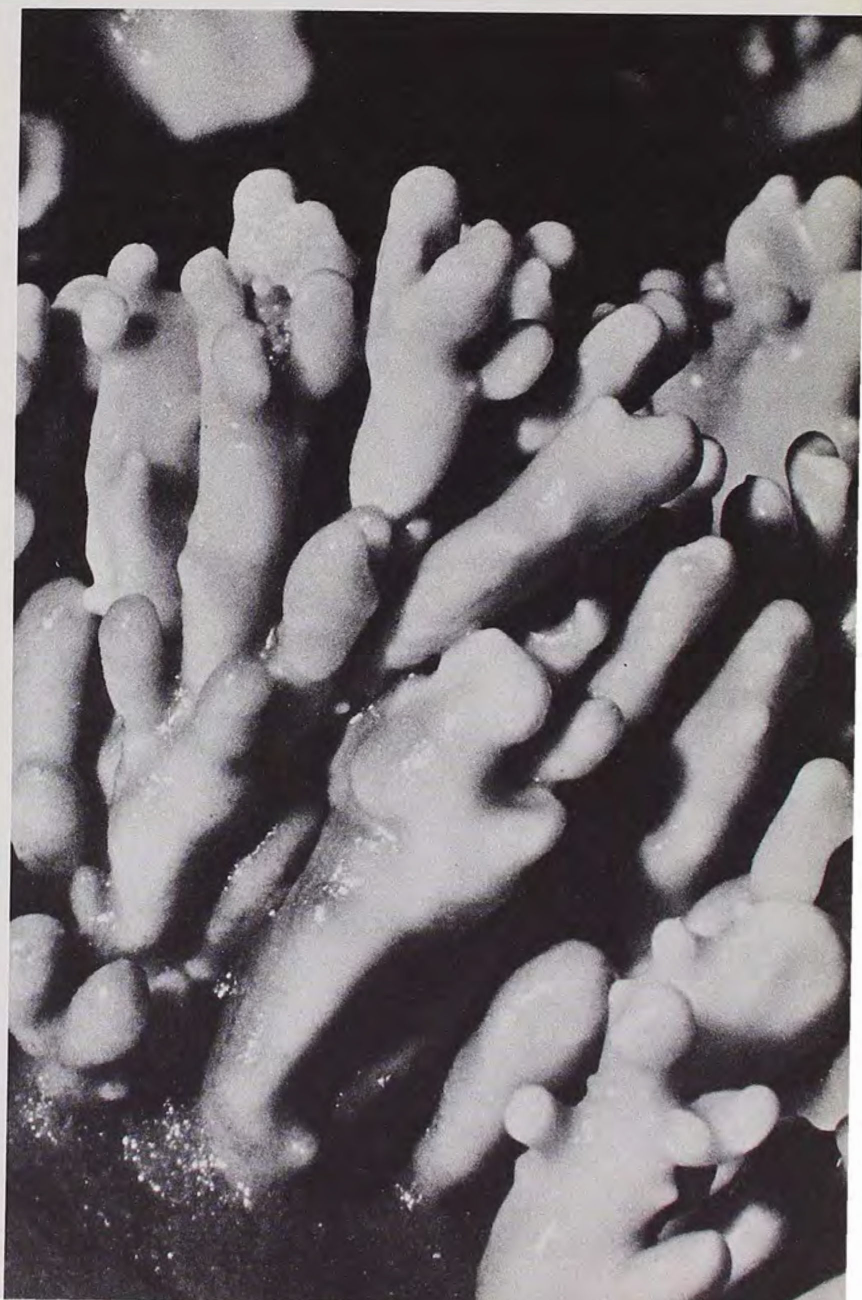
Broughton, P.L. "Secondary Mineralisation in the Cavern Environment"; *Stud. Speleol.* 2, 191-207, 1972.

Moore, G.W. and G. Nicholas *Speleology—The Study of Caves;* Health and Company, Boston, 1964.

Warwick, G.T. "Cave Formations and Deposits"; pp.83-119. in *British Caving* (ed. C.H.D. Cullingford), Routledge and Kegan Paul, London, 1962.

Wells, A.W. "Cave Calcite"; *Stud. Speleol.,* 2, 129-148, 1971.

A Pavey



Cave coral of the hig humidity type grows calcite flowstones. This specimen in Old Inn Cave at Yarrangobilly, NS

THE FORMATION AND DEVELOPM

BY J.N. JENNINGS

In a small shallow hollow in a plateau of the southern tablelands of NSW, an innocent-looking hole just big enough to enter descends no less than fifty-four metres before narrowing too much for further penetration. This is Putrid Pit cave at Bungonia Lookdown. A vertically-developed cave, it is made up of a series of interconnected, enlarged joints in limestone, which run in different direction. This is a simple case of a cave forming by the effect of rainwater seeping down under gravity in an uppermost hydrological zone in the rocks where voids are partly filled with air and partly with water.

Rainwater, seeping through the soil into the originally tight joints in the bedrock, contains carbon dioxide in solution. Some of this is dissolved from the atmosphere, but most is provided by the respiration of plant roots and microbes in the soil. This makes the water slightly acid and through complex chemical action it can dissolve considerable amounts of limestone as it descends. Small springs beneath the Bungonia Lookdown cliffs, fed from the Putrid Pot and similar nearby potholes, commonly contain 350 milligrams per litre of dissolved calcium carbonate. By this solution the joints are enlarged, linked together and so the Putrid Pit has formed.

Though the Putrid Pit is not the place for the uninitiated explorer, some of the Wombeyan Caves are. There, in the central tableland of NSW, Wombeyan Creek goes underground into the marble of the large impressive Victoria Arch. At times of high discharge, the stream carries on from the back of the arch through Creek Cave, emerging two hundred metres along and eleven metres lower at the head of Wombeyan Creek gorge. Creek Cave is really just a river canyon with a lid. The rapids of the cave stream pass over many swirl-holes—bedrock bowls in which gravel and sand are whirled around with an abrasive action. In other sections, covered over thinly with sediments, the turbulent abrasive floods erode the whole channel. High up in the cave, jammed tree-trunks are moved and battered against the projecting walls during floods, occasionally breaking off chunks of rock. Thus the stream is mechanically deepening and enlarging this underground canyon. Remnants of former stream beds can be seen at various levels above the present channel and belong to earlier stages in the cave's erosion. Solution is

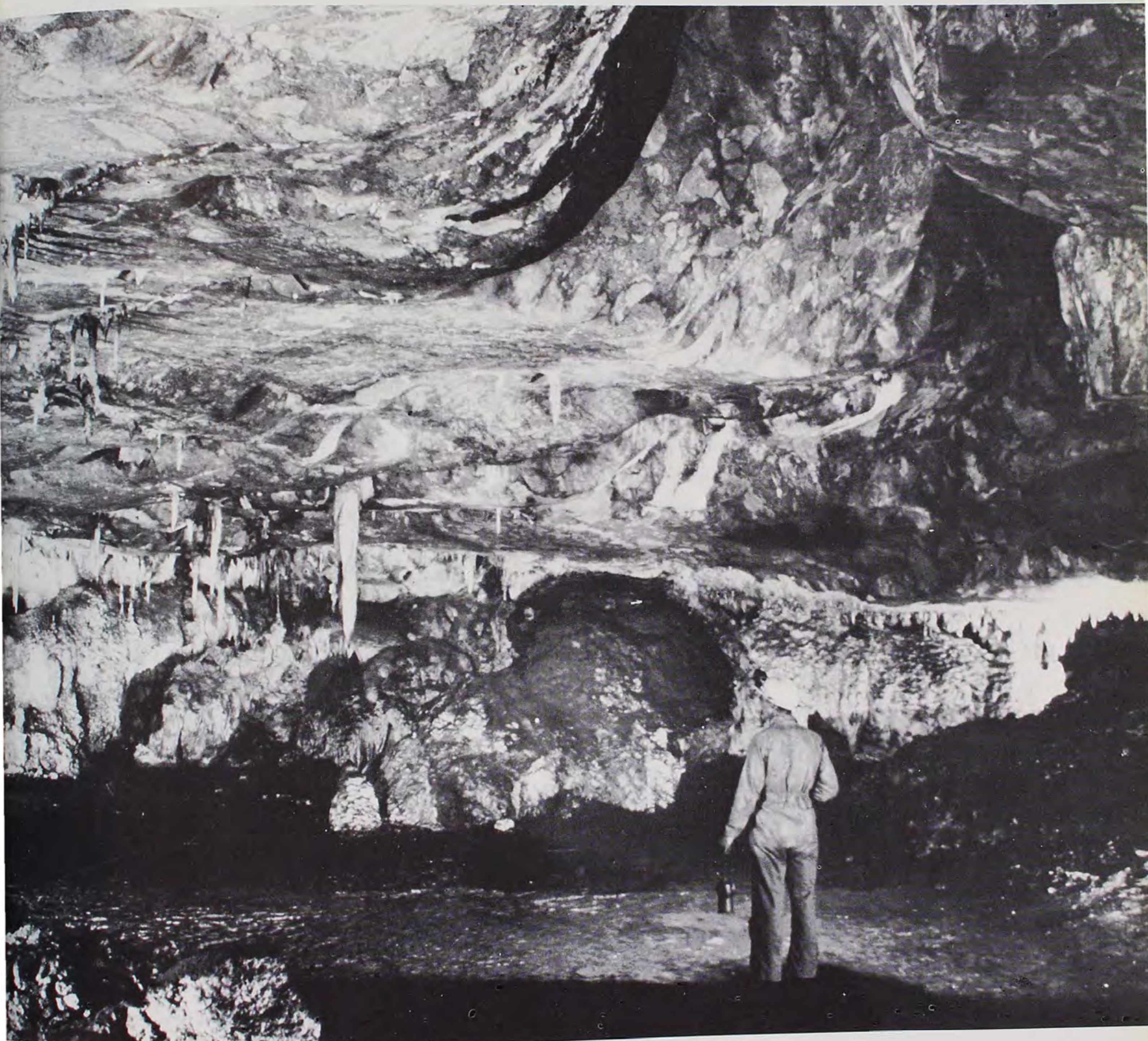
J.N. JENNINGS is Professorial Fellow in Geomorphology at the Australian National University and a former president of the Australian Speleological Federation.

A Healy

'The Ballroom' in Punchbowl Cave, Wee Jasper, NSW.

ENT OF AUSTRALIAN CAVES

also going on substantially as chemical analysis of the water shows. Most rock is removed by voluminous flood waters, despite faster flow when less is dissolved per litre than in low flow. Indeed in flood, marble is dissolved in Creek Cave at the rate of three-quarters of a cubic metre each year. Asymmetrical current markings or scallops on the wall are produced by tiny eddies of water close to the wall. Thus Creek Cave is a kind of limestone cave carved mainly by mechanical and chemical attack of a stream not filling the cave fully—a free surface



J.N. Jennings

is pressure conduit n Punchbowl Cave, Vee Jasper, formed when fast-flowing water filled the ave. Sediment now covers the floor and the headlamp on the left gives an idea of the size of the passage.

Obviously, vigorous streams cannot flow through limestone until holes appear and, therefore, caves are initiated under other hydrodynamic conditions. Below the level at which all voids are filled with water, tiny threads of water percolate through joint and bedding planes in the rock in interlacing patterns, dissolving tiny embryonic 'passages' in intricate nets as can be seen on the roof of the Grand Arch at Jenolan Caves, NSW. Eventually, the easiest routes through these minuscule labyrinths are enlarged preferentially and a water-filled cave is created.

In low-lying or flat country, movement in these water-filled tubes will remain slow so that currents and heights of springs will scarcely influence the course of solution. Joints and bedding planes can then strongly control the cave pattern, as is seen in Cathedral Cave at Wellington in the central-western slopes of NSW. Nearly all its roof and walls are smooth solution surfaces in the form of innumerable rounded domes, apses and symmetrical cusps, resembling cavities in a gigantic sponge. This is the effect of slow eddying in completely water-filled spaces and the highly irregular shape of the cave is partly concealed by the level floor of red clay.

Cathedral Cave now lies in a low limestone ridge, but must have been carved out when the Bell River flowed thirty-five metres higher than today in an old limestone valley floor. It is an old cave related to past conditions of very different relief. There are other caves at Wellington similar in origin to Cathedral Cave, but they are largely filled with much younger sediments which have yielded important bone collections.

Cave diving, dangerous even to highly trained people, is the only means of examining caves of this type while they are still forming as they are near Mt. Gambier in South Australia. Here they reach the surface in deep blue pools set in large circular cavities in the limestone such as Little Blue Lake and Goulden's Hole.

In hillier country, water filling caves will be under pressure from above and so it will move faster with more force, and can travel upwards as well as downwards. Virtual pipelines are driven through the rocks; these pressure conduits are usually circular or elliptical in shape because solution occurs all round them, not just on the floor as in a free surface stream. These are the most difficult caves to explore when in the active water-filled condition. They must be examined after they have drained, but are likely to have been modified by free surface streams then.

Barber Cave at Cooleman Plain in the Kosciusko National Park, NSW gives a good illustration of this. It has two entrances in a steep, little valley tributary to Cave Creek in its gorge below Cooleman Plain and two exits in the wall of that gorge. The tributary stream now sinks underground into the higher entrance and flows through a lower passage to the lower exit only two metres above Cave Creek. The upper passage links the lower entrance with the higher exit thirteen metres above Cave Creek. This passage begins as a canyon cut by a free surface stream but then becomes flat-roofed at the level of its exit. This flat-roofed part is a remnant of a pressure conduit. When it formed, Cave Creek flowed at the level of the upper exit, which was then a spring, controlling the upper limit of pressure flow solution.

Afterwards the gorge was cut down to its present level. To begin with the upper passage drained partially and a free surface stream cut down into the floor of the former pressure conduit. Eventually the stream found a fresh route through the limestone which took over from the old passageway. This present active stream passage is undergoing the same history as its predecessor but has not yet gone so far. Thus Barber Cave shows chiefly the effects of two phases of solution by fast flow in water-filled passage separated by a phase of free surface flow.

One further important process in limestone cave formation is illustrated by Warbla Cave in the Nullarbor Plain, Australia's largest limestone region. When a cave ceases to be full of water, it loses support and thereafter breakdown can be expected as rocks fall under force of gravity from the roof and walls. Streams may undercut walls to promote this but, more importantly, seepage water enlarges joints and bedding planes so that blocks drop down or fall inwards, sometimes triggered by earth tremors. The whole floor of Warbla Cave is buried in rock fall; the highest piles are beneath domes in the roof out of which they have dropped. The entrance to the cave is a vast hole in the roof made by collapse.

The domes and arches of this and other deep caves in the Nullarbor are not smooth from solution, but are largely rough due to fracture. Cave breakdown can only take place into space created by other processes such as solution and abrasion. The deep Nullarbor caves originated by solution, chiefly at times of lowered sea-level during cold periods of the Pleistocene, when decreased evaporation increased the available water.

Each of these simple limestone caves has been discussed to draw attention to a particular process and hydrodynamic situation—vertical seepage of water, free surface stream flow, slow water movement in water-filled caves, fast movement in what are virtually pipelines, rock collapse into cavities created in these ways. Generally, however, limestone caves have been subject to combinations of processes in varying circumstances so that they have endless variety and complexity. The same is true of dolomite, another common carbonate rock. Large dolomite caves are known in Australia as, for instance, around Camooweal in northwestern Queensland.

Volcanic activity is the next most common cause of substantial caves, but in Australia only some of the Victorian and Queensland lavas are young enough to preserve them.

Church Cave at Byaduk North in western Victoria is a typical lava tunnel formed in a basalt flow from the Mt. Napier volcano. This tunnel, with a small branch, lies along the line of the flow and is entered where its roof has fallen in over two long stretches. Despite some roof fall in the remainder, original forms of lava can be seen inside the cave, including ropes of lava which dribbled out of a smaller pipe into the main tunnel. Lava tunnels can be formed in several ways. Lava channels open to the sky crust over or are encroached upon by lava piling along their sides or are bridged by moving blocks jamming across them. Other tunnels are due to chilling of a skin of lava around a quickly moving thick flow or toe of lava. In some flows, more fluid lava separates out between layers of more viscous lava and concentrates into a few streams, which erode cylindrical ways for themselves. These sometimes drain in part or entirely, leaving a tunnel. Church Cave is of this type. The study of Earth's lava tunnels helps us to understand the 'rilles' on the surface of the moon.

A very different kind of lava cave forms in the central vents of volcanoes. The lava out of which a volcano is built rises up a pipe. When the volcano ceases to be active, a vertical cavity may be left in the pipe either because of the blowing out of lava or through a final contraction of the liquid lava still in the pipe. There is a cave of this type in the summit of Mt. Eccles in western Victoria.

Large, complex limestone caves have attracted most attention. Their investigation poses logistic problems but the information gained is often valuable for our understanding of surface topography and how it comes into being. Smallness has, however, too often discouraged investigation of a cave's origin. Small caves are widespread throughout Australia as a result of atmospheric weathering of many kinds of rock. Some have been used by Aborigines for various purposes and their sheltering climates may allow distinctive biological communities to occupy their special habitats. The same is true of caves cut by waves along the coast, especially when these are abandoned by the sea. Though these small caves cannot be discussed further here, their importance for the natural historian and the prehistorian must not be overlooked.

FURTHER READING

Australian Speleological Federation *Speleo Handbook;* Sydney, 1968 (1st Ed. out of print; 2nd Ed. in press).
Dunkley J. and T.M.L. Wigley (eds.) *Caves of the Nullarbor;* Speleological Research Council, Sydney, 1967.
Jennings J.N. *Karst;* Australian National University Press, Canberra, 1971.
Ollier C.D. and M.C. Brown "Lava Caves of Victoria"; *Bulletin Volcanologique,* 28, 215-229, 1965.
Sydney Speleological Society *Bungonia Caves; S.S.S.Occ.Pub.* 4. 1973.

L. Reider

'The Dune' in Mullamullang Cave, Western Australia, is one of the many rare features in this unique cave

RECONSTRUCTING THE PAST

EXCAVATIONS IN FOSSIL CAVES

BY ROD WELLS

During the last century, when biologists were still marvelling at the unique vertebrate faunas found living in Australia and New Guinea, the fossil remains of giant marsupials, monotremes, varanid lizards, dromornithid birds and meiolanid turtles were evidence of an even broader late Tertiary, Pleistocene diversity. In Australia as in other parts of the world, large accumulations of late Pleistocene fossil vertebrates are often found in caves.

In 1969, members of the Cave Exploration Group of South Australia followed a breeze emanating from a rock pile in Victoria Cave Naracoorte and broke into three kilometres of new caverns. Within this new section of the cave they found three chambers, the floors of which were littered with a vast array of skulls and limb bones of extinct marsupials. These fossil deposits appeared extremely rich and provided an opportunity to use modern techniques of retrieval and dating in an attempt to determine when and how the fossils accumulated in the cave.

The work is divided into two major areas: the first involves a study of the history of the formation of the caves and their filling with sediment and bones; the second involves the excavation, reconstruction and description of the animals.

If we examine the southeast of South Australia we find a low-lying country punctuated at intervals by a series of parallel-trending sand ridges (the remnants of old stranded coastal dunes) stretching southeastwards from the Murray River to the Victorian border. These beach dunes, or 'ranges', as they are known locally, were formed during the Pleistocene when variations in sea level in association with a gentle upwarping of the land surface produced changes in the position of the coastline.

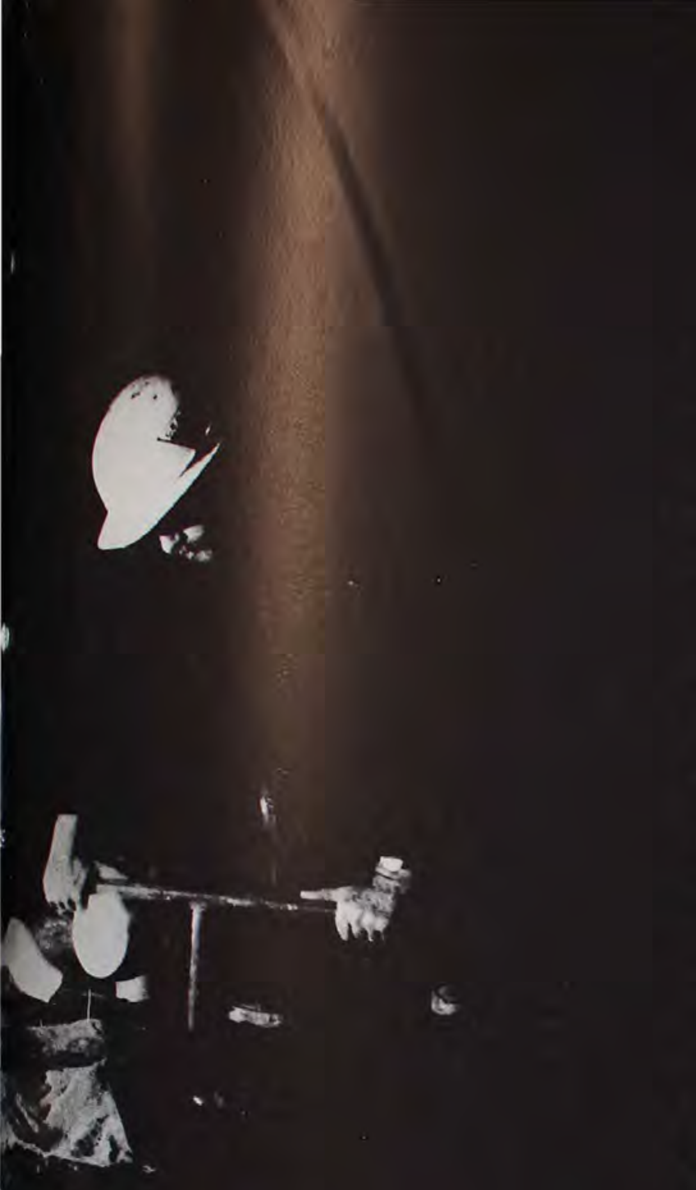
One of the oldest and most northeasterly of these dune systems passes through the town of Naracoorte. The Naracoorte dunes overlie a thick sequence of shallow-water marine limestones which were deposited in the Otway basin in Oligocene times. Evidence is mounting which suggests that these limestones have been exposed to weathering during at least two different periods in the past. This weathering has resulted in the development of a karst topography which, in the Naracoorte area, is evident in the development of the caves.

One of the puzzling questions about these caves is their location. Why should the only relatively deep caves in this area be restricted to the Naracoorte dune range, and why should these be the only caves to contain large quantities of bones? Part of the answer lies in the past geological history of this area, for the Oligocene limestones lie draped over a fault in the underlying basement rocks. When the sea first retreated from this area in mid-Miocene times it exposed a scarp approximately sixty metres high. Rivers draining from the east

---

ROD WELLS, Senior Demonstrator in the School of Biological Sciences at Flinders University, South Australia, is Scientific Director of the excavations at Victoria Cave, Naracoorte. He is interested in the evolutionary history of Australian marsupials.

E Sangster



Cores of cave sediments are removed using hand augers in Victoria Cave, Naracoorte, South Australia.

gradually cut valleys into the face of the scarp and the water table in the adjacent country was gradually lowered and limestone caverns were dissolved out by the acid ground-waters feeding these rivers. Much of this karst was subsequently removed when the sea once again surged over this area in the late Pliocene. The last time it withdrew, in the late Pleistocene, it left behind a beach dune covering the remaining evidence of the old Miocene/Pliocene karst, the Naracoorte Caves.

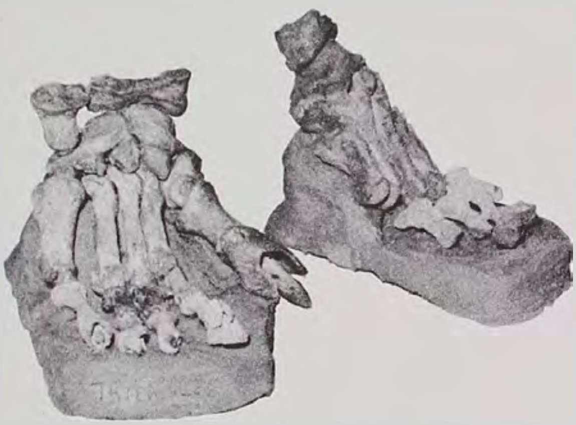
These caves occur today as low clay-filled passages running along joint lines in the limestone and connecting with a number of larger dome-like caverns. Increased water action in these old caverns during the late Pleistocene has led to further collapse of the roof structure, and in some cases this has allowed the formation of an opening to the surface through which sand from the overlying dunes has poured into the caves forming large cones of sediment. These openings to the surface acted not only as pitfall traps for unwary animals, but also allowed access to those which normally sought refuge in caves. The remains of these animals and their prey now lie buried in the sand of the cave floor.

During periods of high rainfall, active streams within the caves carried the bones and sediments further underground. In fact, it is not uncommon to discover fragments of large ox-sized marsupials, such as the extinct herbivore *Zygomaturus trilobus*, hundreds of metres along very low tunnels within the cave. As more sand poured into these caverns, great cones of sediment rose higher and higher until eventually the entrances were completely blocked, sealing a sample of the fauna within the cave. This process has continued at Naracoorte for tens of thousands of years and can still be observed occurring today. Exploration of the Naracoorte Cave complex is continuing and as more fossil chambers are being discovered, carbon and bone material is being carefully collected for carbon-14 isotope dating in the hope that we may be able to construct a faunal succession for the southeast of SA during the latter half of the Pleistocene period.

Today, the major activity is centred around the Fossil Chamber in Victoria Cave. A portion of this cavern measuring sixty metres by fifteen metres is filled to a depth of three metres with sand and bones of thousands of mammals, birds, reptiles and amphibians. The first speleologists to reach the fossil chamber viewed a floor littered with the skulls of extinct kangaroos of the genus *Sthenurus* and the cave lion *Thylacoleo carnifex*. Subsequent coring of the sediment using hand augers revealed large accumulations of bone at depth within the sediment. Although the arrangement of bones on the surface of the sand did not indicate any obvious relationships between the components, the surface of the sediment was marked out in a grid pattern so that all the excavated material would carry with it a reference number indicating its position within the deposit.

It was considered essential to know the depth, or the stratigraphic horizon within the deposit from which a specimen was retrieved, as this could prove to be the only means of determining its age relative to those specimens occurring above or beneath.

Excavation is carried out using small brushes, trowels and dustpans. Sediment is removed for a given depth, usually five or ten centimetres, over a relatively large area and all the large bones, skulls, jaws, etc. are reliefed out and left in place. They are then sketched and photographed in position and placed in containers bearing the appropriate grid reference numbers and removed for further cleaning and preparation. In some cases, large specimens are too fragile to be lifted from the dig without special treatment. They are first surrounded with damp tissues and then with sand and the specimen is finally encased in either a plaster of paris or polyurethane foam jacket. In this fashion, badly fragmented



R. Wells

The strong, heavily clawed front feet of *Thylacoleo carnifex*, the extinct marsupial lion.

material can be removed to the laboratory for careful restoration. The excavated sediment is placed in bags with the grid reference label and carried out of the cave and spread on sheets of plastic to dry in the sun. It is then carefully picked up with a dust pan and broom and placed in sieve boxes. As the sandy sediments contain only a small quantity of clay, the dry sand is very friable and dry screening has proved to be the most economical way of collecting the fine bone material. Occasionally these dried sediments are washed through the screens but this has only been necessary when the clay content of the sediment is higher than normal. The dried residues are spread on table tops and diagnostic portions, such as mammalian skulls and jaws, bird limb bones, reptile jaws and vertebrae and frog pelves are sorted from the residues.

The fauna from Victoria Cave can be divided into three major categories:
(i) extinct animals, and
(ii) extant animals which
(a) no longer inhabit the area, or
(b) still live in the area.

The extinct animals include birds and reptiles as well as mammals. Amongst the latter there are large numbers of different species of kangaroos belonging to the genus *Sthenurus*.

Richard Tedford of the American Museum of Natural History divides the sthenurine kangaroos into two subgenera on the basis of their skull structure. The short-faced forms he suggests are forest browsers, whereas those showing a tendency towards an elongation of the anterior palate he equates with a grazing niche. Specimens representative of both these genera have been found in the sediment, suggesting that the country surrounding the cave during this period consisted of both open plains and forest or savannah woodland. A similar situation occurred in the area in the early days of settlement with sclerophyll forest capping the dune ranges and open grasslands and savannahs covering the interdune plains. An almost perfect skull was found of one of the largest of the browsing kangaroos *Procoptodon*. It is interesting to note the small peg-like incisors so typical of browsing animals such as the koala. This kangaroo stood about two or three metres high and from the structure of the scapula, Tedford has concluded that it could raise its long arms above its head, presumably to pull down branches on which to feed.

Another animal found within the cave is *Thylacoleo*, the cave lion (see *Australian Natural History*, Vol. 17, No. 1), an animal described by Sir Richard Owen as "the fellest and most destructive of Predatory beasts". At Naracoorte, we recently recovered a partial skeleton of this animal which included two well-preserved forelimbs and a partial hind foot. All the digits of the forepaw bear hooded claws with that of the first digits being exceedingly large. The first digit is not opposable to the remainder and lies approximately parallel to them. The structure of the hind foot bears many similarities to that of the climbing possums. Perhaps *Thylacoleo* was an arboreal predator on possums and koalas.

Zygomaturus trilobus is a large quadrupedal marsupial herbivore about the size of an ox. It is a relative of the large Diprotodons of Lake Callabonna (see *Australian Natural History*, Vol. 17, No. 11) and its remains are relatively common within the fossil deposit. Although the bones of marsupial predators have been found within the cave it is considered unlikely that any were large enough to kill an animal of this size. In fact, the only evidence of damage to the bones of *Zygomaturus* are the gnawing marks of rodent incisors; it is therefore believed that these large animals fell into the caves.

A larger but more lightly-built relative also found in the deposit is *Palorchestes*. The large slender jaw of this animal and portions of its skeleton have recently been recovered and preliminary study indicates that it may have fed on the vegetation of swamps and wetlands.

Among the extant animals, Meredith Smith has identified bettongs, potoroos, ringtail possums, gliding possums, short- and long-nosed bandicoots, Tasmanian tigers, Tasmanian devils, and native cats, as well as the small marsupials, *Antechinus* and *Sminthopsis*.

From the presence of these small mammals, she concludes that at the time of accumulation of the bones, Victoria Cave was surrounded by dry sclerophyll forest. She has also pointed out the considerable variation between species in the presence of adult animals in the deposit, concluding that for these small creatures the cave did not act as a simple pitfall trap but that the bones were brought in by predators. In a recent paper, van Tets and Smith have described some bird fossils from the cave. They include remains of the masked owl, *Tyto novaehollandiae*, a predator, and of the black-faced sheathbill, *Chionis minor*, a scavenger —both of which are known to roost in caves and rock crevices. Thus some of the small mammals could have come from owl pellets or from carcasses brought into the cave. As there is an upper limit to the size of the prey these birds could carry, this could account for the absence of adults of some of the mammal species. They also point out that, paradoxically, all the eighteen species of birds found in the cave thrive under wet, coastal conditions.

In attempting to make any palaeoecological reconstructions from deposits such as those in Victoria Cave, we must be very careful to determine the manner in which the fossils were accumulated, particularly as the assemblage may include separate owl and carnivore accumulations, and may not necessarily be a random sample of the fauna living in the area at that time.

Students of the School of Earth Sciences at Flinders University have spent many hours with hand augers searching for the original entrance to the Fossil Chamber and have now found it hidden beneath the sandy surface of the Naracoorte Cave Range. It consists of a long trench with steeply sloping sides finishing in a drop of approximately eleven metres to the cave floor. Such an entrance would not only act as a pitfall trap but would also provide an ideal roosting site for predatory birds. The remaining two bone chambers, the Upper and Lower Ossuaries, are notable for the absence of small vertebrates. This suggests either that the bones in these chambers accumulated in a different manner from those in the Fossil chamber or, alternatively, that water action has carried the smaller material deeper into the cave, leaving behind only the larger bones.

The skull of *Procoptodon rapha*, a large extinct browsing kangaroo.

Carbon-14 dating of the carbon from the Upper Ossuary indicates an age of 36,500 $^{+4,350}_{-2,800}$ years ago (ANU ref. 1269), whereas a technique developed by Dr. Bada of the University of California based on the racemisation of amino acids in the bone indicates an age of 20,000 years – 20% for the material in the Upper Ossuary and 40,000 years – 20% for the bone in the Fossil Chamber.

With current work in the old water levels in the cave and more carbon-14 dates on the bone, we are slowly moving toward a reconstruction of the diverse Pleistocene fauna of this part of southeastern South Australia and toward an understanding of the climate in which these creatures lived.

FURTHER READING

Smith, Meredith J. "Small Fossil Vertebrates from Victoria Cave, Naracoorte, South Australia. I. Potoroinae, Petauridae and Burramyidae (Marsupialia)"; *Trans. Roy. Soc. S. Aust.* 95:4, 185-198, 1971.

Smith, Meredith J. "Small Fossil Vertebrates from Victoria Cave, Naracoorte, South Australia. II. Peramelidae, Thylacinidae and Dasyuridae (Marsupialia)", *Trans. Roy. Soc. S. Aust.* 96:3, 125-137, 1972.

van Tets, G.F. & M.J. Smith "Small Fossil Vertebrates from Victoria Cave, South Australia. III. Birds (Aves)"; *Trans. Roy. Soc. S. Aust.* 98:4, 225-228, 1974.

This work is supported by an ARGC grant and a grant from the South Australian Government.

SPELEOCHRONOLOGY: THE STORY

BY CLIFF OLLIER

"So," says the cave guide, placing his hand between a stalactite and a stalagmite, "if I left my hand here for a million years it would become part of the solid rock!" Is it possible? Is a million years the right order of magnitude? Elsewhere we may be told that caves are millions of years old (or thousands, or thousands of millions, or ageless) or that fossils or artefacts in a cave are of some incredible age. I remember expressing doubt about a date reported by a cave guide, and he slyly remarked "Well, really, how would they know!" *They*—the ones who try to establish the ages of caves and cave contents—are engaged in the study of speleochronology. I shall try to explain "how they know"—and what of it.

Firstly and most obviously, a cave cannot be older than the rock in which it is found. If a cave occurs in Pleistocene limestone then it cannot have been formed in pre-Pleistocene times, nor can any of the contents of the cave be of pre-Pleistocene age; a cave in Miocene limestone must be of Miocene or younger age, and likewise its contents. Geologists have worked out a table of geological history which has been cross-checked many times and related to absolute ages. It is usually quite easy to date a limestone by its fossil content, but even rocks which do not contain fossils may be dated by their relationship to underlying or overlying rocks which are fossiliferous. Most limestones are Palaeozoic or younger and usually contain abundant fossils. Limestone caves are usually considerably younger than the enclosing rock. Limestone is formed in the ocean, and must consolidate into rock and be lifted above sea level before cave formation can commence.

Lava caves, which are produced while the lava is actually flowing, are of the same age as the lava. It is relatively easy to date lavas by the potassium-argon method, which can be used on rocks ranging in age from about two billion to less than twenty thousand years ago. Thus we find that Panmure Cave in Victoria is in a flow dated at about half a million years, while Parwan Cave near Bacchus Marsh, Victoria, is probably about two million years old.

The potassium-argon method cannot be used for flows younger than about twenty thousand years, so more devious methods are required. A number of lava caves are associated with Mount Eccles, Victoria, a volcano that blocked old drainage channels, diverted streams, and formed Condah Swamp. The oldest organic material in the swamp sediments should give a minimal date for the eruption, and the oldest date so far recorded, a radio-carbon date reported by E.D. Gill, is about six thousand years, though these caves sometimes look incredibly fresh. The Condah Swamp deposits *overlie* the Byaduck flow from Mount Napier, so the Byaduk flow, and the Byaduk lava caves, must be older than six thousand years. Of course the age of some lava caves is known by direct observation as in Hawaii and elsewhere.

The birth of limestone caves is not so obvious. When does a crack become a cave? Our general anthropocentric approach suggests that a cave must be big enough for men to go through, and must have an entrance. It is not uncommon for cave entrances to appear in limestone areas by collapse of cave roofs. Such openings are usually elliptical.

In limestone, cave formation may continue for a long period—thousands or millions of years. Different periods of cave formation may be recognised, for example, when the first part of cave formation takes place beneath the water table and later activity occurs when most of the water has been drained away. In Jenolan Caves there is evidence of an early water-filled (phreatic) phase before the later river-cave (vadose) phases. As with the creation of many landforms, the formation of caves is less likely to be continuous than periodic. Events such as changes of climate, changes of sea level, movement along faults, can all lead to periodicity in cave formation. At Jenolan Caves there is an obvious set of river caves associated with the present-day river, and the series of passages at a higher level were clearly formed in the same way at an earlier time.

Photo By Courtesy of NSW Dept of Tourism

CLIFF OLLIER is a Research Fellow in the Department of Biogeography and Geomorphology, Research School of Pacific Studies, Australian National University. He is especially interested in the limestone caves of Ireland and Papua and in Australian lava caves.

IT TELLS

When cave fill is examined, the basic laws of stratigraphy—the study of layered sediments—apply as they did in determining the age of the rocks themselves. If there are several layers of debris in a cave, the layer at the bottom is the oldest, the uppermost layer is the youngest. Of course care must be taken to avoid traps such as intrusive burials, or the infilling of animal burrows, but careful work can decipher the history of cave fill.

The most detailed work carried out on Australian cave sediments is probably that done by Bud Frank on caves of New South Wales near Wellington, Stuart Town and Orange. He could distinguish an entrance material, pond deposits, soil particles, slope wash deposits, and flowstone (stratified calcite precipitated on cave floors). By careful reasoning and the piecing together of evidence from many different parts of many caves, Frank has been able to assemble a history of climatic change in the area he studied, from the cave fill.

An initial wet period between forty thousand and thirty thousand years ago is evidenced mainly by pond deposits in Wellington Caves, but supporting evidence for a relatively wet surface climate at this time comes from evidence of fluvial erosion and deposition at Borenore Caves. A high proportion of soil particles in the lowermost deposits at Wellington suggest a prior dry phase.

A second dry phase is indicated by a combination of flowstone and fluvial evidence from the Borenore Caves, and a second wet phase is recorded by slope-wash and pond deposits in Douglas Cave (Stuart Town) and Wellington Caves. Following the second wet period the surface climate became drier until it finally reached its present state.

Studies of cave strata, such as Frank's, are very much assisted by carbon dating, which gives an absolute age rather than a relative one. Radioactive carbon-14 is continuously produced in the upper atmosphere by cosmic ray bombardment of the stable isotope of nitrogen (nitrogen-14). Carbon-14 decays with a half-life of 5,570 years—that is, from any given number of carbon-14 atoms, half will decay in that time. A balance has been attained between production and decay of carbon-14 in the atmosphere and in any carbon compound derived from the atmosphere. This applies (with many reservations) to living things, and to stalactites and stalagmites. With very careful techniques it is possible to date stalactites, or even parts of them. Using such methods, it is possible to estimate the rate of growth of stalactities and stalagmites, but perhaps better results are gained from direct observation.

Folklore seems to prefer stalactites to grow extremely slowly, but measured rates of growth are in fact quite rapid. In some caves, stalactites several centimetres long can be seen growing on wire netting, rails or other artificial foundations, and the guides' explanation that they grow faster because the metal is 'magnetic' is untrue. Nevertheless the enormous formations of many show caves must have taken many thousands of years to grow.

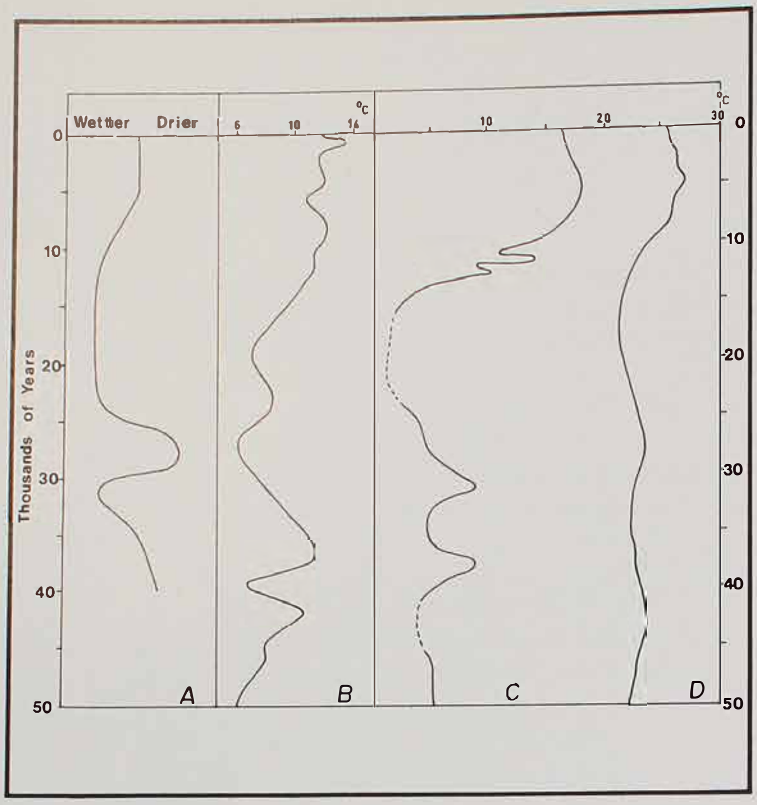
Rates of solution can also be of interest, and many cave scientists are putting a lot of effort into determining the nature of limestone solution and process rates.

The Nullarbor Caves occur in an arid area where cave formation must be exceedingly slow, but since the same processes have been able to operate uninterrupted for fifteen million years, some authorities believe that the caves could have been entirely produced in the present climate. Others invoke wetter periods, being perhaps more impressed by the size of the caves than the enormity of the time available.

In contrast, the caves of County Clare, Ireland, are being formed at such a rate that present processes appear capable of forming them entirely in the last twenty thousand years. This turns out to be in agreement with geomorphic evidence: most caves follow dry valleys which are not filled by glacial drift; the valleys are therefore post-glacial and so are the caves.

Stalactites and stalagmites (often grouped together as speleothems) preserve a history of climatic variation which can be deciphered by a study of oxygen isotopes. The ratio of two isotopes of oxygen, oxygen-18 and oxygen-16, can be determined in the laboratory on quite small samples. The ratio depends on the temperature of the water from which the crystals grew, and this can be determined

Queen Esther Cavern, River Cave, Jenolan NSW.



C Ollier

Paleoclimate over the last 50,000 years: A-relative wetness and dryness; B-paleotemperatures; C-estimated July main temperature in Holland; D-generalised temperature curve for surface waters of the Caribbean.

with an accuracy of perhaps 0.1° C. Again there are many reservations to the application of the method, but with great care sensible results are obtained.

In New Zealand, Chris Hendy has used a combination of carbon dating and oxygen isotope analysis to determine the salient features of climatic change over the past fifty thousand years. The temperature curve obtained from New Zealand stalactites is in good agreement with curves obtained from other parts of the world by quite different meth

A. Pavey

Kubla Khan is the largest known stalagmite in Australia and occurs in the cave of the same name at Mole Creek in Tasmania.

One feature is an interesting warm period about a thousand years ago. Hendy writes that this warm time is well-known from historical records and is thought to be responsible for the great changes in civilisation in Northern Europe. It is possible that the Maoris, like the Vikings of the North Atlantic, used this warm period to migrate to, and become established in New Zealand.

Studies of the chronology and palaeotemperature of stalactites and stalagmites from North America has produced data on a much greater time scale, going back three hundred thousand years. Thompson, Schwarcz and Ford used a thorium-uranium method for dating, and oxygen isotopes for palaeotemperature determination. They discovered periods when formations did not grow at all, which should correlate with glacial periods (there would be a shortage of seepage water and a lack of biotic activity to produce carbon dioxide, both necessary for growth of formations). Fluctuating but higher temperatures in interglacial periods are revealed by oxygen-18 enrichment. They find that their data fit in well with ideas of palaeoclimatology derived from other sources. In particular, there is a good correlation with summer insolation curves for the Northern Hemisphere, calculated from minor variations in the Earth's motion. They also point out that the insolation theory predicts that under certain conditions an insolation maximum in the Northern Hemisphere is accompanied by an insolation minimum in the Southern Hemisphere, so that glacial advances and retreats should be out of phase in the two hemispheres. Ages of stalactites and stalagmites and isotopic data should help to resolve such theories of climatic change.

It is interesting that while Hendy provides a curve of temperature variation, Frank's work on cave sediments indicates relative wetness or dryness. There appears to be a rough correlation between their results, with associated cold wet (not necessarily rainier) conditions prevailing between ten and twenty thousand years ago, and a warmer dryer period about twenty-five thousand years ago. When the two methods are used together in the same area we shall really start to measure the climates of the past. Our knowledge of past conditions will be further advanced if we can also use fossils, pollen and artefacts to fill out the total ecological set-up.

The time scale for biological evolution may, in some cases, be comparable with the scale of cave development, so biological data may be used in speleochronology. In Malaya, caves in isolated limestone hills have been separated for sufficiently long periods for them to evolve distinctive species and sub-species. In Europe all living troglobites appear to be descended form species that originated before the last Ice Age. The troglobitic animals of North West Cape, Western Australia, live in caves in a coastal platform not more than five thousand years old. It is inconceivable that the animals could have evolved their present morphology in such a short period and it has been suggested that the fauna developed in late Tertiary or Pleistocene times in the Cape Range caves, and colonised the caves of the platform in recent time. Some very ancient fills have been found associated with caves of the Mendips in England, dating back to Triassic times, 180-230 million years ago. 'Modern' Mendip caves contain Pleistocene fossils such as cave bears, hyenas, and elephants. Caves have evidently been formed in the same area at widely separated times.

In Cloggs Cave, Buchan, there is a stratified and undisturbed occupation deposit containing bone and stone tools and a rich faunal assemblage which has been examined by Jeanette Hope and Jo Flood. The lowest level excavated was dated at about twenty-three thousand years and yielded extinct fauna including giant kangaroo, Tasmanian wolf and Tasmanian devil. Immediately above this layer were Aboriginal stone tools dated to about eighteen thousand years. The cave appears to have been vacated about eight thousand years ago, and throughout the period of occupation the neighbouring environment appears to have been very similar to that of today.

Elsewhere, changes in environment may be recorded by fossils (as at Mount Hamilton, Victoria) or by pollen (as in Kairimu Cave, New Zealand), and archaeological remains may reveal cultural changes with time. The stone tools of Kenniff Cave, Queensland, studied by John Mulvaney, document the passage of Aboriginal technology from hand-held to hafted forms. Overseas, many great palaeoanthropological finds have been made in caves, such as the discovery in South African caves of *Australopithecus* ('ape-man') remains which may be two million years old.

In Europe, remains of cave art have been found at hundreds of sites, and a chronology has been built up. Cave art is common in Australia, though much of it is not in true caves, but in rock shelters. True cave art is, however, known from caves such as Mountain Creek Waterhole, a tunnel two hundred metres long in the Northern Territory. At Koonalda Cave on the Nullarbor, Alexander Gallus discovered what is probably the oldest cave art yet known in Australia; associated flint mining has been dated to between thirteen thousand and twenty thousand years old.

Speleochronology, the dating of caves and their contents, employs data and techniques from many sciences—geology, biology, physics, chemistry and others. This interdisciplinary approach is beginning to tell a story, not merely of the age of caves, but of the evolution of landforms, climatic changes, ecological development, and the emergence of man, his tools and his art.

FURTHER READING

Hendy, C. "Isotopic Studies of Speleothems"; *Bull. N.Z. Speleo. Soc.* 4, 306-319, 1969.

Thompson, P., H.P. Schwarcz and D.D. Ford "Continental Pleistocene Climatic Variations from Speleothem Age and Isotopic Data"; *Science*, 184, 893-895, 1974.

Frank, B. "Evidence for Late Quaternary Climatic Change from Cave Sediments in Central Eastern New South Wales", *Australian Geogr. Studies*, 13 in press.

The 'Chevalier Terrace', strata of rimstone pools in the Jenolan Caves, NSW. These pools are also known as gours.

CAVES AND ABORIGINAL MAN

BY SANDRA BOWDLER

The last decade has seen many exciting development in the field of Australian archaeology. Scientific investigation of archaeological sites has revealed the immense antiquity of Aboriginal man in Australia and the stability and sophistication of his culture from earliest times. It has also elucidated many facets of his ecological adaptations to a changing environment. Of the sites investigated, at least seventy-five percent are in the form of caves or rockshelters. The oldest site known at the present time is not, however, a cave but a series of small camp-sites around the shores of Lake Mungo in western New South Wales which are of the order of forty thousand years old. There are, though, cave sites in Australia with evidence of human occupation dated by the radiocarbon technique to older than twenty thousand years, and these sites have given us many fascinating insights into the culture of the first inhabitants of the continent.

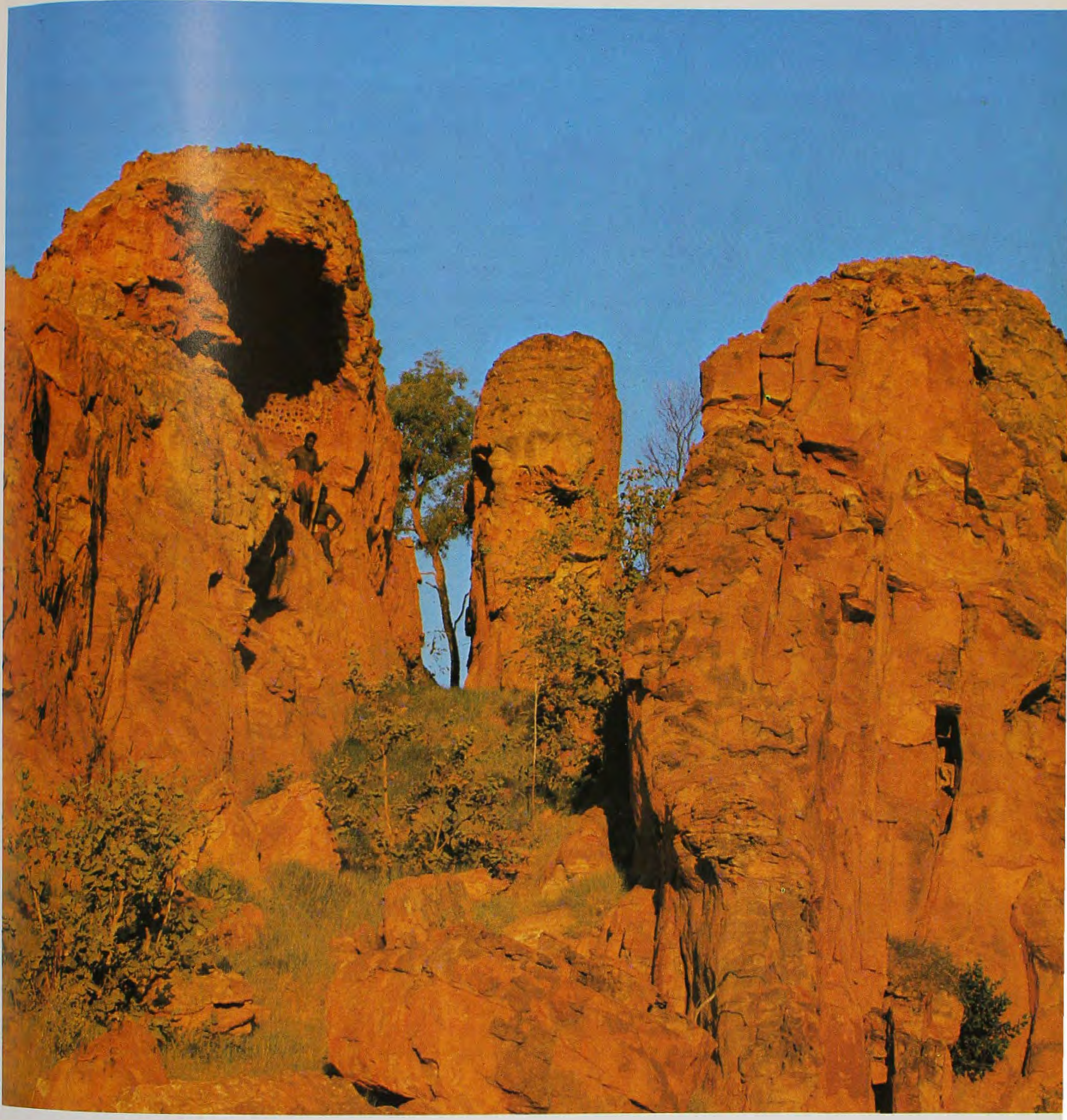
Why are cave sites, not only in Australia but all over the world, so valuable to the archaeologist? In caves, there is often a continual process of deposition, which may be caused by natural sedimentation, especially if water flows through, or by the accumulation of man's rubbish. In an open site, any accumulation of layers is more subject to dispersal by weather, and they may be spread more thinly on the ground since there is no limitation imposed as there is by the walls of a cave. A cave is a fixture in the natural landscape, while an open site may be more arbitrarily located. Hence, people returning to a cave to make their camp will always return to much the same spot. In a cave site, we would expect to find layering of greater depth and regularity than might be the case with an open site. This layering is called stratigraphy and is used by the archaeologist in recording and interpreting his site.

Kenniff Cave, in the Queensland Great Dividing Range, was the first site to show conclusively that Australia was colonised by man during the late Pleistocene, or last Ice Age. This geological period endured up till about ten thousand years ago, and charcoal associated with stone tools from the bottom of over two metres of deposit at Kenniff Cave has been radiocarbon dated to about nineteen thousand years ago. During the Ice Age, much of the world's water was frozen into glaciers at the poles, and worldwide sea levels were considerably lower than they are today—up to one hundred metres lower in fact. The Australasian island group thus had a considerably different shape from that with which we are familiar: Australia, New Guinea and Tasmania would all have been parts of a single land mass. This does not mean that man could have walked into Australia from Southeast Asia, dry shod all the way; there would always have been a deep-water barrier between the two regions. Man's initial entry into Australasia must have been effected by some form of maritime journey, whether intentional or accidental we do not know.

Of about the same age as Kenniff is Koonalda Cave in the Nullarbor Plain, a fascinating site unique in Australian prehistory. This gaping limestone sink-hole leads to a deep complex of passages and chambers. Men penetrated to more than fifty metres below the surface of the plain to extract flint from the walls of this cave, and archaeologists have recovered the waste products of this ancient mining operation. Not only technological debris was found; here, in total darkness, grooves and thin scratches have been made on the soft limestone walls. These man-made incisions, at least twenty thousand years old, are thought to be the oldest example of Aboriginal art in Australia.

One of the oldest Australian cave sites is Malangangerr, a sandstone rockshelter near Oenpelli in eastern Arnham Land, NT. Near the bottom of a deposit 1.8 metres deep were found stone axes with edges formed by grinding, and with a groove around the middle of each to facilitate the attachment of a handle. Charcoal associated with these implements was dated to twenty four thousand years ago. This date occasioned much surprise, as previously it had been thought that the grinding of stone to create a sharp edge was a sophisticated technique only practised by people who were agriculturalists.

SANDRA BOWDLER is a research scholar in the Department of Prehistory, Research School of Pacific Studies, Australian National University. She is currently preparing a PhD thesis on the prehistory of Hunter Island, Tasmania.

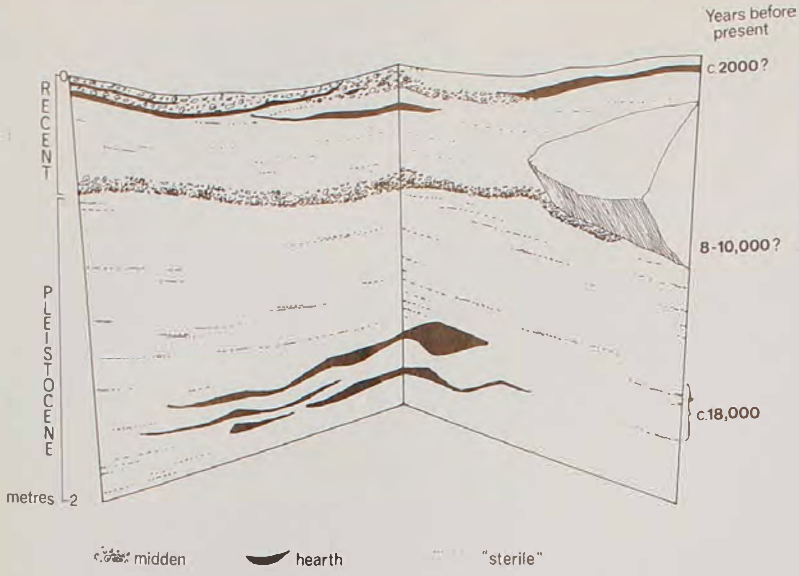


Two Aborigines explore karst formations at Derby, Western Australia.

Unfortunately, the three sites so far mentioned contained little information about the subsistence economies of man in Pleistocene Australia, or the environment at that time. Koonalda was a place for very specialised activities, but Malangangerr and Kenniff Cave were presumably generalised campsites.

Within the last five years, four cave sites have been investigated which have deposits of Pleistocene age containing evidence of man's presence, and good preservation of bone. All four caves are on the southern fringe of the continent, and many similarities of content may be observed. They are the Devil's Lair, WA; the Seton Site on Kangaroo Island, SA; Cloggs Cave near Buchan, Victoria; and the Cave Bay Cave on Hunter Island, Tasmania. All are still being studied, and any conclusions drawn at this stage may have to be revised in the future.

The Devil's Lair has almost three metres of deposit, dated to between twenty four thousand —and twelve thousand years ago. At Cloggs Cave, human artefacts have been dated to between seventeen thousand and eight thousand



Sections of an excavated trench in Cave Bay Cave, Hunter Island, Tasmania.

years ago. At the Seton site, there are two layers of human occupation separated by eighty centimetres of deposit. The lower layer has been dated to sixteen thousand years ago and the upper layer to eleven thousand years ago. This site is of particular interest as the occupation of Kangaroo Island has been a subject of much speculation for many years. When Flinders visited the island in 1802, he found it to be uninhabited; yet many stone artefacts have been found lying on the surface of many parts of the island. Well before the advent of radiocarbon dating, Norman Tindale suggested that Kangaroo Island must have been colonised during the Pleistocene. His argument was that the colonists walked into the island across a Pleistocene land bridge, and after it became an island with the post-glacially rising seas, the colonists became extinct. The Seton site has verified the Pleistocene occupation of Kangaroo Island, though the excavator, R.J. Lampert, argues that it is more likely that the colonists retreated to the mainland as the land link eroded about eight to ten thousand years ago. These three sites are all limestone caves, and limestone, being alkaline, creates an ideal environment for the preservation of bone.

The problem of the origins of the Tasmanians has puzzled ethnologists, archaeologists and physical anthropologists for the last two hundred years. The excavation of the Rocky Cape caves, where the oldest deposits are eight thousand years old, suggested strongly that the Tasmanians came from Australia during the Pleistocene. More recent work on the Cave Bay Cave on Hunter Island, six kilometres off the northwest tip of Tasmania, puts the matter beyond any doubt. This site, a sea cave in a slate cliff, has been dated to eighteen thousand years. At this time, Hunter Island would have been a hill on the land bridge between Australia and Tasmania.

What do these four sites have in common, besides their age and excellent conditions of faunal preservation? Firstly, implements made of bone have been found at each. These are sturdy, pointed tools made of macropod bone and highly polished. Secondly, a high percentage of the stone artefacts at all these sites was made of quartz, and a particular mode of manufacture called the 'bipolar technique' is observable. Thirdly, none of these caves would appear to have been intensively occupied. Each has been the haunt of non-human predators—owls, kestrels, native cats, the Tasmanian wolf and Tasmanian devil. We know this not only from finding the identifiable remains of these animals, but also from the nature of the other bones found. Masses of tiny rodent bones suggest the regurgitated pellets of owls and other birds of prey; kangaroo, wallaby and possum bones broken up into tiny fragments suggest the work of marsupial carnivores. It seems unlikely that man and carnivore would have co-habited simultaneously; probably they alternated their occupancy of these sites. Let us look at one in detail.

The sides of an excavated trench, representative of the Cave Bay Cave sections is illustrated on this page. The sequence presented here is speculative, insofar as more radio-carbon dates are pending. The earliest date so far obtained is eighteen thousand years, as mentioned, but a still earlier one is possible. Stratigraphically, the earliest evidence for man's presence in the site is the lowest of the three black hearths in the diagram. These hearths are distinguishable from the layers below, above and between them as they contain an abundance of charcoal, numbers of stone tools, and large amounts of wallaby bone. This bone is in the form of complete jaws, and long bones broken only on the ends. Many are heavily burnt. The presence of only one or two species suggests a cultural preference—the result of human hunters selecting in favour of a single prey. The bone in the surrounding layers represents more diverse species: rodent, marsupial 'mouse' (*Antechinus* sp.), pygmy possum, ringtail possum, bandicoot (*Perameles* sp.), pademelon, wallaby, wombat and native cat (*Dasyurus* cf. *viverrinus*). The multitude of rodent and *Antechinus* bones, often in small concentrated pockets, suggest they were the prey of owls; the extremely fragmented nature of the bones of the larger animals suggests the work of the Tasmanian devil. Many of these species are not now to be found on Hunter Island, and further reinforce our impression of this piece of land being part of the Australian-Tasmanian greater land mass.

Half-way up the sequence is a layer of dense shell midden, indicating a period when the sea level was close to its present position, and marine shellfish were readily obtainable. Today, this cave directly overlooks the foreshore. My estimate of ten to eight thousand years is merely that—an estimate—but for the following reasons. This layer rests directly on top of layers deemed to be of Pleistocene age on the basis of the animal species represented, and is comparable to the lowest levels of Rocky Cape South, dated to eight thousand years. Rhys Jones, who excavated the Rocky Cape caves, argued that the oldest levels there represented people with a well-developed coastal economy pushed back by the rising seas and practising this economy at Rocky Cape after the sea reached its present level. The midden layer at Cave Bay seems directly analogous. Above the midden layer there seems to be another hiatus in human occupation. Rodent bones are again abundant, but instead of larger marsupials we find the bones of innumerable seabirds. Here we might seek an analogy with Kangaroo Island: the midden layer might represent the period just before Hunter Island came into being, and the people may have retreated when they saw the last link with what is now Tasmania bout to be severed. The most recent deposits in the cave contain further evidence of human occupation, hearths and lenses of shell midden, and the bottom of this complex could represent the maritime discovery of Hunter Island. We know from historical sources that most of the islands of the Hunter Group were visited by sea by the Tasmanians, who came to exploit the muttonbirds.

Let us re-focus our attention on the Pleistocene deposits in the Cave Bay Cave. The traces of man here are remarkably sparse when we consider that the total period represented is of the order of ten thousand years, and no water barrier intervened between the site and the people's major hunting and gathering domain. The stratigraphy and fauna at Devil's Lair, Cloggs Cave and the Seton site present a similar picture. A comparison with Rocky Cape South emphasises this, as here it can be seen that a truly massive two and a half metres of occupational debris has built up in only four thousand years, and the deposits contain no sign of the action or living presence of non-human predators. To return to the Oenpelli region, for every site here in excess of ten thousand years old, there are at least ten which were occupied for the first time within the last five thousand years. Similarly, in the Sydney-South Coast region, Burrill Lake is the only known cave site of Pleistocene antiquity. The only other archaeological site of comparable age in the area is Bass Point—an open campsite dated to seventeen thousand years. Dozens of other caves and shelters excavated in the area had all been occupied for the first time within the last eight thousand years. These areas are near present-day coastlines, and coasts seem to be areas capable of supporting dense populations of hunter-gatherers. It must also be borne in mind that Pleistocene coastal sites are now under the sea. While prehistoric population estimates, be they ever so broad, are notoriously fraught with peril, we might push this argument a little further and suggest that during the Pleistocene, the Australian land mass was less densely occupied than in more recent times. Whatever the reason, it does seem that during the Pleistocene, cave sites were less intensively used by man than subsequently.

At this point it would be pertinent to enquire into the use made of cave sites by Aborigines in historic times. In Australia, the archaeologist is greatly aided by sources of information not available to workers on the European stone age. In this country over the last two hundred years, detailed observations have been made of hunter-gatherers leading traditional lives. There are written documents containing such observations by the earliest settlers, there is the work of trained anthropologists, and recently, archaeologists have been betaking themselves into the bush to observe at first hand the way hunter-gatherers live. Curiously, very little can be gleaned from these sources pertaining to man's use of Australian caves. It would seem that caves figure very rarely in the day-to-day life of the average hunter-gatherer. We are left, then, with a paradox: the type of site most sought after by the archaeologist was probably of least importance to the people who, sporadically, occupied it.

FURTHER READING

Lampert, R.J. *Burrill Lake and Currarong, Terra Australis* I; Department Of Prehistory, Research School of Pacific Studies, Australian National University, Canberra, 1971.

Mulvaney, D.J. *The Prehistory of Australia* (2nd ed.); Pelican, 1975.

Mulvaney, D.J. and J. Golson, (eds.) *Aboriginal Man and Environment in Australia;* Australian National University Press, Canberra, 1971.

Wright, R.V.S. (ed.) *Archaeology of the Gallus Site, Koonalda Cave;* Australian Institute of Aboriginal Studies, Canberra, 1971.

ECOSYSTEMS UNDERGROUND

BY J.A. HARRIS

Caves provide homes for a variety of organisms and provide interesting challenges for ecologists who study them—challenges concerning not only life in caves but also the workings of ecosystems in general.

The cave environment may be conveniently divided into a twilight zone near the entrance, a middle zone of complete darkness and variable temperature, and a zone of complete darkness where temperature is constant. The last zone is usually emphasised as being 'the cave environment'. The temperature of this zone usually approximates the mean annual temperature of the region in which the cave is located. The relative humidity is generally high and comparatively constant, while both silence and darkness are characteristic.

There are many ways in which caves become occupied by living things. Leaves, twigs and soil may fall or be washed into caves along with the small animals associated with this material. Flowing streams also can bring life into caves. Fungi and bacteria, along with small insects and spiders, enter caves on wind currents. Large animals such as bats and rats can colonise caves unaided. When considering

which organisms live in caves, it is important to remember that photosynthesis cannot take place in absolute darkness. Consequently, plants are virtually absent from caves except near entrances.

Cave animals usually are classified according to their place in the cave and the extent of their adaptation to the cave environment. There are surface-dwelling species that wander, fall or are washed in purely as accidental visitors and are therefore called 'accidentals'. Carpet pythons are occasionally accidentals as they sometimes wait at cave entrances to feed on bats as they fly in and out. Other animals, Noctuid and Geometrid moths for example, occur outside caves but will regularly shelter in cave entrances. Leaf-tailed geckos feeding on these moths also shelter in entrances. The parasites that live on bats and other cave animals are another category. Batflies (Diptera: Streblidae and Nycteribiidae), that look more like spiders than flies are excellent examples of specialised parasites living on their bat hosts. The three major categories of cave animals are:

(1) species that spend part of their lives within caves and part outside (the trogloxenes). These usually have a daily cycle of activity, as in cave-dwelling bats, birds or crickets, where the animals shelter within the cave but emerge to seek food.

(2) species that live only within caves (the troglobites). Included in this group are the species famous for their spectacular morphological adaptations to 'the cave environment' exhibited as a reduction or loss of pigment and eyes.

(3) species that complete their total life cycle within the cave, but which lack evident morphological specialisation and may occur in surface habitats (the troglophiles).

In a faunal study of forty-seven caves of the Nullarbor Plain, southern Australia, Aola M. Richards of the University of New South Wales recorded ninety-five species of arthropods comprising twenty-five percent accidentals, seventeen percent trogloxenes, fifty-two percent troglophiles and six percent troglobites. Australian caves have few animal species that exhibit obvious morphological adaptations to 'the cave environment' and the tendency has been to classify most species as troglophiles although they have been collected only from caves.

Bats are undoubtedly the outstanding example of trogloxenes. The most common and numerous bats occurring in caves are bent-winged bats *(Miniopterus australis* and *M. schreibersii)* particularly in eastern Australia. Both of these species are small insectivorous bats and are usually found together in the same caves. In the limestone caves system at Mt. Etna, near Rockhampton, Queensland, a colony of these species numbering 300,000 to 400,000 individuals is dependent on a single cave for the birth and rearing of their young. Hence the name 'nursery cave' or 'nursery' is used to describe these caves that are occupied by maternity colonies of bats at certain times each year. These bats have been studied by P.D. Dwyer of the University of Queensland, and he has found that all the bent-winged bats of eastern Australia depend on relatively small numbers of nurseries, each of which serves a large area usually bounded by major physiographic features such as watersheds or divides —a fact that is of great importance for their conservation. Through observations and a programme of tagging thousands of individual bats with metal arm bands, Dwyer found that in early summer, females fly to the special nursery caves for the birth of their young. Following birth, baby bats cling to the ceilings of their nurseries in dense clusters until weaned.

A different kind of cave-dwelling bat is the false vampire or ghost bat *(Macroderma gigas)*. The largest of the carnivorous and insect-eating bats (forearms 100—120mm, weight approx. 150g) it feeds on lizards, small mammals, birds and other bats at night in tropical latitudes. Their roosting colonies are no greater than a few hundred individuals.

A small number of Australian birds use caves either as roosting or nesting sites but only

Female bent-winged bats, *schreibersii Minipterus* flying in their nursery cave. Note the naked young clinging to its mothe

JOHN A. HARRIS is a lecturer in ecology at the Canberra College of Advanced Education. His research interests are cave ecology and the evolution of Australian communities of cave animals and plants.

H.G. Cogger

Leaf-tailed geckos, *Phyllurus cornutus*, feed on moths that are sheltering near cave entrances.

one species is a true trogloxene—the grey swiftlet. This species occurs in northeastern Queensland and they build their nests of plant material in clusters deep within caves. They can fly in the dark, apparently with the aid of a metallic clicking call used for echo-location. In addition, they have large eyes and probably are able to make maximum use of whatever dim light is available.

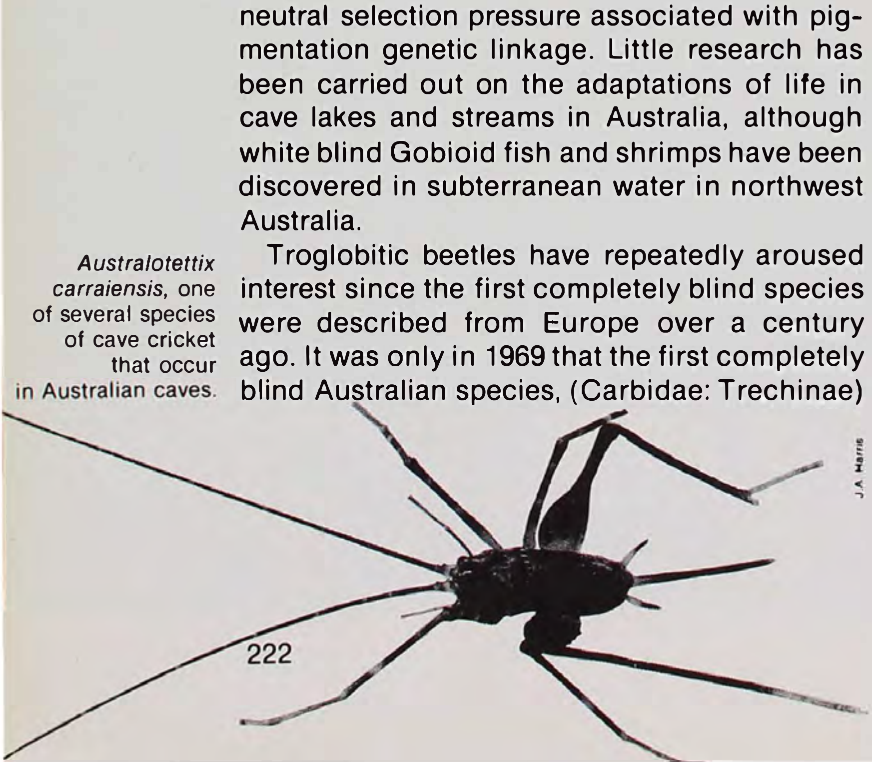
A common invertebrate trogloxene is the cave cricket (Orthoptera: Rhaphidophoridae). Several species of cave crickets rest on the ceilings and walls of caves, in or close to the twilight zone, during the day and usually venture outside the cave to feed at night. Their food consists of small arthropods, possibly ants and millipedes, living in the forest floor among leaves and twigs.

The troglobites of Australian caves include fish, crustaceans, spiders and insects. They exhibit specialised adaptations as a response to the particular selection pressures occuring in 'the cave environment'. In complete darkness, there is strong selection pressure for the development of structures highly sensitive to touch and smell. Hence the cockroach, *Trogloblattella nullarborensis,* found in caves of the Nullarbor Plain, is completely lacking in eyes but has very long antennae and legs. The cause of the lack of pigment in many troglobites is a complex question. This lack seems to have resulted from neutral selection pressure associated with pigmentation genetic linkage. Little research has been carried out on the adaptations of life in cave lakes and streams in Australia, although white blind Gobioid fish and shrimps have been discovered in subterranean water in northwest Australia.

Troglobitic beetles have repeatedly aroused interest since the first completely blind species were described from Europe over a century ago. It was only in 1969 that the first completely blind Australian species, (Carbidae: Trechinae) was discovered at Ida Bay in Tasmania. Since that time two other blind species of trechine carabids have been found in Tasmania. The Australian troglobitic beetles so far known are all of the family Carabidae. Their distribution patterns are closely related to the southern Pleistocene periglacial zones. Large caves appear to have provided refuge for certain animals from the climatic extremes of this glacial period. Generally, troglobitic beetles appear to have been derived from groups that were, in a sense, preadapted to life underground and in continual darkness. These mainly lived in the moist, deep litter layers of forests. Troglobites have become so specialised to their environment over a period of time that they are able to migrate only by means of underground cracks that may link, intermittently, their normally isolated homes. They are also numerous in temperate latitudes.

Troglophiles are more mobile and less restricted in their habits than troglobites. They may persist for many generations in caves if food supplies permit, but they are able to subsist on surface sources and may move from one habitat to another. A wide variety of invertebrates are troglophiles, perhaps the best known of all being the glow-worm. The biology of the glow-worm is described in an article by A.M. Richards, in *Australian Natural History,* September 1963. The most prevalent troglophiles are the guano mite *(Uroobovella coprophila)* and moths of the family Tineidae (which contains the clothes moth) that are associated with bat guano deposits. There are numerous species of centipedes, beetles, flies, mites and spiders living as troglophiles in Australian caves.

How does food become available in sufficient quantity to enable animals to live entirely in caves? Cave food is provided as rotting vegetation and other organic matter washed in during flooding, together with the droppings and dead bodies of animals which feed outside by night and return to the cave by day. Bats, cave crickets and particularly birds in the Nullarbor caves are important in this respect because of their gregarious roosting habits and the droppings of guano they produce. Roosting bats produce droppings of guano which in turn can be colonised by fungi. If the number of bats roosting on the ceiling in one site is sufficient, a small guano heap is produced, providing sufficient food to sustain a number of organisms such as beetles and moths that feed on bat dung and fungi. Spiders, in turn, may be attract-



J.A. Harris

Australotettix carraiensis, one of several species of cave cricket that occur in Australian caves.

ed to the dung heap to feed on beetles. A short food chain has been initiated within a simple community of organisms. Should the bats choose a different roosting site, the major source of food available to this community is cut off, and only those species that have evolved adaptations that enable them to grow and reproduce on a scarce food supply will survive. Many species are able to live temporarily without food (e.g. spiders), or to search out an alternative source of food (e.g. winged beetles). Rotting vegetation transported into the cave may provide an alternative food source, but its small quantity and irregular occurrence again allow the development of only relatively simple communities—simple in the sense that there are few species and numbers of individuals present. This seems to be the situation in many Australian caves.

There is a class of cave where this situation is modified—the bat cave, or more specifically, the bat-guano cave. The regular roosting of large numbers of bats in caves markedly modifies 'the cave environment'. Bat-guano caves occur throughout eastern Australia where the bent-winged bats are present. These caves may be heated up by the activities of bats, but a combination of factors is necessary before temperature change can occur.

If the body temperature of a roosting bat falls to the same air temperature as the cave, the cave temperature obviously will not be influenced. Even when the body temperature of bats is maintained above that of the cave, the cave (or chamber) is suitably domed and protected from drafts of surface air to enable the generated body heat to be conserved so that bats will influence the cave temperature. The extent to which bats may heat up caves is best shown in the nursery caves of the bent-winged bats. Their nurseries usually possess domed ceilings and the capacity to house nursery colonies of many thousands of individuals. Temperatures in these caves may fluctuate more than 10°C over a year and are often 10°C above the mean annual temperature of the surface location site.

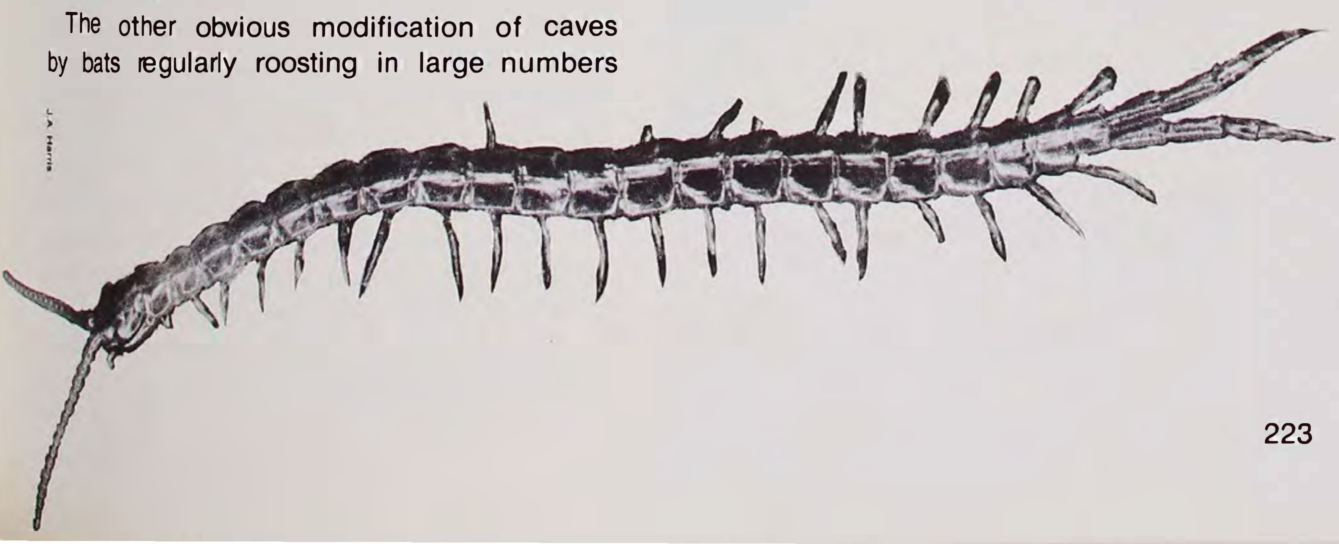
The other obvious modification of caves by bats regularly roosting in large numbers is the build-up of guano deposits which enormously increases the food supply to cave organisms. Nevertheless, large, durable deposits of guano are built up only in those caves which are important to the bats' physical or social requirements and where there is an absence of frequent flooding or flowing water. These specific caves, or specific chambers of caves, because of their importance to the bat's way of life, are occupied regularly by many thousands of individuals at about the same time each year. Examples are nursery caves and those where mating occurs. The heaps of guano found in these particular caves support resident communities of organisms. These are different from transient communities that are associated with less durable heaps commonly found scattered throughout large caves where bats roost in many different sites.

Carrai Bat Cave (a limestone cave, near Kempsey NSW) is a bat-guano cave in which I spent several years investigating a community of organisms living in a durable guano heap, one and a half metres high, that stands in a small inner chamber (Chamber C). This bat-guano ecosystem is unique, in common with each and every living system, but it exemplifies the kinds of processes occurring in other bat-guano caves as well as providing clues to the workings of ecosystems in general.

Chamber C is reached by crawling through a short tunnel. The chamber is about seven

J. Green/CSIRO

Goedetrechus mendumae, one of the firs eyeless troglobitic beetles to be discovered in Australian caves.



J.A. Harris

This centipede, belonging to the genus *Scolopendra*, commonly occurs in caves and in the forest litter outside

J A Harris

Summer cluster of bent-winged bats *Miniopterus schreibersii* in Carrai Bat Cave, near Kempsey, NSW.

metres long and four metres wide. It is an enclosed chamber with a partially domed ceiling of four metres maximum height. Between one thousand and three thousand bent-winged bats roost there, clinging upside-down from the ceiling, each day from late January to June and again from October to early December with intermittent roosting occuring during most of December and January. These regular roosting cycles are known to have been repeated with little variation for over ten years. The air temperature measured near the chamber wall is 14°C ± 2°C annually.

The resident community of organisms inhabiting the heap comprises bacteria, fungi, protozoans, nematodes, mites, beetles, flies, moths and spiders. Counts of the number of bacteria and fungi indicate that these micro-organisms occur in largest numbers in the surface layers. This trend is also shown for protozoans and nematodes. Mites, in particular the guano mites, which occur in very large numbers, and beetles crawl throughout the layers of guano to a depth of about twenty-five centimetres. The guano fly *(Cypselosoma australis)* and spiders are found only close to the top of the heap in the fresh guano, while moths tend to rest on the lower surfaces.

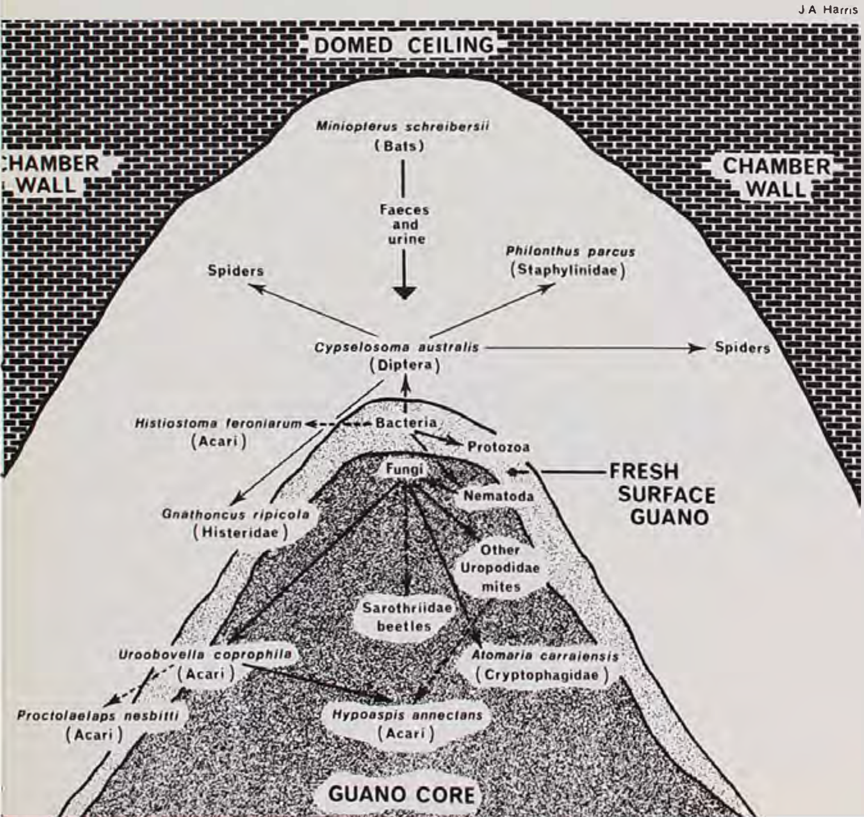
When bats are absent from Chamber C during July to September there is no source of food to the guano community. The organisms on the heap either become inactive, neither growing nor reproducing (e.g. the guano mite) or their numbers drop as in the case of the guano flies, which have very few larvae and only a few adults. Resting histerid beetle larvae occur thirty centimetres into the heap. Only the staphylinid beetles disappear from the heap and presumably migrate to another part of the cave. The organisms seem unable to feed on the partially decomposed guano which accumulates to form the red-brown central core composed mostly of chitinous remains of moths and other arthropods.

With the arrival of bats in large numbers during October, fresh dung pellets and urine are deposited on the heap and there is a spectacular change in the activity of the community. The micro-organisms (bacteria, fungi, and protozoa) colonise the fresh guano and increase their numbers rapidly. The previously inactive mites feed, grow and reproduce quickly. The adult flies lay eggs in the fresh guano. Immature guano mites grow rapidly and moult, while previously inactive females begin laying eggs. The mature larvae of the histerid beetle pupate, after 'wintering' some thirty centimetres down inside the heap, and later a few newly-emerged adults make their way to the surface. The population of guano mites builds up quickly (maximum number recorded was 33,700,000 per square metre) with the hatching of larvae and the moulting of immature stages to reproducing adults. The density of flies, because of their initial low numbers, takes longer to increase. The fly larvae feed directly on the freshly-deposited guano.

Following the arrival of bats in October, the activity of the guano community is intense for a period of about one and a half months. Through continuous measurements of the temperature of the guano heap using an automatic temperature recorder, I discovered that significant physical changes were occurring to the heap at the same time. Temperature of the surface layers of guano to a depth of

The food web of the bat-guano community

J A Harris



two centimetres increased from 14—15°C to almost 24°C within a month of bats arriving to roost.

When the majority of roosting bats vacate Chamber C in early December, to give birth to their young at a nursery cave six kilometres away, there appears to be sufficient fresh guano available to tide the guano community over till large numbers of bats return to roost and mate in late January. From this time until June, fluctuations in numbers of individuals of each species and the community relationships appear relatively stabilised. This series of changes appears to be a regular annual cycle.

Considering the usual description of life in caves one might wonder why the species in Chamber C are not more mobile and show greater retention of the ability to exploit other food sources quickly. The majority of organisms remain on the guano heap and their behaviour has been synchronised with the cyclical input of food. There seems to be little movement to and from the heap itself. The central guano core increases the amount of usable space available for the guano community. Like soil, it forms a depth of material that provides protection for soft-bodies animals such as histerid beetle larvae as well as guaranteeing that the species remain 'in position' to receive the next input of food. Vital stages in the development of guano mites (e.g. moulting) also occur in the central core. The presence of the core seems necessary in order to maintain the exceedingly high numbers of organisms in the guano heap. In summary, the bat-guano community is made up of a small number of species that have evolved adaptations over a period of time to their special bat-guano cave environment. Their environment is characterised by a reliable seasonal input of food (guano and urine) caused through the interaction of bats with the cave structure, and a highly variable physical environment brought about by the interaction of all organisms comprising the guano community.

This particular bat guano ecosystem is, nevertheless, part of a wide network of living systems. In Chamber C of Carrai Bat Cave, we see a variation of familiar ecological processes that govern the interrelationships of each and every species in all natural communities. These cave interrelationships are fine examples of the diverse products of the evolutionary process that has produced all life on our planet including our own species. Caves themselves are a further demonstration of the ever-changing character of the Earth's physical environment. They form, develop for a time, then collapse in an unending natural process. It is this process that provides the variety of unpredictable physical events that promote the continuing function of biological evolution. Therefore, caves are vital places for life, as well as places for learning about the working of living systems—the ecological rationale for their protection and that of their living inhabitants.

FURTHER READING

Dwyer, P.D. "The Population Pattern of *Miniopterus schreibersii* (Chiroptera) in North-Eastern New South Wales"; *Aust. J. Zool.* 14, 1073-1137, 1965.

Harris, J.A. "Structure and Dynamics of Cave Population of the Guano Mite, *Uroobovella Coprophila* (Womersley)"; *Aust. J. Zool.* 21, 239-275, 1971.

Richards, A.M. "An Ecological Study of the Cavernicolous Fauna of the Nullarbor Plain, Southern Australia"; *J. Zool.* (London) 164, 1-60, 1971.

J.A. Harris

The bat-guano heap in Carrai Bat Cave.

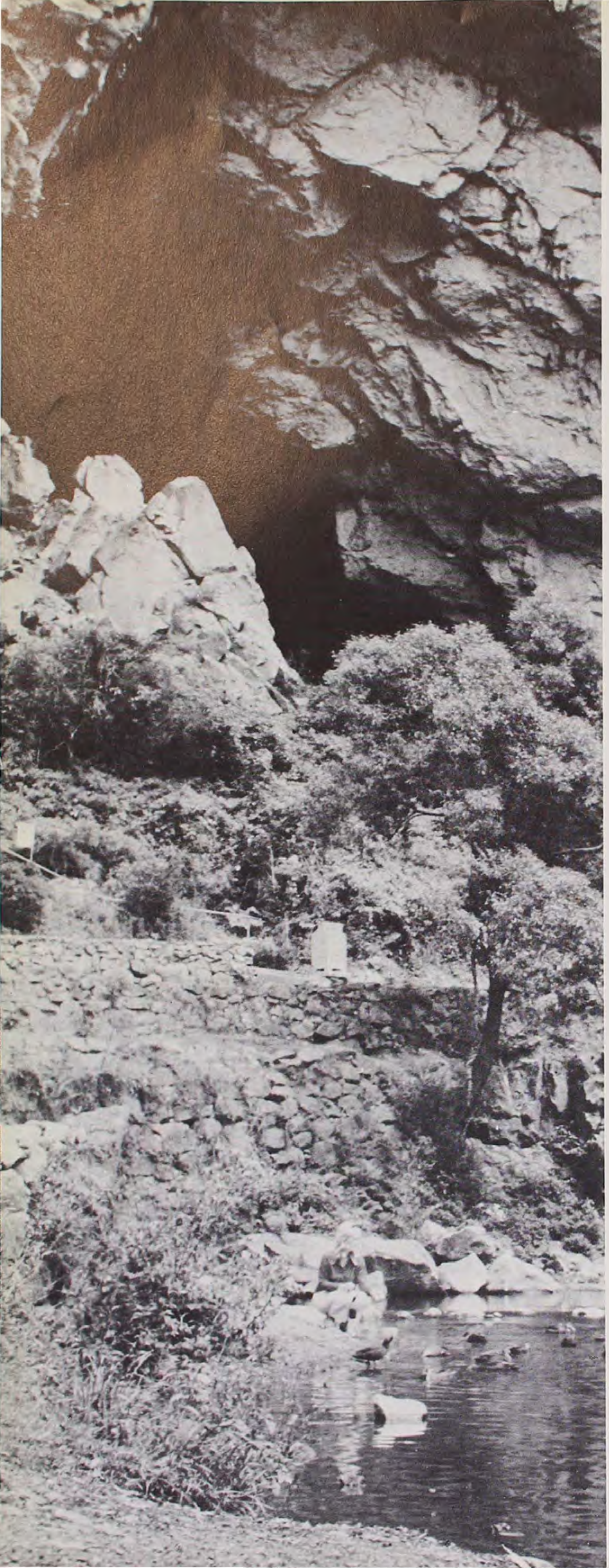


Photo: By Courtesy of NSW Dept. of Tourism

THE

From the days of *Australopithecus*, man has been known to use caves—though his reasons for doing so have evolved along with man himself. As man's curiosity led him to explore the depths of his primitive shelter, he discovered things both beautiful and useful. There must always have been the argument about which of these values should take precedence over the other, but as Earth's store of natural resources and of natural delights has been steadily depleted by her rapidly expanding human population, the argument has gained momentum.

Caves and karst landscapes are one example of natural features whose beauty must be adversely affected if they are to be made useful to man. They are, of course, particularly susceptible to mining but even tourism unwittingly takes its toll. There are many caves in Australia that have been developed as tourist attractions; they can be found in every state. Each location varies in the type of landscape it presents and in the stories it has to tell.

Growth in cave tourism has been remarkable as is well-illustrated by the number of visitors to Jenolan and its show caves—from less than twenty thousand in 1930 to more than one hundred and eighty thousand in 1974. Indeed, the popular Lucas Cave is sometimes visited by as many as two thousand people in one day. The reasons for such increases are tied to factors such as increased leisure time, and greater income and mobility.

In some areas there is little debate about appropriate methods of conservation. Mullamullang Cave on the Nullarbor Plain is remote, undoubtedly unique and ideally suited to the preservationist concept of conservation. Lucas Cave at Jenolan is synonymous with high density tourism, incompatible with other interests, and the only question is how to fulfil this function over the long term. However, in most cases, and especially in karst areas close to population centres, it is necessary to ensure not only that representative landscapes are properly preserved, but that competing interests are satisfied. To some extent this depends on

JOHN DUNKLEY is a teacher with the Commonwealth Teaching Service in Canberra, and has a particular interest in cave conservation.

HEAVY HAND OF MODERN MAN

BY JOHN DUNKLEY AND LUDWIG REIDER

the controlling authority. Thus Jenolan, Yarrangobilly and Bungonia (NSW) provide primarily for tourism, tourism/scientific, and recreational demands respectively, reflecting the spirit of three different legislative arrangements. Within each such area, however, master plans can zone both surface and underground environments for different purposes.

There is a wide range of conservation issues concerning caves and karst areas in Australia quite apart from tourist problems. Some caves require conservation measures because they typily the biological and geological features distinctive to a location. Mullamullang Cave, located on the dry Nullarbor Plain in Western Australia typifies an underground wilderness concept having such features as collapse doline entrances, underground sand dunes, huge chambers, rare gypsum and halite formations as well as being the type locality for two troglobitic invertebrates. On the other hand, Exit Cave in the remote forest country of Ida Bay, Tasmania illustrates the multiple use concept as Australia's largest cave with sixteen kilometres of surveyed passage, huge chambers, immense rock falls and several underground rivers. Here there are superb decorations and rare fauna occurs in portions of the cave. Among the largest caves in Australia, Mullamullang and Exit Caves receive less than two hundred visitors per year at present.

In contrast, the Texas Caves, located in grazing country near the small Queensland border town of Texas, are to be inundated by construction of a nearby dam. This area represents the only karst landscape within reasonable reach of groups from Brisbane.

Another important conservation issue concerns the use of caves for the dumping of wastes. For example, Earls Cave near Mt. Gambier in South Australia, a small cave with a shallow water table has been used as a rubbish dump as have others in the area. Bacteria and other pollutants have found their way through the water table into the processed water of Mt. Gambier's vegetable canning factories and possibly into the town water supply, which requires heavy chlorination.

The range of conservation issues can be represented in the form of a continum which recognises partly overlapping interest groups and leads to a consideration of conservation problems removed from the extreme positions of total preservation versus total exploitation.

TOTAL PRESERVATION	←————→	TOTAL EXPLOITATION
COMMUNITY INTERESTS	wilderness, scientific, passive recreation, education, tourism, speleology, active recreation (scouts, etc.), forestry, frazing, agriculture, guano mining, highways, built-up areas, limestone mining	
AESTHETIC FACTORS	←————→	ECONOMIC FACTORS

Aided by a grant from the National Estate Commission of Enquiry, an inventory of Australia's karst and cave resources is now being coordinated by the Australian Speleological Federation. However, legislative action will be slower and only in a few places is a master development plan yet extant or proposed.

Whatever use criteria are devised and applied, it will be essential to establish and maintain, through proper research and management policies, ceiling rates of cave usage. These ceiling rates of usage should be conceived in terms not only of physical and/or environmental carrying capacity of a cave area, but of user satisfac-

The impact of tourism on the karst landscape may be direct and indirect. Direct forms can be divided into surface impacts, resulting from the provision of parking space, walking tracks, picnic areas, tunnel access, amenities areas, accommodation sites and management structures; and subsurface impacts caused by the provision of facilities necessary for comfortable cave inspection, such as electric lighting, wiring, pavements and protective fencing.

The indirect forms of impact on the karst landscape have only recently been given due consideration, which has usually been more conceptual than practical. For example, the high yearly throughput of tourists in some of the major show caves at Jenolan has resulted in a noticeable decline in the quality of the caves'

The entrance the to Grand Arch, Jenolan, NSW with the Blue Pool in the foreground.

LUDWIG REIDER, a Research Officer with the NSW Department of Tourism, is Vice-President of the Sydney University Speleological Society. His main interests include cave surveying, conservation, geomorphology and cave tourism and recreation.

environment and has adversely affected their value as a tourist resource even though tourist traffic is well controlled. This situation has led to the use of steam cleaning in an effort to restore the show qualities of the caves concerned. Cleaning disclosed considerable amounts of lint and other textile fibres derived from visitors over the years. Furthermore, not only does the large throughput of visitors produce significant pollution, but the removal of these pollutants may often entail the destruction of a cave ecosystem in which subsequent loss of show quality may be accelerated. The interdependence of surface and subsurface impacts resulting from high tourist use may be illustrated by the construction of car parks on limestone areas. These concentrate runoff and reduce infiltration which in turn alters drip, stream flow and sediment parameters within the caves, and hence the growth of formations. The construction of tunnels to aid access to remote caverns has the effect of damaging some decorations and changing the atmospheric circulation in the caves despite the provision of semi-sealed doors.

It seems necessary to gather more information about the impact of man-made structures in caves to add to the paucity of knowledge that currently exists. Some of the more important questions are:

What kind of material should be used?
What are the best types of pavement structure?
What kind of lighting techniques are best so as to minimise the growth of algae?
How can unsightly cables be eliminated or hidden?

Cave tourist areas may provide for a number of diverse and seemingly conflicting interests such as entertainment, interpretation, environmental studies, picnicking, accommodation and cave inspections. A noticeable feature of cave tourism is that it has been traditionally endowed with magic, fantasy and fairy tale qualities. This is shown by the many mythical names given to caves and their decorative features— e.g. Temple of Baal, the Ruined City, Lot's Wife. However, many with a keen interest in cave tourism management believe that the resource should provide a more valuable and meaningful experience for the cave tourist. For this reason, increasing emphasis should be given to interpreting the educational, historic, scientific, cultural and natural values of this resource. It would seem important that in addition to interpreting the karst landscape in a more meaningful way, the tourist should be made aware of the landscape's conservation problems, of which he forms an integral part. In general, the perception of what a cave tourism experience should be is now moving from one with a myopic and generally meaningless quality to one with diverse qualities providing a more enriching and intellectual appreciation of one aspect of the world in which we live.

It seems necessary to recognise the major elements of the cave tourisms experience so that research leading to better management and quality can be properly organised. While appearing obvious, few seem to recognise them for their organising value. These elements include: the anticipation of the trip, the travel to the place, the on-site experiences, the travel home, and the recollections of the experience. Any attempt at improving the quality of a cave outing must be considered in light of these.

In the long term, the conservation of Australia's cave resources inevitably depends on attitudes of the public and of government. Caves will not be preserved for altruistic motives, but because the social ethic demands that they be conserved as valuable resources. There are strong arguments which strengthen the long-term value of planned conservation and erode the economic case for short-term exploitation. For example, leisure activities can be viewed as mental regeneration, as an escape from the complexities and frustrations of modern society, so that adequate provision for tourism and recreation can be viewed as an investment in the nation's productive capacity. Uncertainty as to future wants and needs, prices, costs and technology make possible the development of a social ethic which will limit economic expansion. Then, there is the argument related to statistical calculation based on the present value of all future returns from alternative resource uses.

It is quite likely that short-term financial returns from industrial uses are far exceeded by long-term indirect returns from alternative recreational uses of caves.

FURTHER READING

Clawson, M. and J. Knetsch. *Economics of Outdoor Recreation*, John Hopkins Press, New York, 1966.

Jennings, J.N. "How Well Off is Australia for Caves and Karst?—A Brief Geomorphic Estimate"; Paper delivered at 10th Biennial Conference of Australian Speleological Federation, 1974.

McHarg, I. *Design with Nature*, Natural History Press, New York, 1969 (paperback edition, 1971).

Skinner, A.D. *Mass Recreation at Ida Bay, The Development of Exit Cave;* Tasmanian College of Advanced Education, Hobart, 1973.

Photo By Courtesy of NSW Dept. of Tourism

Two tourists admire a minaret in one of the caves at Jenolan, NSW. These stalagmites obtain their unusual form by the dripping of solution from stalactites above.

L. Reider

Accumulations of rubbish in Earls Cave, South Australia.

PRINTED IN AUSTRALIA BY OFFSET ALPINE PTY. LTD.

CAVE SITES IN AUSTRALIA