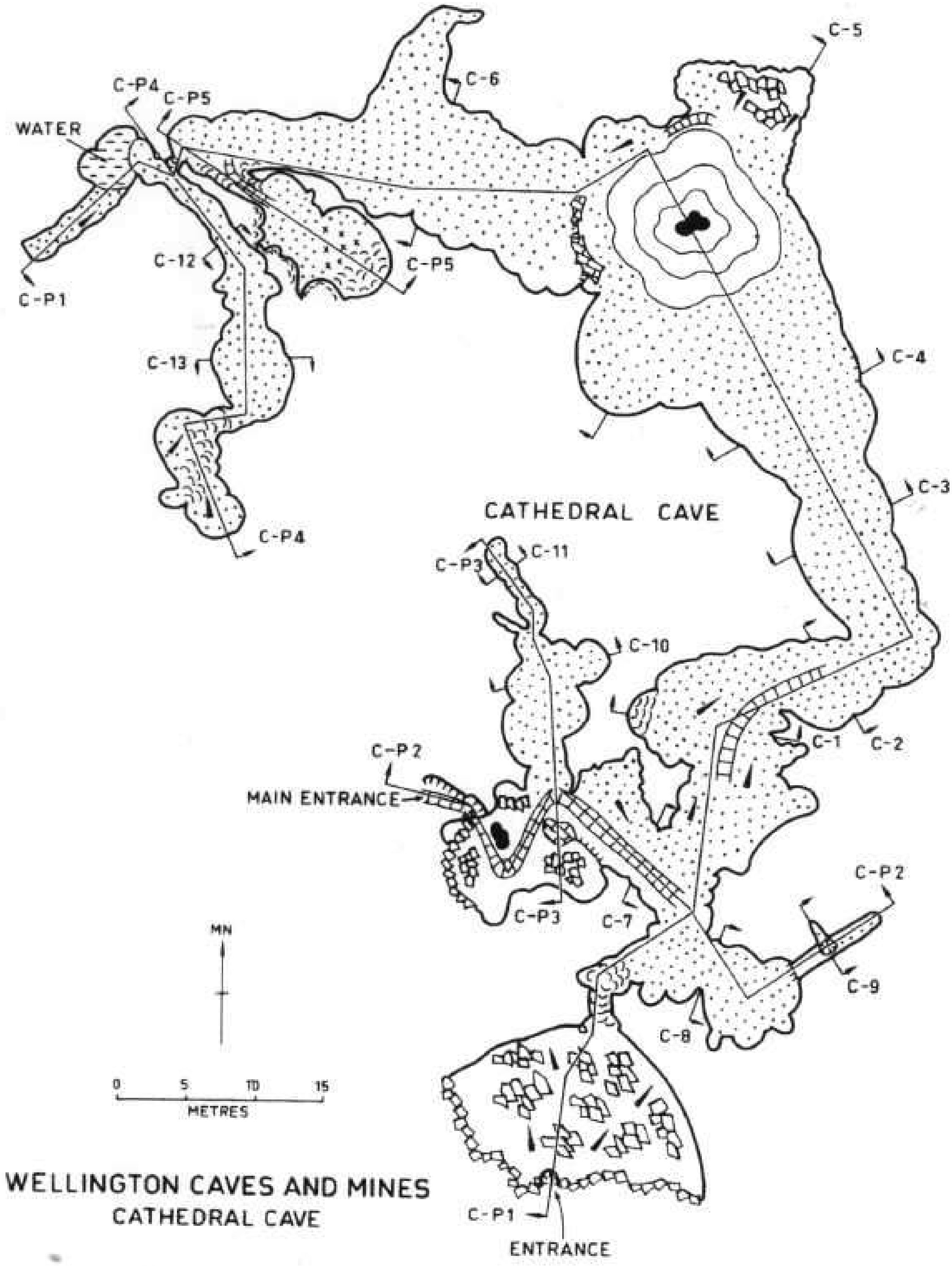
VOLUME 37 (1) 2001

Helictite

Journal of Australasian Speleological Research



Helictite

Journal of Australasian Speleological Research

ISSN: 0017-9973

Helictite was established by Edward A. Lane and Aola M. Richards in 1962 who were the foundation editors. It is intended to be wide ranging in scope from the scientific study of caves and their contents, to the history of caves and cave areas and the technical aspects of cave study and exploration. The territory covered is Australasia – Australia, New Zealand, the near Pacific Islands, Papua New Guinea and surrounding areas, Indonesia and Borneo.

In 1974 the Speleological Research Council agreed to support the Journal with financial assistance and in 1976 took over full responsibility for its production. From 1974 to 1997 the Journal was edited by Julia James assisted by other members of the Speleological Research Council Ltd. In 1998 Susan White and Ken Grimes took over as editors with Glenn Baddeley as Business manager.

In 2000 ownership was transferred to the Australian Speleological Federation, Inc. (ASF) and is administrated by the Helictite Commission of the ASF.

The aim of the Helictite Commission of the Australian Speleological Federation is:
To publish the results of scientific studies in all fields of speleology in Helictite – Journal of Australasian Speleological Research and other publications.

Australian Speleological Federation Inc.

Helictite

Journal of Australasian Speleological Research

Volume 37 (1) 2001

Contents

Cover: This map of Cathedral Cave, at Wellington, NSW, first appeared in Helictite volume 9, No 1, 1971, as part of a paper by R. Frank, on the Clastic Sediments of the Wellington Caves. In this issue we publish a review of karst studies at Wellington.

Helictite, Volume 37, 2001 will consists of two issues. Price of Volume 37 is $20 post paid. Price per volume starting with Vol 38, will be Aust. $25.00 post paid (Australia and New Zealand) and Aust $27.00 (rest of the world). "Helictite" is printed and published by the Australian Speleological Federation Inc.

All correspondence to: 123 Manningham St., Parkville, Victoria, 3052, Australia.

This issue is published in June, 2001

Editorial

Ken Grimes and Susan White.

Changes to the ownership of Helictite

As foreshadowed in our last editorial, in October, 2000, ownership of *Helictite* was passed from the Speleological Research Council Inc. (SRC), to the Australian Speleological Federation, Inc. (ASF). The SRC has now wound up and we would like to express our appreciation to the various members of that small group, who not only produced *Helictite* for a period of 24 years, but also published many significant karst monographs. These included several books on the caves of Thailand, The Wee Jasper Caves book, the "blue" and "yellow" books on the caves at Jenolan, and, perhaps most importantly, Kevin Kiernan's *The Management of Soluble Rock Landscapes, an Australian Perspective.*

Stocks of many of these publications still exist, and have been transferred to the ASF. Back issues of *Helictite* can be purchased either through the ASF, or direct from Helictite, 123 Manningham St., Parkville, Victoria, 3052, Australia.

Under the ASF, *Helictite* will be run as an independent commission. Current commission members are listed on the inside front cover. Editorial policy continues as before - *Helictite* will continue to be a high quality, internationally respected, refereed scientific journal. We intend to continue with the current format of mid-length refereed scientific, documentary and technical papers, but with the addition of short notes, theses abstracts, book and article reviews and a regular "News and Views" section. We hope that *Helictite* will continue to be a vehicle of encouragement for publication of speleological work in the Australasian region.

The Logo

As a tribute to the efforts of the SRC over the years we have decided to adopt the SRC Logo (a view, from above, of a caver reading a book) as the Helictite Logo.

Thank-you

The editors wish to thank various reviewers and the organisers of the Wellington Workshop for their assistance in the production of issue 37(1).

Volume 37 (1)

This issue has a Wellington Caves theme. As well as the extended abstracts of the papers presented at the recent Karst Seminar held at the Wellington Caves, there is a full paper by R.A.L. Osborne which reviews the current state of research at the Wellington Caves.

Subscriptions

Price of volume 37 (two issues) will be $20 (Australian), post paid. However, as a consequence of rising postage and other costs, commencing with volume 38 the price per two-issue volume will be $25 post-paid for Australian and New Zealand subscribers, and $27 post-paid for overseas subscriptions.

Wanted:

- **Local representatives** are needed in each Australian state and other countries, to promote *Helictite* locally and to assist in soliciting articles. Also people in major institutions who are prepared to send summaries of research in progress and other items for the "News and Views" section.
- **Team members:** We need volunteers from the speleological and karst scientific community to join the editorial and production team.
- **Authors!** A continuing supply of papers is essential. Cavers should not be shy. Look through our back issues, there have been many authors who were "informed speleologists" rather than professional scientists. In particular we would like to encourage reviews of particular karst areas - documenting the caves and the karst features and drainage by use of text, maps and photos. Such papers provide a useful background for more detailed specialist work. They are within the capability of many amateur speleologists, especially when done as a team effort with each member providing their own expertise. If you are not associated with a major institution, we can assist with drafting of figures and formatting of photos and are happy to make preliminary comments on proposals for papers. See the Information for Contributors inside the back cover.

Osborne, R.A.L., 2001: Karst Geology of Wellington Caves: a review. *Helictite* **37** (1), 3-12.

Karst Geology of Wellington Caves: a review

R.A.L. Osborne

School of Professional Studies, A35, University of Sydney, NSW 2006, Australia.
Email: a.osborne@edfac.usyd.edu.au

Abstract

After 170 years of scientific investigation and speculation, significant problems in the karst geology of Wellington Caves remain unsolved. Work in progress is addressing issues relating to: the role of geological structure in cave development; the mechanism of cave formation; the palaeontology, stratigraphy and sedimentology of the cave sediments; the origin of the phosphate deposits and the relationship between the caves and the surrounding landscape. Little progress has been made in understanding the hydrology of the karst or the meteorology of the caves. These latter problems will require long-term monitoring and data collection, which has yet to commence.

Keywords: caves, speleogenesis, cave sediments, vertebrate fossils, Wellington Caves.

Introduction

Wellington Caves, located 7 km south of the town of Wellington in central western New South Wales (Figure 1), are the birthplace of vertebrate palaeontology and cave science in Australia (Dawson, 1985; Lane & Richards, 1963; Osborne, 1991). How and when Wellington Caves formed, and were then filled with bone-bearing sediments, has puzzled researchers since the 1830s. Despite 170 years of research and debate, ten key questions about karst and cave geology at Wellington Caves remain without entirely satisfactory answers:

- How did bedrock and geological structure guide cave and karst development?
- How were the caves excavated?
- How many phases of cave development occurred and when did they occur?
- How were the cave sediments deposited, and what is their stratigraphy?
- How was sediment removed between the major depositional events?
- How did the animals die and their bones enter the caves?
- What is the source of the phosphate deposits?
- How do the caves relate to the history of the surrounding landscape?
- What is the nature of the hydrological system in the karst?
- What is the source of the carbon dioxide in the caves?

This review draws on the published literature to show the attempts that have been made to answer these questions and indicates how they are being addressed by work in progress. Information reported here from work in progress must be viewed as tentative and indicative only.

Role of bedrock and geological structure

The caves at Wellington have formed almost exclusively in, or at the boundary of, a massive lime-mudstone facies of the Middle Devonian Garra Formation (Strusz, 1965). The exception is Anticline Cave, which is developed along the hinge plane of an anticline in thinly bedded limestone.

Two prominent ridges of massive limestone crop out in the reserve. Bedding in the western ridge, which contains most of the caves, dips generally to the east, while that in the eastern ridge dips to the west. This suggests that the Caravan Park (Figure 2, A) is underlain by a plunging anticline, as seen in Anticline Cave (Figure 2, B) and in the paddock to the south. It also suggests that the area between the two limestone ridges is a plunging syncline (Figure 3).

The main Chamber of Cathedral Cave is developed along an unconformable boundary between massive lime-

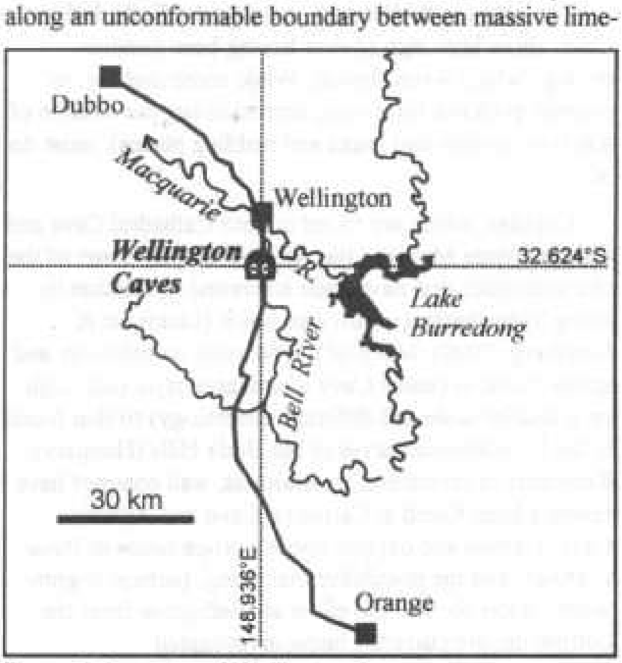


Figure 1: Location of Wellington Caves.

mudstone and tightly-folded thinly-bedded limestone consisting of graded beds rich in faecal pellets. The stratigraphic significance of this boundary remains unclear and attempts at extracting conodonts from either of the facies have proved unsuccessful.

Recent karst mapping (Figure 2), shows that many cave entrances, dolines and other karst features plot as chains, parallel to two sets of faults. One set of faults trends approximately NNW-SSE and the other set trends ENE-WSW, across the strike of the limestone. Some of sections of the main caves appear also to have been guided by these structural trends.

Mechanism of cave excavation

Thomson (1870) was the first to consider how Wellington Caves might have formed. He concluded that the caves resulted from "the dissolving action of carbonic acid water". The process of cave excavation was not discussed again until the work of Bud Frank in the 1960s.

Frank (1971) noted the presence of wall and ceiling pockets, high domes, rock bridges, ceiling pendants, and large symmetrical hollows in the bedrock walls of the caves. Frank considered that these features indicated excavation by eddy currents in the phreatic zone. Francis (1973), following Jennings (1971), considered that the wall pockets in Cathedral Cave resulted from the "injection of strong currents below the water table". Jennings (1977) used the term *Nothephreatic* to describe the style of solution in Cathedral Cave. There is much confusion about the use of this term. Jennings (1977) apparently imagined solution by relatively still bodies of water. Recent definitions of nothephreatic, such as that of Field (1999), use it to indicate slow laminar flow conditions in phreatic conduits.

The caves at Wellington, in particular Cathedral Cave, show little sign of ever having been conduits through which water flowed. While some speleogens provide evidence for mixing corrosion (eg penetration of solution cavities into joints and bedding planes), most do not.

Cupolas, which are found in both Cathedral Cave and the Phosphate Mine (eg the Atrium), display many of the characteristics that have been attributed to solution by rising hydrothermal or artesian water (Lauritzen & Lundberg, 2000). Much of the bedrock morphology and speleothems in Gaden Cave is similar in style (although on a smaller scale and different mineralogy) to that found in the hydrothermal caves of the Buda Hills (Hungary). Remnants of crystalline, subaqueous, wall coatings have recently been found in Cathedral Cave and Anticline Cave. Carbon and oxygen stable isotope ratios of these coatings, and the possibility that rising, perhaps slightly warm, water formed the caves at Wellington from the bottom up, are currently being investigated.

Phases of Cave Development

Observations in Cathedral Cave (Osborne, 1984) and my earlier work in the Phosphate Mine (Osborne, 1982) suggest that there have been at least three major phases of cave excavation (and filling) at Wellington Caves.

The first phase is represented by the breccias in the wall of Cathedral Cave and the block-filled structure near the Altar in the main chamber of Cathedral Cave. These features are completely truncated by the existing cave and represent a very early phase of excavation.

The second period is the initial cavity into which the older sediments (Phosphate Mine Beds) were deposited. In the Phosphate Mine the walls of this cavity are frequently lined with dense phosphatic rim rock, no traces of which have been found in any of the other caves.

The lack of the rim rock in the other caves led me to propose (Osborne, 1982) that the second phase of development was largely restricted to the Phosphate Mine, with other caves having been formed entirely, or substantially modified, by a later phreatic phase. The presence of re-dissolved flowstone (Osborne, 1984) and new observations of ancient sediment remnants in Cathedral Cave, suggest that there was a second phase of excavation in Cathedral Cave as well.

The third, most recent event was the excavation of the cavity in the Phosphate Mine Beds into which Pleistocene bone-bearing sediments (Mitchell Cave Beds) were deposited. Cathedral Cave and the other open caves were either excavated or re-excavated during this phase.

The timing of these periods of cave development is as yet unclear. Late Devonian palaeokarst has been identified in the Garra Formation. Breccia in the walls of Cathedral Cave may be of this age. There is yet no indication of the age of the large block fill near the Altar. The two most recent major cave forming events are likely to be Miocene and earliest Pleistocene in age.

Caves without Roofs

As well as underground evidence for earlier periods of cave development, recent detailed mapping of the limestone outcrop has indicated the presence of a number of "caves without roofs". The most obvious of these is the open-cut section of the Phosphate Mine, but other examples are now known in the limestone to the south of the main cave area.

Caves without roofs have been given much recent currency in the literature from south central Europe (Mihevc *et. al,* 1998) where they are regarded as a novel concept. Their history at Wellington, however, goes back 130 years to when Thomson (1870) noted that bone breccia and stalagmite bases were exposed on the

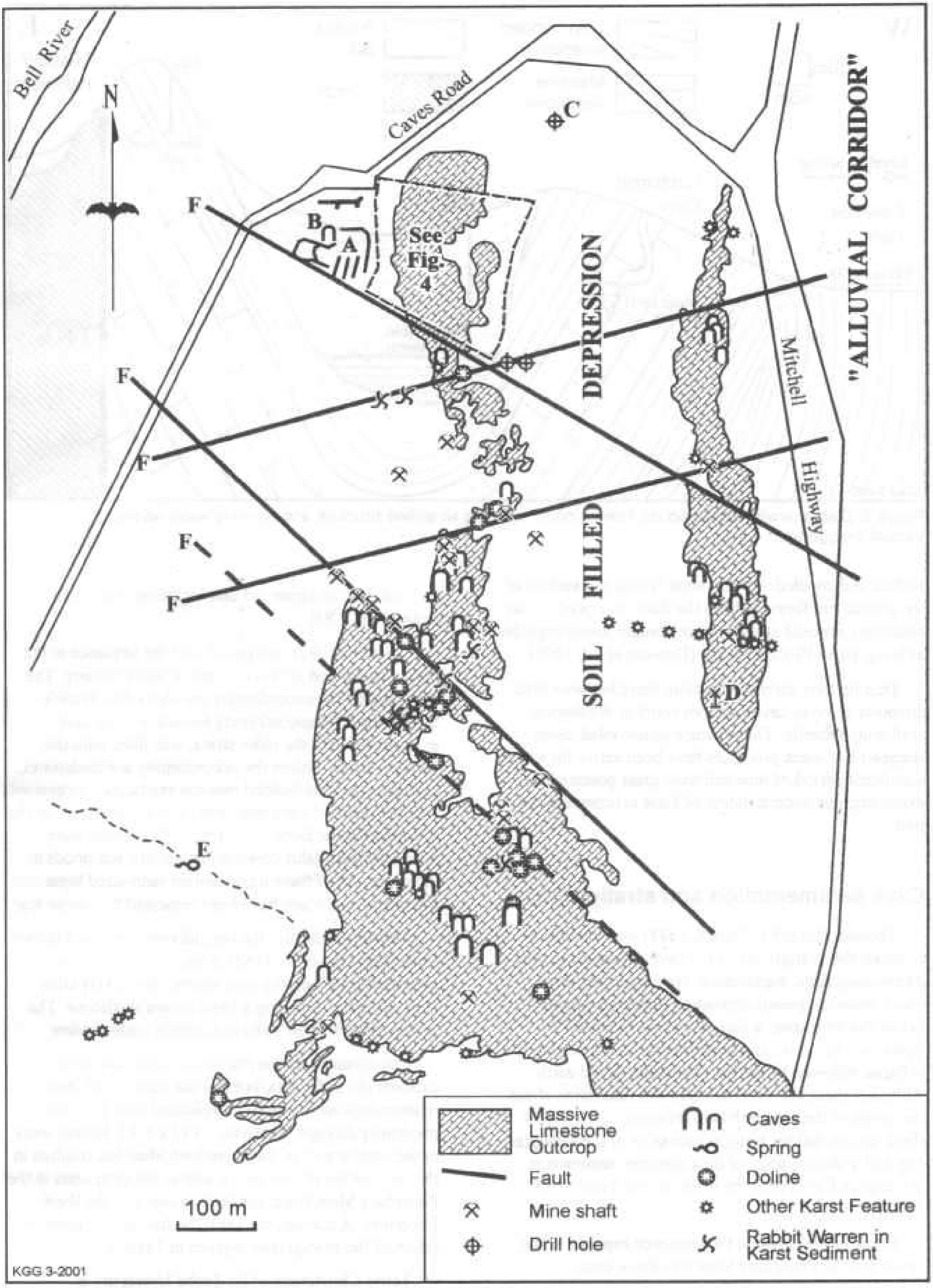


Figure 2: Simplified Karst Geology Map. Based on field mapping by R.A.L. Osborne and B. Scott, in 1999 and 2000. Initial cartography by B. Scott.
A: Caravan Park, B: Anticline Cave, C: Deepest drill-hole, D: Well in eastern limestone ridge,
E: Spring in thinly-bedded limestone, F: Faults.

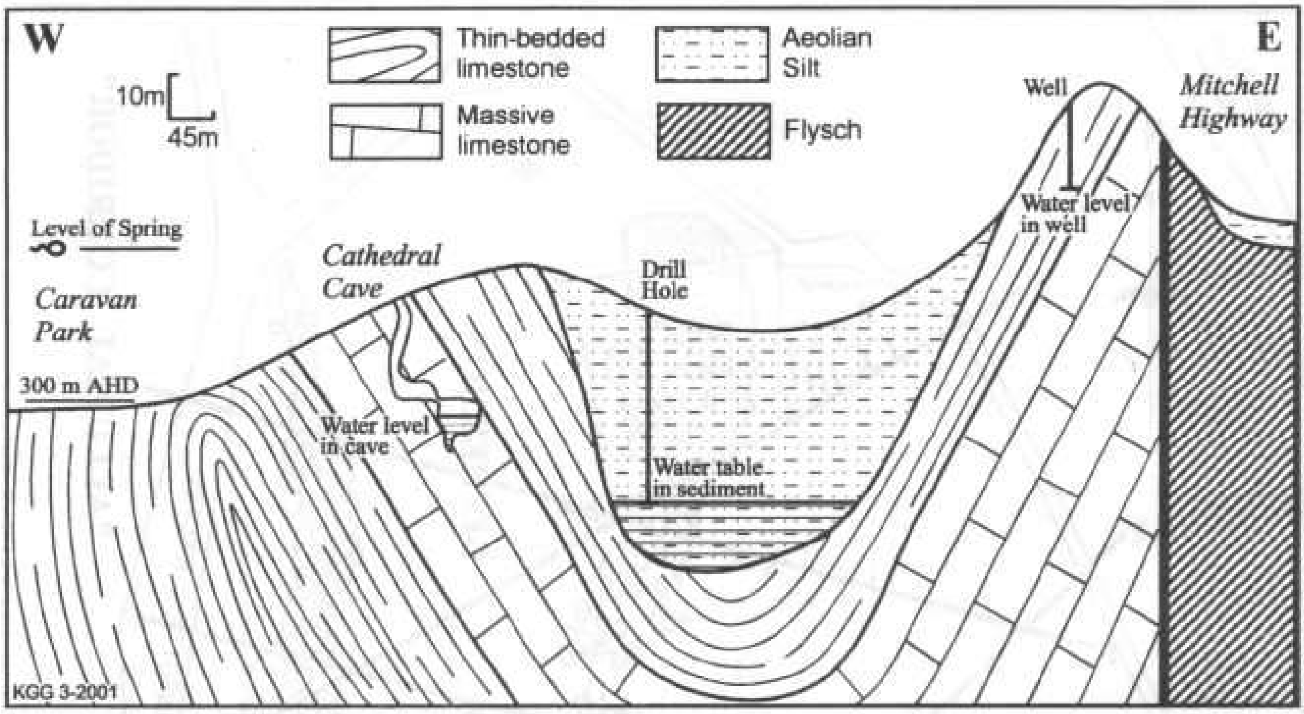


Figure 3: Diagrammatic cross-section, looking north, showing simplified structure and standing water levels. Vertical exaggeration 4.5 x

surface and concluded that: "what is now the surface of the ground has formerly been the floor of a cave". Cave sediments exposed at the surface contain fossils regarded as being Early Pliocene in age (Dawson *et. al*, 1999).

Despite their early recognition, there has been little attention given to caves without roofs at Wellington until quite recently. The presence of unroofed caves suggests that karst processes have been active for a very significant period of time and have great potential for expanding our understanding of karst processes in the past.

Cave sedimentation and stratigraphy

Thomas Mitchell (Mitchell, 1838) was the first to consider the stratigraphy of the cave deposits and their palaeogeographic significance. He recognised three major events: aqueous deposition indicated deposits below the flowstone; a long dry phase indicated by flowstone, red earth and bone breccia; and a period of collapse followed by further deposition of red earth. Although there was considerable later discussion about the origin of the red earth (see Osborne, 1991, 1992), there was no further serious discussion of the stratigraphy and sedimentology of the Cainozoic sequence at Wellington Caves until the work of Bud Frank in the 1960s.

Frank (1971) divided the sequence exposed in the caves and the Phosphate Mine into three units:

Unit 1 BG, a basal grey coloured bedded unit.

Unit 2 FS, a flowstone unit.

Unit 3 R, an upper red unit including bone-rich facies, Unit 3 RB.

Osborne (1982) recognised that the sequence in the mine was divided in two by a major unconformity. The strata below the unconformity are older than Frank's three units. The unconformity formed when a cave, excavated within the older strata, was filled with the younger strata. Below the unconformity are mudstones, turbidites (graded-bedded osseous sandstones, organised and disorganised conglomerates) and phosphorites of the Phosphate Mine Beds (Osborne, 1982), which were deposited from talus cones slumping into still ponds in the caves. All of these units contain sand-sized bone fragments, and many have been cemented by coarse spar.

Above (and inside) the unconformity are the Mitchell Cave Beds (Osborne, 1982), a sequence of poorly-cemented bone-bearing cave earths, most likely talus cone deposits, overlying a basal brown sandstone. The stratigraphy of these units is currently under review.

Rehabilitation of the Phosphate Mine has better exposed the sediments, but this has shown that their relationships are far more complicated than had been previously thought (Osborne, 1997 a & b). Recent work in the eastern part of the Phosphate Mine has resulted in the recognition of two new informal mapping units in the Phosphate Mine Beds, the Pig Sty unit and the West Loop unit. A current, but yet to be formalised, interpretation of the stratigraphy is given in Table 1.

Terrie Christensen of La Trobe University is currently making a detailed study of stratigraphy of the Mitchell Cave Beds in the Phosphate Mine East with the aid of palaeomagnetic dating.

The contrast in depositional environments between the Phosphate Mine Beds and the Mitchell Cave Beds indicates that a major environmental change occurred at Wellington sometime between the Pliocene and the Pleistocene. The Phosphate Mine Beds were deposited by the slumping of *Macroderma* guano, re-mobilised older cave sediments and some large surface-derived bones into still ponds that regularly dried out. The Mitchell Cave Beds show no evidence of carnivorous bats and indicate a much drier environment. The sequence consists largely of talus cones of aeolian silt and bone fragments transported into the caves by gravity and rain-wash. There is no evidence for large ponds, only small muddy pools at the base of talus cones.

The mechanism of sediment removal

The major unconformity between the Mitchell Cave Beds and the Phosphate Mine Beds, smaller erosional breaks within the sequences, and sediment remnants in Cathedral Cave all suggest that significant volumes of sediment have been removed from the caves at one or more times in the past. This raises two important questions, how was this sediment excavated, and where did it go?

There is no evidence of a major stream entering the caves, no obvious outflow point for a stream, and little evidence of sediment being removed by scouring or down cutting. There are, however, fallen blocks of old sediment incorporated into later deposits and rip up clasts incorporated in the higher energy parts of the turbidite sequence.

I have puzzled over this problem for some time. Wellington is not the only cave system where it occurs. The same problem occurs at Ochtinská Aragonite Cave in Slovakia, which is a cryptokarst cave with no known natural entrance. Ochtinská Cave (see Bella, 1997), shows clear evidence of sediment being deposited and later removed but there is no indication as to where it was transported.

Some possible explanations for removal of sediment from caves without apparent exits, which have occurred to me, are:

Table 1:
STRATIGRAPHY OF THE WELLINGTON CAVES PHOSPHATE MINE EAST

HOLOCENE	Mitchell Cave Beds	upper red unit	6.6m
PLEISTOCENE		Bone Cave breccia unit	5 m
		flowstone	0.5 m
		West Loop unit	2.4m
		UNCONFORMITY 4	
		Pig Sty unit base not exposed	3 m+
		UNCONFORMITY 3	
EARLY PLIOCENE	Phosphate Mine Beds	Big Sink unit	5 m+
		conglomerate unit	3 m+
		DISCONFORMITY	
		graded-bedded unit	2 m
		laminite unit	0.5 m
		UNCONFORMITY 2	
		phosphatic rim rock	0.1 m
UNCONFORMITY 1			
DEVONIAN	Garra Formation		

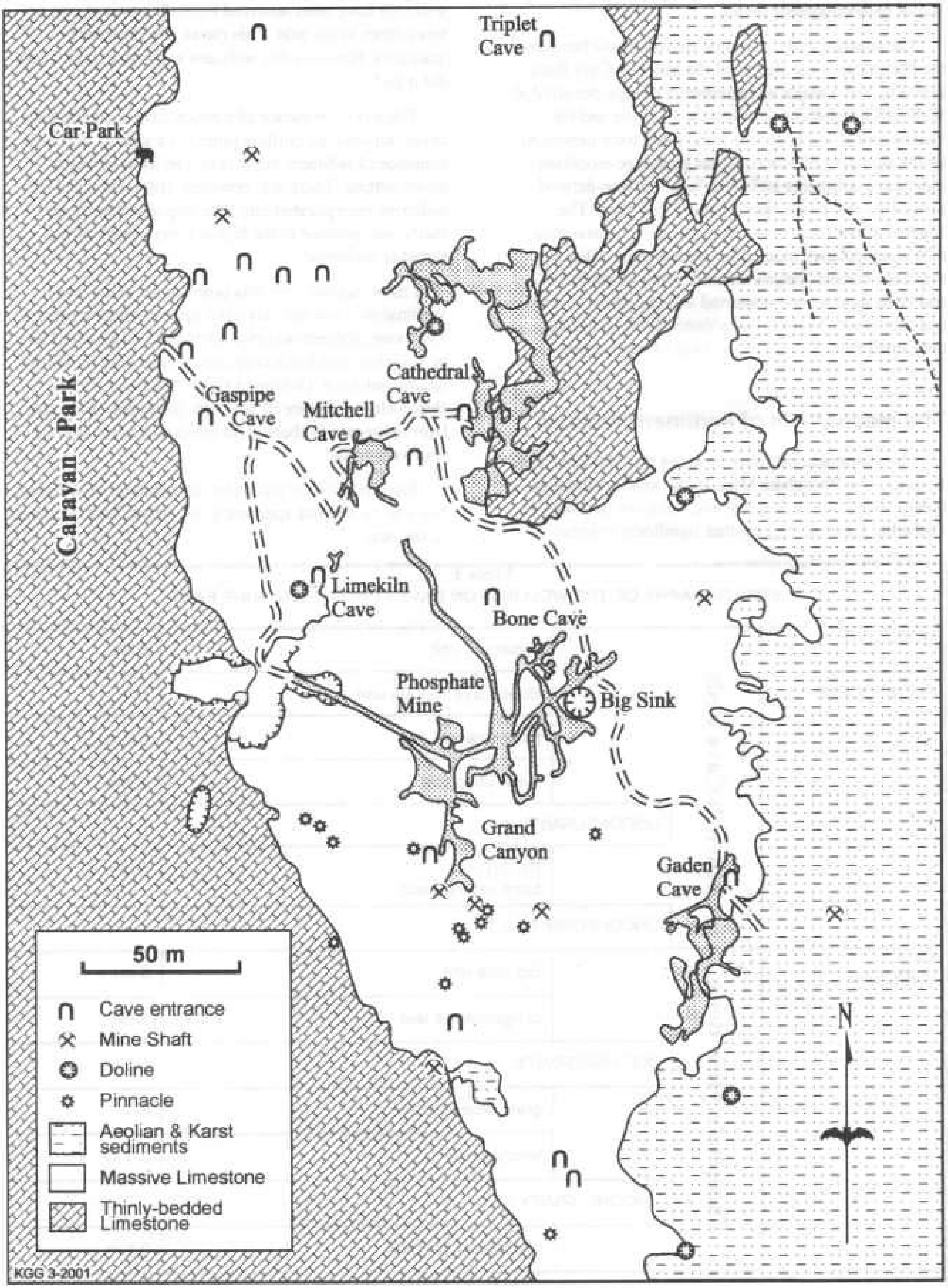


Figure 4: Detail of Show Caves Area. Based on field mapping by R.A.L. Osborne and B. Scott in 1999 and 2000. Cave plans modified from Frank (1971). Initial cartography by B. Scott.
The boundary between the massive and thinly bedded limestone dips to the east. Consequently, thinly bedded limestone crops out at the surface to the west of Cathedral cave, but is not exposed in its eastern wall at depth.

i there was an exit through which the sediment was removed by normal fluvial action, but valley-fill sediments now obscure it.

ii sediment slumped down into progressively lower sections of the cave, as solution at depth opened up new cavities. I call this the sediment-shuffle hypothesis.

iii the sediment was removed in a stoping process, by water rising up from below. As there are few large insoluble clasts in the sediment, carbonate, phosphate, fine silt and clay were carried away by groundwater.

The third explanation might apply at Wellington.

Source of the bones

In 1830, when the bone deposits were discovered at Wellington, the possibility that universal deluge had occurred quite recently was an issue of lively scientific debate. Many early workers (see Osborne, 1991) suggested that various types of floods washed the bones into the caves, while Strzelecki (1845) found them "as difficult to account for here as the ossiferous caves in Europe". Thomson (1870) rejected any flood hypothesis and suggested that the bones had accumulated in a high level cave that has since collapsed. Thomson also suggested that carbon dioxide emanating from the caves might have killed the animals, causing them to fall into the caves.

Anderson (1926) believed that the bones were those of animals that had died after falling into the cave entrances, in his own words they " slipped down the treacherous incline and perished miserably". Lundelius (1966) proposed that the broken nature of the bones, and the presence of thylacine and thylacoleo fossils, indicated that the caves had been carnivore dens.

Few of the explanations offered account for all the features of the vertebrate fossils found in the red earth, or for the characteristics of the red earth itself including:

- the diversity of the bones in species and size
- the broken nature of the bones
- the grainsize of the red earth
- the presence of large cobbles as well as large bones
- the variability of bedding

While the source of the bones remains controversial, slow accumulation of bones from animals caught in pit traps, following Anderson (1926), may well be the best explanation.

Source of the phosphate

Carne (1919) saw no problem with the origin of the phosphate and quoted the explanation of Jensen (1909) that:

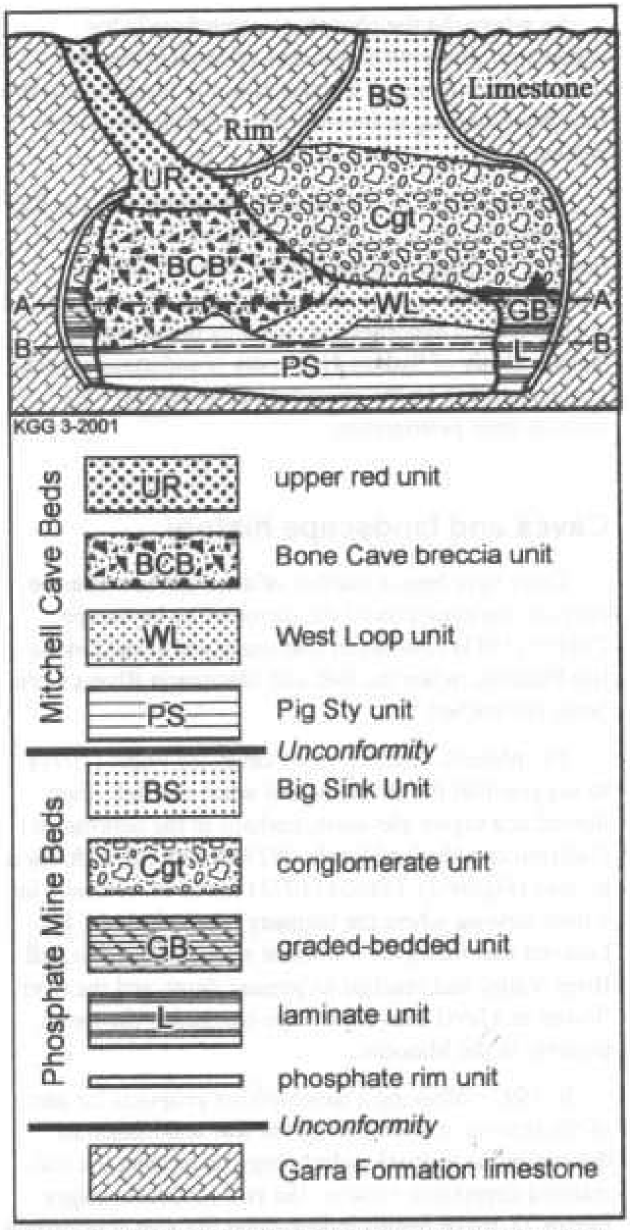


Figure 5: Rock relationship diagram for eastern part of the Phosphate Mine. A & B are roof and floor of mine.

"Secondary phosphate rock owes its origin to the decomposition of organic remains.

Guano, bone breccia, decaying animal and vegetable matter, &c., have the soluble phosphates of lime, magnesia and ammonia leached out by meteoric waters containing carbon dioxide. The soluble phosphate solution filtering down comes in contact with carbonate of lime and alters it to phosphate..."

There has been little subsequent scientific discussion concerning the origin of the phosphate deposit. It became popularly believed that the mine operators were simply grinding up fossil bones to make their product. While some fossil bones clearly did go into the mill, both the documentary evidence (Carne, 1919), and physical evidence in the mine, indicates that a variety of phosphatic deposits (not bones) were being extracted. The most important of these was a bedded grey phosphatic mudstone, the phosphorite unit of Osborne (1982).

So where did the phosphate come from? One suggestion was from dissolution of fossil bones, but there is no evidence of leached bones in the deposits, in fact, bone-bearing sediments often contain phosphatic cement.

The discovery of fossil *Macroderma* teeth in the Big Sink unit (Hand *et. al*, 1988), and more recently in the osseous sandstones of the Graded Bedded unit (D. Nipperess, pers comm), made bat guano the obvious source. This is hypothesis is currently being tested. Nathan Healy of Sydney University is undertaking trace element studies on the phosphate deposits and I am revising their petrography.

Caves and landscape history

There have been a number of attempts to relate the caves to the evolution of the surrounding landscape. Colditz (1943) considered that the caves formed in the late Pliocene, when the Bell and Macquarie Rivers were being entrenched.

The phreatic features in the caves led Frank (1971) to suggest that the caves formed when the Bell River flowed at a higher elevation, perhaps in the depression ("alluvial corridor" of Frank, 1971) where the highway is located (Figure 2). Francis (1973) found no evidence for a river flowing where the highway is now located. He believed that the caves formed at a time before the Bell River Valley had reached its present depth and the river flowed at a level above the ridge containing the caves, possibly in the Miocene.

In 1992, following a development proposal for part of the reserve, a drilling program was undertaken to determine the bedrock morphology underlying the soil-mantled depression between the two limestone ridges Figure 2). Initial results indicate that the area is underlain by a filled valley, more than 40 m deep, and some filled karst depressions. The valley is filled with aeolian silt, probably of Pleistocene age, similar to the red earth in the caves.

This suggests a new interpretation of the Pleistocene character of the caves area. The caves ridge, with deep-rooted trees reaching down into the limestone for water, probably formed a green oasis standing above a dusty red landscape. Animals drawn to the lush vegetation would end their days at the bottom of a pit trap, lying dead and broken, waiting for excavation and their journey to London, Edinburgh, Paris, Munich, California, College Street or Kensington.

Karst Hydrology

Thomas Mitchell observed in 1830 that the pools in the caves were at approximately the same level as the water in the Bell River. Frank (1971) found that the cave pool levels were between 1 and 2 metres below river level. Exploration of Lime Kiln Cave by divers in the late 1980s showed that the water body in the caves was much more extensive than had been imagined. Extensive flooded speleothems (Spencer, 1997) indicated that water levels had been more than three metres lower than today for a considerable period in the past. Houshold et al (1990) proposed that the karst aquifer at Wellington was relatively independent from the granular aquifer in the Bell Valley alluvium that adjoins it to the west.

The recent drilling program, and other observations, has greatly increased our knowledge of the hydrology, but not increased our understanding. The deepest hole (C in Figure 2) reached refusal in wet silt at a depth of 47 m. This is approximately 20 m below the standing water level in the Cathedral Cave pool. A well in the eastern limestone ridge (D in Figure 2) has a standing water level some 50 m above the Cathedral Cave pool. A spring rising from thinly bedded limestone south of the caves (E in Figure 2) is 37 m above the cave pools.

These recent findings suggest a complex hydrology of perched and depressed aquifers in the karst (Figure 3). Simple notions of water sinking in the filled valley to the east entering the cave pools are no longer appropriate. Considerably more research and monitoring are required if the karst aquifers at Wellington are to be properly understood and managed.

Source of carbon dioxide

Foul Air, air with high concentrations of carbon dioxide, has been reported at Wellington Caves since the 1870s. Thomson (1870), Australia's first professor of geology, suggested that the animals whose bones are preserved in the caves may have been killed by carbon dioxide flowing out of the caves and suffocating them on the surface. Chronic exposure to foul air while working at Wellington may have contributed to his untimely death in 1871 at the age 30! Ramsay (1882) noted that candles used by bone collectors frequently went out due to foul air. Trickett (1901) reported foul air in Gaden Cave and, consequently, recommended that it not be developed for tourist use.

The first attempt to measure carbon dioxide concentrations at Wellington was made by Fraser (1958) who recorded 13.5% carbon dioxide and 20% oxygen in the CO_2 Pit of Gaden Cave in May 1958 using a *Fyrite* Carbon Dioxide Indicator.

No further data were reported until I began making measurements in Gaden Cave late 1977 (Osborne, 1981) using *Dräger* tubes and a *G.F.G.* Uni Gas (thermal conductivity) instrument. These data showed that high levels of carbon dioxide in the CO_2 Pit were associated with depleted oxygen levels, unlike Fraser's findings that suggested carbon dioxide enrichment without oxygen depletion. Halbert (1982) re-evaluated the published data and concluded that it all indicated that respiration (ie volume for volume replacement of oxygen by carbon dioxide) was the source of the foul air. The source of the carbon dioxide remains a puzzle. There has been lots of conjecture but substantially more data is required.

In 1978 Jeff Bartlett, Garry Price and I reached a chamber at the base of the CO_2 Pit using oxygen therapy equipment to assist our breathing. Reconstruction of the Gaden Cave entrance has both improved air conditions and encouraged water to flow into the Pit, moving some sediment down. A new generation of cavers armed with scuba are now penetrating further into the pit; its bottom, however, remains as elusive as ever.

Discussion

Wellington Caves presents a complex multi-dimensional puzzle; there are rocks, minerals, fossils, caves and sediments. Both the water and the air behave strangely. Despite 170 years of research and speculation, many critical questions remain without satisfactory answers. While the palaeontological and geological problems are likely to yield to new techniques and continuing detailed study, the problems posed by the cave atmospheres and the karst hydrology require long-term monitoring and data collection, which has yet to commence.

Acknowledgments

I would like to thank the Councillors and staff of Wellington Council who have contributed resources, staff time and funds in support of fundamental and applied research at Wellington Caves over the past 20 years. Members of the council administration who have been particularly helpful include; former Tourist Officers, Arnold Worboys and Garry Greening; former Shire Engineer Peter Gesling; Planning Officer Syd Craythrorne and GIS Officer Brett Scott. Ken Grimes redrafted the figures.

Current Caves Manager, David Hearn; former Manager, Alan McMahon; Mine Manager, Brian Palmer and all the cave guides are thanked for their hospitality and help in various ways.

References

ANDERSON, C., 1926. The Wellington Caves. *Australian Museum Magazine*. **2**: 367-374.

BELLA, P., 1977. Morfologické a genetické zanky Ochinnskej Aragonitovej Jaskyne. *Aragonit*. **3**:3-7.

CARNE, J.E., 1919. Phosphate deposits in limestone caverns in New South Wales. *N.S.W. Department of Mines, Geological Survey, Mineral Resources*. **25**: 393-400.

COLDITZ. M.J., 1943. Physiography of the Wellington District, N.S.W. *Journal and Proceedings of the Royal Society of New South Wales*. **76**:235-251.

DAWSON, L., 1985. Marsupial fossils from from Wellington Caves, New South Wales; the historic and scientific significance of the collections in the Australian Museum, Sydney. *Records of the Australain Museum* **37(2)**: 55-69.

DAWSON, L., MUIRHEAD, J & WROE, S., 1999. The Big Sink local fauna: a lower Pliocene mammalian fauna from the Wellington Caves complex, Wellington, New South Wales. *Records of the Western Australian Museum Supplement*. **57**: 265-290.

FIELD, M.S., 1999. *A Lexicon of Cave and Karst Terminology with Special Reference to Environmental Karst Hydrology*. National Center for Environmental Assessment, U.S. Environmental Protection Agency, Washington, 200p.

FRANCIS, G., 1973. Evolution of the Wellington Caves landscape. *Helictite*. **11**(4): 79-91.

FRANK, R., 1971. The clastic sediments of Wellington Caves, New South Wales. *Helictite*. **9**(1): 3-26.

FRAZER, N.R., 1958. Foul Air in Caves- Molong and Wellington, N.S.W. *Sydney University Speleological Society Journal*. **5**(1): 3-10.

HALBERT, E.J.M., 1982. Evaluation of carbon dioxide and oxygen data in cave atmospheres using the Gibbs triangle and the Cave Air Index. *Helictite* **20**(2): 60-68.

HAND, S., DAWSON, L. & AUGEE, M.L., 1988. *Macroderma koppa*, a new Tertiary species of False Vampire Bat (*Microchiroptera, Megadermatidae*), from Wellington Caves, New South Wales, *Records of the Australian Museum*. **40**: 343-351.

HOUSHOLD, I., STANTON, R. & SPATE, A., 1990. *Geomorphic and hydrologic resources of the Wellington Caves area*. Report to Wellington Shire Council. 75p

JENNINGS, J.N., 1971. *An Introduction to Systematic Geomorphology*. Volume 7, Karst. Australian National University Press, Canberra. p.164.

JENNINGS, J.N., 1977. Caves around Canberra. *Proceedings of the 11th Biennial Conference, Australian Speleological Federation*, Canberra, 1976: 79-95.

JENSEN, H.I., 1909. The possibility of finding phosphate deposits in Australia. *Agricultural gazette of New South Wales*.**20** (12): 1094-1099.

LANE, E.A. & RICHARDS, A.M., 1963. The discovery, exploration and scientific investigation of the Wellington Caves, N.S.W. *Helictite*. **2**(1): 1-53.

LAURITZEN, S-E. & LUNDBERG, J., 2000. Solutional and erosional morphology. *in* A. B. Klimchouk, D.C. Ford, A. N. Palmer & W. Dreybrodt eds, *Speleogenesis: Evolution of Karst Aquifers*, National Speleological Society, Huntsville.408-426.

LUNDELIUS, E.L. Jr., 1966. Marsupial Carnivore Dens in Australian Caves. *Studies in Speleology*. **1**:174-180.

MIHEVC, A., SLABE, T. & SEBELA, S., 1998. Denuded caves: A inherited element in the karst morphology; the case from Kras. *Acta Carsologica*. **27**(1), 10: 165-174.

MITCHELL, T.L., 1838. *Three Expeditions into the Interior of Eastern Australia.* T. & W. Boone, London.

OSBORNE, R.A.L., 1981: Towards and air quality standard for tourist caves: Studies of carbon dioxide enriched atmospheres in Gaden-Coral Cave, Wellington Caves, N.S.W. *Helictite*. **19**(2): 48-56.

OSBORNE, R.A.L., 1982: Cainozoic stratigraphy at Wellington Caves New South Wales. *Proceedings of the Linnean Society of New South Wales*. **107**(2): 131-147.

OSBORNE, R.A.L., 1984. Multiple karstification in the Lachlan Fold Belt in New South Wales: Reconnaissance evidence. *Journal and Proceedings of the Royal Society of New South Wales*. **117**:15-34.

OSBORNE, R.A.L., 1991: Red earth and bones: The history of cave sediment studies in New South Wales. Australia. *Earth Sciences History*. **10**(1): 13-28.

OSBORNE, R.A.L., 1992. Australian red earth and bones. *Journal and Proceedings of the Royal Society of New South Wales*. **125**:111.

OSBORNE, R.A.L., 1997a: Rehabilitation of the Wellington Caves Phosphate Mine: Implications for Cainozoic Stratigraphy. *Proceedings of the Linnean Society of New South Wales*. **117**: 175-180.

OSBORNE, R.A.L., 1997b. Wellington Caves Phosphate Mine. in E.J. Morgan ed. Geology and Metallogenesis of the Fifield-Peak Hill-Wellington-Gulgong-Mudgee Region of New South Wales: Narromine and Dubbo 1:250,000 Geological Sheets, Field Conference Guide 6-11 April 1997. *New South Wales Geological Survey Report.* GS 197/080.

RAMSAY, E.P., 1882. Curator's Report on the Exploration of Caves and Rivers. *Votes and Proceedings of the Legislative Assembly N.S.W. 1882*. **5**:45.

SPENCER, M., 1997. Mysterious McCavity. *Australian Geographic*. **45**: 48-63.

STRUSZ, D.L., 1965. A note on the stratigraphy of the Devonian Garra Beds of N.S.W. *Journal and Proceedings of the Royal Society of New South Wales*. **93**:85-90.

STRZELECKI, P.E. De., 1845. *Physical description of New South Wales and Van Diemen's Land accompanied by a geological map, sections, and diagrams, and figures of the organic remains.* Longman, Brown, Green, and Longmans, London, 462p.

THOMSON, A.M., 1870. The geology of the Wellington Caves. *Votes and Proceedings of the Legislative Assembly N.S.W. 1870-71*. **4**: 1182-1184.

TRICKETT, O., 1901. Wellington Caves. *Annual Report of the Department of Mines, N.S.W.* **1900**:200.

Abstracts from the 5th Karst Seminar, Wellington Caves, 2000.

Introduction

In February, 2000, the fifth of a series of informal Karst Seminars was held at the Wellington Caves, in central New South Wales. Previous karst seminars (or karst workshops, as the earlier ones were called) had been held at Buchan (1992), Wombeyan Caves (1994), Naracoorte Caves (1996) and Mole Creek (1998).

The seminar was organised by Mia Thurgate and Ernst Holland and hosted by the Wellington Shire Council. Support was provided by the Wellington Shire Council, the Jenolan Caves Reserve Trust and the Dubbo Office of the Department of Land and Water Conservation.

The abstracts have been arranged in alphabetical order by author.

Palaeontology of Wellington Caves

M.L. Augee

Wellington Caves Fossil Studies Centre

I. Devonian fossils

There are numerous invertebrates in the limestone visible at Wellington Caves.

II. Quaternary mammal fossils.

A. Historical collections

1. Thomas Mitchell - started excavations on 26 June 1830 and sent 1,000 specimens to the Geological Society later in 1830. Published in *Edinburgh New Philosophical Journal* 1831. Material collected went to:

   Jameson – Edinburgh

   Clift - Royal College of Surgeons, London

   Cuvier -Paris (died 13 May 1832)

   Pentland – Paris

   Note: Lyle (1833) summarised the significance of the Wellington Caves fossils.

2. Richard Owen - studies Wellington Caves fossils for many years. He clearly summarised the current opinions concerning the extinction of the megafauna. "No other adequate cause (for the extinction of the megafauna which had been first described by him) has suggested itself save the hostile agency of man" but it was also possible "the smaller animals could have survived unfavourable conditions which destroyed the larger species".

3. Gerard Krefft (Curator at the Australian Museum 1861) organised an 1869 expedition inspired by Owen - washed material and noted bones of rodents and small macropods. 2,100 duplicate (to those held at Australian Museum) fossils sent to Owen.

4. E.P. Ramsay - supervised excavations 1881, collected "many thousands of bones".

5. Department of Mines (1888-1904) – material kept at the Geological Museum at The Rocks (now held at Australian Museum).

6. The phosphate mine (1913-1918).

   First mention of phosphorite at Wellington in 1851 (Stutchbury).

   Macquarie (Wellington) council workers collected phosphorite in 1912 while surveying the Grand Canyon for a possible tourist cave site.

4. C. Anderson 1926 collected fossils from the phosphate mine.

5. Dehm and Schroeder 1939 - first attention to microfossils.

6. The American era -

   Marcus (1952-54) collections reside at University of California.

   Lundelius and Turnbull 1965 (collections reside at Field Museum, Chicago, and the Amer. Mus. Nat. Hist., N.Y.).

7. The UNSW excavations – Cathedral and Bone Caves (1983-1986).

8. Opening of the phosphate mine to tours (1995).

9. Establishment of the Wellington Caves Fossil Studies Centre 1997.

B. The fossils

1. All fossils are disarticulated and usually fragmented. No complete skeletons are known from Wellington Caves.

2. There are two cohorts:

   a. Small vertebrates, dominated by rodents. Small reptiles are very rare and bird material is extremely rare.

   b. Megafauna.

   c. Usually mixed; sometimes separate.

3. Probable sources:

   a. Profile of small species fits that of owl deposits (especially sooty owls as described by Morris et al. 1997).

   b. Megafauna - died and concentrated away from caves. One model is based on mammal species entrapped in mud around African water holes. Collection may represent several periods of drying with intermittent flooding. Small, medium and arboreal species are not trapped by such mechanisms - producing the profile seen in the Wellington deposits.

4. Original deposition may have been in higher chambers which have now eroded. In the resulting slumping there is likely to have been considerable mixing of deposits of different ages.

C. Age

1. Bone Cave/Phosphate Mine deposits are well beyond carbon dating, although the Cathedral Cave dig spanned the last 40,000 years.

2. The only date in the Bone Cave/Phosphate Mine system is 250,000 BP from a flowstone floor in the Phosphate Mine. However its relationship to the fossil deposits is uncertain.

3. Faunal correlation allows a very rough estimate if the components are identified to species level and if dating of comparable faunas is reliable. The first requirement is not yet met for Wellington. In general the megafauna in the Bone Cave/Phosphate Mine system is comparable to that of fauna from the time zone 250,000 -1 million BP dated elsewhere.

4. Faunal analysis does allow one to establish *relative* dates, and one deposit at Wellington Caves is clearly older than the well known deposits in the red soil. These are the much less concentrated bones in harder substrate in Big Sink. They are Pliocene, possibly lower Pliocene (2 million BP).

III. Current work

Current work at the Wellington Caves Fossils Studies Centre is focussed on proper registration of fossils recovered from Wellington Caves and identification of the small (mostly rodent) and medium (up to the size of quolls) mammals present in the Phosphate Mine system. Future excavations are planned for Big Sink.

Interactive Marble Tombstone Deterioration Model

Paula Avramidis[1] and Julia James[2]

[1]School of Chemistry, L2 Carslaw Blg F07, University of Sydney, NSW 2006

[2]School of Chemistry, F11, University of Sydney, NSW 2006

Email: paula@scifac.usyd.edu.au

Marble is a commonly used monumental stone as it can be easily polished, carved and shaped. As a result, marble has been widely used in Australia as both a building and decorative stone, and it was shipped out from Europe by the first settlers. Marble, both imported and domestic quarried marble, therefore represents a longstanding part of the Australian built environment since that time. Limestone, in general, also represents an important landscape, both in karst systems and natural outcrops in Australia, and therefore the implications of this research for all limestones is important.

Research into the complex interactions of marble with different environmental variables has been extensive in Europe where noticeable changes have been seen to take place in highly populated regions. Despite this large empirical database on marble weathering in Europe, a relatively small amount of work has been directed at changes to marble by environmental factors in Australia. Furthermore, the work that has been done has not been incorporated into a system that allows comparisons to be made with international findings.

The aim of this research was to localise the key variables that contribute to weathering of marble in Australia and incorporate them into a simulated model. The structure of the model reflects trends obtained from experimental and theoretical data. The research will also investigate the viability of using marble and its associated lichen as indicators of environmental conditions.

The creation of a computer simulation incorporating the data collected in the practical component of the research was decided on as the most relevant and useful expression of the results. The simulation requires the intersection of the system simulation, modelling and the digital computer to achieve the desired result (Whicker and Sigelman, 1991). A model is essentially the 'representation of a theory' via the amalgamation of various constituent hypotheses with defined variables parameters, inputs and outputs (Beck et al., 1993; Lehman, 1977).

The system used to create the model was Powersim 2.5, a system dynamics software package designed to create dynamic models. The system uses visually representative diagrams defined mathematically. The system also allows resultant models to be capable of interactive experimentation.

The aim was to create an interactive model that incorporates all the features and rates of marble weathering with all of the components that contribute to marble weathering.

The model variables were divided into five distinct influence sections related to their origins. These sections were defined by constant and variable information converters, which enabled information links and numerical definitions of the key marble deterioration impacts to be determined. These equations were then fed into the marble model section. The marble model section was created in order to combine the resultant forces and results of the influence sections into the process of marble deterioration. This section was created using flows and stores of "relative impacts" which are the defining governing variables in the quantification of marble deterioration in this model.

The "link buttons" provided in the model establish the interactive nature of the model. The buttons were defined to control the start of the simulation with original model data, the adjustment of specific variables in the model, and re-running of the simulation with altered variables. The combination of these links is intended to create a user-friendly platform for system manipulation. The other changing variables in the model are also important in the 'system verification' and 'validation' and the tests as to whether the simulation adequately describes the system both qualitatively and quantitatively.

References:

Beck, M. B., Jakeman, A. J. and McAleer, M. J. (1993). Construction and evaluation of models of environmental systems. In *Modelling Change in Environmental Systems* (ed. A. J. Jakeman, Beck, M.B. and McAleer, M.J.), pp. 3-35. Chichester: John Wiley and Sons Ltd.

Lehman, R. S. (1977). *Computer Simulation and Modelling: An Introduction* (ed. R. S. Lehman). New Jersey: Lawrence Arlbaum Associates, Publishers.

Whicker, M. L. and Sigelman, L. (1991). *Computer Simulation Applications: An Introduction* (ed. M. L. a. S. Whicker, L.), pp. 152. Newbury Park: Sage Publications.

Radon – Is there a need for badge programs?

Craig M. Barnes[1], Julia M. James[2] and Stewart Whittlestone[3]

[1]School of Chemistry (Environmental Science), Madsen Bld F09, University of Sydney, NSW 2006.

[2]School of Chemistry, F11, University of Sydney, NSW 2006

[3]Environment Division, ANSTO, PMB 1, Menai, NSW 2234

Email: craigb@mail.usyd.edu.au

Although at first unrecognised, many Australian caves contain regions where radon levels can exceed 1000 Bq m^3. This is the radiation level beyond which a person constantly working in such an environment (24 hrs a day, 7 days a week) can be designated as an occupationally exposed radiation worker. Other radiation exposure restrictions are quoted as dosages, where a person is not allowed to receive a dose of more than 20 mSv per year averaged over 5 years. In a cave, however, it is important to recognise two things. Firstly, radon levels are rarely constant. Indeed radon levels vary naturally over a wide range with local climatic conditions (diurnally and seasonally) as well as varying spatially (both within a cave and between cave systems). Secondly, people are exposed to the cave environment for several different purposes (as a visitor, caver, guide or maintenance worker), in different locations, for varying lengths of time, and at different times of the year. Consequently, a designation as an occupationally exposed radiation worker is not realistic for cave workers, cavers or visitors.

For those caves around the world where average radon levels have been found to be above the "safe" levels, the solution has often been ventilation. Under the dry climate conditions found in Australia, ventilation is not an option and in many cases would be unnecessary as the radon levels rarely remain above "safe" levels for long periods of time. So, the first step in determining whether or not a monitoring program is even needed is to measure the radon levels and how they vary at a particular location. On the other hand, lengthy exposure to even relatively low radon levels can result in a greater health risk. Thus, although we can discount any hazard to cave visitors (due to theu brief and limited exposure), there is a need to be able to easily and reproducibly calculate dose levels (where a monitoring program is indicated) for individuals who spend long periods underground.

Dose considerations are usually dominated by the levels of radon progeny (decay products), but the total levels of these are difficult to measure. Further, it has always been assumed that there is a fixed ratio between radon and its progeny which is constant from cave to cave. But several studies have recently shown this not to be the case, for a variety of reasons, making the conversion from progeny levels to dose complicated. Moreover, radon progeny measurements are normally expensive due to the specialised equipment needed. However, the relatively cheap techniques of measuring radon levels have been found to provide a good meter for dose calculations. Unfortunately, the usual methods of measuring radon dosage have some major limitations, including bulky apparatus, the need for rapid treatment and analysis, and method of detection (continuous rather than accumulative). The only reliable and cheap method of calculating an individual's dosage is a badge program.

Badges can be constructed in different ways, using several types of detection material, but the ones described here are track-etch detectors (TEDs). TEDs are made of a plastic film that when impacted upon by an alpha particle leaves a crater or track that can be later etched and counted. These are normally left at a site where they accumulate impacts from that site over time, thus providing an average level over that period. But because they are used in this stationary fashion, TEDs can often be over-exposed (with impacts overlaying each other and making counting difficult) even in short periods of time, especially in a cave where radon levels can reach high values. Badges are TEDs used in a portable rather than stationary fashion, where the film is placed in an unobtrusive plastic container clipped in some way to the clothing. Badges accumulate impacts at all sites visited by the wearer for the duration of the visit, thus allowing a measure of exposure over time. Because the badge wearer is rarely underground 24 hrs a day, the film is mostly exposed only to background radiation and so avoids the over-exposure problem. Indeed, such a badge is good for around 3 months wear before it should be taken away for counting and replaced with new badge (longer periods are possible but increase the possibility of over-exposure). Moreover, a badge provides a measure of *personal* exposure rather than site measurements. Consequently, badges are useable by all cave workers and cavers all the time, regardless of their location or time underground.

While there is an entrenched resistance by cavers to anything that might cause cost or loss of experience, each individual assumes the risk of their actions. But an employer of cave workers (guides and maintenance workers) has a duty of care to conduct personal monitoring programs where there is the possibility of accumulating 20 mSv per year averaged over 5 years. And the easiest way to do this is to use a badge program.

Presenting World Heritage Values to the Visitor

Steven Bourne

Tourism Services Officer, Naracoorte Caves, PO Box 134, Naracoorte, South Australia, 5271

Email: stevenbourne@hotmail.com

The Naracoorte Caves became a World Heritage Area in December 1994. Since then, many changes have taken place, with the construction of the Wonambi Fossil Centre being the largest project. The display aims to depict the Naracoorte region from around 200,000 years ago, complete with landscape and computer-animated animals. Much of the knowledge to create these extinct animals has come about through research conducted in the Victoria Fossil Cave. This has made it necessary to present a different kind of cave tour, to a more aware public audience than of years ago. This paper covers the changes at Naracoorte in guided cave tours, and ideas for better interpretation.

Condensation Corrosion in Tourist Caves, Case Study: Jenolan Caves

Jeremy Chase[1], David Stone[2] and Julia James[3]

[1]6 Carlotta St, Greenwich, NSW, 2065

[2]Organic Chemistry/Mass Spectrometry, Environment Division, ANSTO, PMB 1, Menai, NSW, 2234

[3]School of Chemistry, F11, University of Sydney, NSW 2006

Email: Jeremy_Chase@allens.com.au

Condensation corrosion is a mechanism by which caves can be eroded. Condensation corrosion can be found in entrance zones or deep inside caves. Condensation corrosion is caused by aggressive waters condensing on the walls and roof of caves. Deep inside caves elevated levels of carbon dioxide can enhance condensation corrosion. This process can be natural, or influenced by tourists visiting the cave.

When tourists walk through caves they produce between 60 and 75 litres of carbon dioxide per hour. The carbon dioxide produced can enhance the process of condensation corrosion. This can result in degradation of the speleothems.

Condensation corrosion was investigated at Australia's premiere tourist cave attraction – Jenolan Caves. Jenolan Caves has 260,000 visitors per year, making it an ideal place to examine the effect of tourists on condensation corrosion.

While some authors have previously considered the problem of condensation corrosion qualitatively, the primary objective of this work was to characterise quantitatively the waters responsible for causing corrosion.

Analysis and collection of condensation waters is notoriously difficult because of the small quantities available and the very low concentrations of species present. For the first time in Australia condensation waters were collected and analysed. The carbon dioxide levels in the cave were also recorded. From these data the saturation index of calcite was calculated.

PHREEQC was used to model waters and reaction pathways to show the effect of adding carbon dioxide or changing the temperature. The ion balance error of the waters collected was determined using the WATEQ4F water modelling program. Typical values for the calcite saturation index of condensation samples were (ion balance in brackets) :

Site 1; -3.1 (-2.1): Site 2; -3.2 (-6.2).

It was concluded that condensation waters are aggressive. Modelling showed that carbon dioxide influenced the aggressivity of condensation waters. The kinetics of the system were examined to determine whether dissolution would take place on a time scale short enough for speleothem degradation to be observed.

It was also found that while condensation waters are highly aggressive, the amount of carbon dioxide produced by tourists would have little impact upon the chemistry of condensation waters.

Palaeoclimatic Information from Biominerals in Odyssey Cave, Bungonia

Annalisa Contos[1], Julia James[1] and David Stone[2]

[1]School of Chemistry, F11, University of Sydney, NSW, 2006

[2]Organic Chemistry/Mass Spectrometry, Environment Division, ANSTO, PMB 1, Menai, NSW, 2234

Email: a.contos@chem.usyd.edu.au

Biomineralisation is the synthesis and deposition of inorganic solids by biological systems. By characterising minerals found in cave it is possible to classify their mode of formation as inorganic or biological origin. The condition under which the minerals are formed can be examined and the sediments accumulated within the cave can then be examined for these markers. Palaeoclimatic data can then be extracted from the sediments in the cave.

A site where biominerals are currently being deposited and incorporated into sediments is Odyssey Cave, Bungonia, NSW. Banded sediments within this cave were discovered in the 1970's and several papers characterising their chemistry were published (eg James, 1975). Unusual environmental conditions, comprising high carbon dioxide in the cave atmosphere and low oxygen in both the cave water and atmosphere have led to a number of unusual chemical and biological processes occurring in these sediments.

James related them to the iron minerals formed during Precambrian times when the oxygen content in the atmosphere was much lower than the present. Deposition of the sediments was probably rapid and sediments one metre into the profile are 600 years old. Preliminary identification of the bacteria involved was made by the Baas Backing Laboratory, Bureau of Mineral Resources, Canberra. Although the palaeoclimatic significance of these sediments was realised at the time, no work was carried out.

The sediments, deposited in a tranquil environment, are in chronological order. Some of the bands contain charcoal making the sediments ideal for palaeoclimatic studies, as they can be dated by AMS ^{14}C techniques. The bands within the sediments are: clastic material from periodic floods; hydrated iron (III) oxide formed through a biomineralisation process; siderite; black mud from partially decomposed carbon compounds and insoluble sulfides formed during dry periods; and calcium carbonate as calcite – climatic conditions unknown.

This project will study the present conditions of deposition in the cave using water and atmospheric chemistry and relate this to the surface climate. Investigation of the sediments should reveal the cave's atmospheric and water conditions during past periods of deposition, which together with the present monitoring should allow the surface climate at the time of deposition to be determined. This study should provide a flood and drought history of the Bungonia region for some thousands of years.

References

James, J. M. 1975. Cold water mineralisation processes in an Australian cave. *Transactions of the British Cave & Karst Research Association*, 2: 141-150.

Mosses and Liverworts of Karst Landforms in the South-east of South Australia

Alison Downing, Ron Oldfield and Patricia Selkirk

Department of Biological Sciences, Macquarie University, NSW, 2109.

Email: Adowning@rna.bio.mq.edu.au

The south-east of South Australia is characterized by a diversity of karst landforms in a limestone area of relatively low relief. The area has a Mediterranean climate, with wet, cool winters and dry, warm to hot summers. The rainfall is highest in the south, and decreases with distance from the coast. Naracoorte has a mean annual rainfall of 575 mm. The first European settlers arrived in 1840. In 1863 a massive drainage program was initiated, cutting kilometres of drains through country which originally consisted of fens and freshwater peat swamps, and now is dominated by open pasture with scattered *Eucalyptus camaldulensis* (River Red Gum). Thus the vegetation now is characteristic of a much drier environment than that first encountered by European settlers in 1840.

The moss and liverwort species which grow on exposed surface calcareous substrates, such as soil, rock, limestone pavement and shallow, dry dolines and uvalas, are typical of those found on calcareous substrates in arid and semi-arid areas throughout southern Australia. The mosses and liverworts commonly grow as components of microphytic soil crusts, in combination with algae, cyanobacteria, fungi and lichens. They are usually small (< 5 mm), with unbranched stems and grow either as ephemerals, short turfs or appressed mats. The leaves are often strongly pigmented (brown, black, reddish or yellow) to minimise damage from high light levels. The mosses are dominated by species from the families Pottiaceae, Bryaceae and Fissidentaceae. The liverworts are composed mostly of thallose liverworts from the order Marchantiales.

However, the mosses and liverworts collected from karst landforms which provide some protection from high light, heat and desiccation, such as caves with collapsed ceilings, doline swamps, cenotes and spring lakes, include species which are more usually associated with closed forests and woodlands ("rainforests") of eastern and southern Australia. These species are usually large (> 5 mm), branching and grow as dendroid (tree-like) plants and in loose wefts. The leaves are large, lax and green to optimise light in the low-light environment of caves, deep sink holes, and underwater in cenotes and spring lakes.

The moss, *Hypopterygium rotulatum* (Hedw.) Brid., was collected from the Bat Cave in Naracoorte Caves Conservation Park. This species is of particular interest as the only previous record for South Australia is a specimen collected by Ferdinand von Mueller in 1852 in a "volcanic cavern" at Mt. Gambier. Although common in closed forests throughout south-eastern Australia and Tasmania, it has not been recollected in South Australia until found during this study. Two liverwort taxa, *Lophocolea bidentata* and *Lophocolea bispinosa*, both also considered to be "rainforest" plants, were new records for South Australia.

The presence of "rainforest" species in this relatively dry area is of considerable interest. The closest extant rainforests are small, isolated stands in the Victorian Otway Ranges,. approximately 300 km to the south-east of Naracoorte. The presence of these "rainforest" species may indicate a link to the widespread rainforest vegetation of the Cretaceous. There is no possibility that these species may have survived in-situ since the Cretaceous. They may have survived in refugia in mountain ranges during the marine transgressions of the Tertiary, recolonising the south-east in times of low sea level, and then surviving in the refugia provided by karst landforms during the increasing aridity of the late Tertiary and Quaternary. These species may now be at risk of extinction, following the changes to drainage and vegetation instigated by European settlement.

Karst of Christmas Island (Indian Ocean)

K. G. Grimes

PO Box 362, Hamilton, Vic 3300.

Email: ken-grimes@h140.aone.net.au

Christmas Island is a tropical island (Latitude 10°30'S), in the Indian Ocean, northwest of Australia. It is a limestone-capped volcano that is rising at a rate of 0.14mm per year. The interaction of uplift and a sequence of old sea-levels has produced a series of terraces cut into the sides of the island. The lowest of these, *The Shore Terrace* has been dated as last interglacial (124 ka) which is the basis for estimates of the uplift rate (Woodroff, 1988). The central plateau (about 200-250m ASL, with hills up to 360m ASL) is phosphate over a pinnacled epikarst limestone surface, with the crest of the volcanic surface about 30-40 m down.

The Caves

Most of the caves are horizontal systems at sea level and entered from the base of the coastal cliffs. Higher up one finds uplifted systems that formed at past sea levels, and on the plateau there are some horizontal stream passages.

Within the **coastal caves** a fresh water lens is floating on sea water, so salt/fresh-water mixing-corrosion will be active and responsible for the extensive spongework sculpturing. Tidal mixing and flushing may also assist in the solution of the limestone. The impermeable nature of the rock has restricted the original passages to the joints, but spongework cavities are actively expanding from these.

The presence of drowned speleothems down to at least -6m in the main flooded passages suggests that the original cave development predates the present Holocene high-stand of the sea, and might date back to an earlier sea-level.

The few known **plateau caves** are different. Smaller, muddy, horizontal stream passages run at or not far above the limestone-volcanic contact, and are entered via vertical shafts or collapse dolines.

Karst Hydrology

In spite of the high rainfall, there are few surface streams and most of the rainfall quickly disappears underground. Barrett (unpublished company report, 1985) suggests that the major water storage is in the epikarst and from there it moves down through fractures and open pipes to the volcanic contact. The main watertable is just above that contact. The water then flows outward and downward to the sea through karst conduits along the surface of the volcanics. Some local storage might occur where the flow is dammed by volcanic dykes. Springs occur where the volcanic contact appears at the surface or within the coastal caves and submarine springs have been reported from depths as great as 200m.

A full paper will appear in a future issue of *Helictite*.

References

BARRETT, P.J., 1989: Christmas Island (Indian Ocean) phosphate deposits. *In* NOTHOLT, AJG., SHELDON, RP., & DAVIDSON, DF., [eds] *Phosphate deposits of the world, Volume 2: Phosphate Rock resources.* Cambridge Univ. Press. pp 558-563.

WOODROFFE, C.D., 1988: Vertical movement of isolated oceanic islands at plate margins: evidence from emergent reefs in Tonga (Pacific Ocean), Cayman Islands (Caribbean Sea) and Christmas Island (Indian Ocean). *Z. Geomorph. Suppl-Bd.* 69: 17-37.

The Prominence Of Jenolan

Elery Hamilton-Smith

Abstract withheld.

What We Do Inside Caves

Ernst Holland and Mia Thurgate

Jenolan Caves Reserve Trust, PO Box 1495, Bathurst, NSW 2795

Email: karstmanager@jenolancaves.org.au

It is well documented that impacts on surface karst environments frequently result in the degradation of subsurface (cave) environments. However, there is often conjecture as to the forms and extent of impacts that are generated directly within caves by human use of these environments.

Some in-cave impacts are obvious, such as the removal of sediments and formation. Other factors, such as changes in cave temperature have been linked to human presence, but whether this constitutes a harmful impact is not always clear. Furthermore, while change to the cave environment may be recorded, the ramifications of such changes to the functioning of caves are often poorly understood. For example, are human-induced changes to cave temperature harmful to cave biota or to wider cave climate processes?

This paper will provide a review of the research that has recorded the types and extent of in-cave impacts associated with human use of caves.

Changes In Karst Water Chemistry At The Black Hole, Lower South-East, South Australia

Stan Lithco and John Webb

Department of Earth Science, La Trobe University, Bundoora, VIC 3083

Email: geosl@popeye.latrobe.edu.au

The Black Hole or the Devils Punchbowl is a large cenote formed within the Tertiary Gambier Limestone. The cenote is situated approximately 10 km southwest of the city of Mount Gambier within the Schank Karst Region of the Lower South-East Karst Province of South Australia (Grimes 1994; Thurgate 1995).

Sampling of the cenote water was performed monthly for the period July 1998 to July 1999 inclusive. The waters were analysed in the laboratory for calcium, magnesium, sodium, potassium, silica, chloride, bicarbonate, nitrate and sulphate concentrations. Field measurements of temperature, conductivity and pH were taken routinely. Dissolved oxygen levels were taken on an occasional basis.

Data for chloride, sodium, magnesium and silica, species not involved in pH-dependent reactions, indicate an overall decrease in concentration over the sampling period. Examination of the daily rainfall record for the region indicates that this trend probably reflects the short term (July 98 – July 99) rainfall pattern, because rainfall in the last 6 months greatly exceeded that in the first 6 months.

The molar ratio of sodium to chloride is 1.02, well above that for seawater (0.857) (Drever 1988), indicating an additional source for sodium apart from seawater as aerosol particles incorporated into rainfall. The excess sodium is presumed to be derived from the weathering of Quaternary volcanics in the area.

The concentrations of nitrate and sulphate over the sampling period are variable but overall relatively consistent, and probably reflect variations in fertiliser and farm waste input into the water.

The concentrations of calcium and bicarbonate follow a similar trend, both rising in winter and falling in summer. In contrast, pH changes oppose or mirror those of calcium and bicarbonate. The change in concentrations for these 3 species is most likely to be due to the effect of temperature on the carbon dioxide level of the surface water.

When the temperature rises the Pco_2 values drop, because of the decreased ability of the waters to hold CO_2:

(1) $CO_2 + H_2O = H_2CO_3 = H^+ + HCO_3^-$

In late spring and summer, as surface water temperatures increase and the lake becomes thermally stratified, CO_2 is lost from the water by exsolution into the atmosphere, and reaction 1 is driven to the left, decreasing the level of carbonic acid ($H_2CO_3^*$).

Calculations of SIc indicate that values exceeded 0.5 for late October to May, so precipitation of calcite was likely to be occurring for this time period, probably in the form of fine crystals in the water column. The waters are also supersaturated for the rest of the year, but because SIc < 0.5, precipitation is unlikely. As Pco_2 drops SIc increases. Both are related to surface water temperature, as temperatures over 15° C correspond with SIc = 0.5 and log Pco_2 = -2.5. As Pco_2 drops, so does the concentration of H_2CO_3 and this favours the precipitation of calcite according to reaction (2):

(2) $H_2CO_3 + CaCO_3 = Ca^{++} + 2HCO_3^-$.

As calcite is precipitated the levels of Ca^{++} and HCO_3^- are depleted; this is shown by a decrease in Ca^{++} and HCO_3^- concentrations from the end of spring into summer. Levels of these species start to rise again into autumn as temperatures fall and CO_2 levels rise.

The period of precipitation of calcite in Blacks Hole corresponds closely with the period of blue colouration in the Blue Lake at Mount Gambier, which is generally from November to April/May each year (Grimes & White 1996). The colour change is believed to be due to the scattering of incident light, particularly in the blue wavelength range, from the fine suspended calcite crystals precipitating in the water (Allison & Harvey 1983). No such colour change is evident at The Black Hole, probably due to its smaller area and resultant more sheltered position from sunlight.

Algal blooms occur within The Black Hole in the summer (Thurgate 1995). Elevated levels of dissolved oxygen at this time (December 12.2 ppm) probably reflect algal photosynthesis. The effect of these blooms on the water geochemistry is uncertain. The CO_2 uptake by the growing algae may enhance the CO_2 loss evident in summer. This effect may be small, because there is no summer decrease in silica, as would be expected if there was a big diatom bloom at this time.

References

Allison, G.B., & Harvey, P.D., 1983. Freshwater lakes. In *Natural History of the South East,* M.J., Tyler C.R. Twidale J.K. Ling & J. W. Holmes, eds. Royal Society of South Australia, Adelaide, pp. 61-74.

Drever, J.I., 1988. *The Geochemistry of Natural Waters,* 2nd ed., Prentice Hall, New York, 437 pp.

Grimes, K.G., 1994. The South-East Karst Province of South Australia. *Environmental Geology*, 23: 134-148.

Grimes, K.G., & White, S., 1996. *Field Guide to the Karst Features in Southeast South Australia and Western Victoria.* For the 3rd Karst Studies Seminar, Naracoorte, South Australia, 34 pp.

Thurgate, M.E., 1995. Sinkholes, caves and spring lakes: An Introduction to the unusual aquatic ecosystems of the lower south-east of South Australia. *SAUSS Occ. Paper 1,* South Australian Underwater Speleological Society: Adelaide, 44 pp.

New Concepts in Cave Atmosphere Studies

Neville A. Michie

Division of Environmental and Life Sciences, Macquarie University, NSW, 2109.

Email: nmichie@laurel.ocs.mq.edu.au

Study of carbon dioxide in cave atmospheres has lead to the development of new concepts in cave structure. Concentrations of carbon dioxide that fluctuate with variations of barometric pressure are explained by porous rock, once part of an aquifer, now abandoned and full of air. This type of air filled rock has been termed an *Aerifer*, and has interesting properties that, it is speculated, will link to the biosphere and karst terrain models.

The Graded-Bedded Unit: A Biogenic Sediment From The Wellington Caves Complex, NSW.

David A. Nipperess

Centre for Ecostratigraphy and Palaeobiology; Department of Earth and Planetary Sciences; Macquarie University, NSW, 2109.

Email: dnippere@rna.bio.mq.edu.au

The Graded-Bedded Unit of Osborne (1983, 1997) is an exceptionally fossiliferous sedimentary unit of the Phosphate Mine Beds exposed in the Phosphate Mine of the Wellington Caves complex, central-western NSW. It is a well-cemented, graded osseous sandstone inter-bedded with thin mud horizons. The 'sand' fraction of this unit is primarily composed of bone fragments rarely more than 2 mm in length. The age of the deposit is unknown, but as the Phosphate Mine Beds are interpreted to lie stratigraphically beneath the Early Pliocene Big Sink Local Fauna (Dawson *et. al.*, 1999), the Graded-Bedded Unit is presumed to have been deposited at some time during the Late Miocene to Early Pliocene. Such an age would make the Graded-Bedded Unit the oldest known fossil-bearing sediment from Wellington Caves.

Stratigraphic mapping of a ~1.4 m thick exposure of this unit (herein dubbed "Koppa's Pool" section) has revealed at least 16 discrete depositional events, each delineated by a thin mud horizon. Samples have been collected from each of these subunits and dissolved in dilute acetic acid. The residue has been sieved, and the fractions sorted for diagnostically useful bone fragments. A preliminary (mostly family-level) faunal list is presented which includes dasyurids, burramyids, murids, megadermatids, lizards, birds and frogs.

The Graded-Bedded Unit is interpreted here as having been accumulated by predatory ghost bats (*Macroderma* sp.) for the following reasons: the fragmentary nature of the bony material, only taxa of small body size (less than 100 g) are represented, and the frequent occurrence of teeth referable to *Macroderma*. Because the deposit consists of graded subunits, it is proposed that material from the original guano pile was periodically transported a short distance before settling out of suspension in water. A reasonable hypothesis is that the guano material slumped from the pile into a nearby pool.

The presence of murid rodents in the fossil assemblage is considered biostratigraphically significant. Murids are known from the Early Pliocene faunas of Rackham's Roost (Godthelp, 1999) and Big Sink (Dawson *et. al.*, 1999) but are not present in Late Miocene faunas, presumably because they had not yet dispersed to the Australian continent from southeast Asia. This would suggest that the Graded-Bedded Unit is Early Pliocene in age, although deposition in the latest Miocene is possible. Further taxonomy is required to generate data suitable for more precise biocorrelation.

The presence of 16 discrete depositional events in Koppa's Pool section may have palaeoecological implications if the assemblages in each of the subunits can be shown to be temporally as well as physically discrete. However, given the current hypothesis for deposition of the Graded-Bedded Unit, cross-contamination of the fossil faunas by reworking seems likely.

References

Dawson L, Muirhead J. & Wroe S. 1999. The Big Sink Local Fauna: a lower Pliocene mammalian fauna from the Wellington Caves complex, Wellington, New South Wales. *Records of the Western Australian Museum* 57: 265-290.

Godthelp H. 1999. Diversity, relationships and origins of the Tertiary and Quaternary rodents of Australia. *Australian Mammalogy* 21: 32-34.

Osborne RAL. 1983. Cainozoic stratigraphy at Wellington Caves, New South Wales. *Proceedings of the Linnaean Society of NSW* 107: 131-147.

Osborne RAL. 1997. Rehabilitation of the Wellington Caves Phosphate Mine: implications for Cainozoic stratigraphy. *Proceedings of the Linnaean Society of NSW* 117: 175-180.

Geology of the Wellington karst area

Armstrong Osborne

A full version of this paper appears at the start of this issue.

Pleistocene fossil sites of the South East of South Australia, with a particular focus on the Naracoorte region and the World Heritage Naracoorte Caves

Liz Reed[1] and Steven Bourne[2]

[1]Vertebrate Palaeontology, School of Biological Science, Flinders University, PO Box 2100, Adelaide, SA 5001

[2] Tourism Services Officer, Naracoorte Caves, PO Box 134, Naracoorte, SA 5271

Email: liz.reed@flinders.edu.au

The caves of the South East of South Australia are well known for their extensive bone deposits, particularly their rich record of the extinct Australian Pleistocene marsupials. Palaeontological research in the region has been steadily increasing in recent years, particularly related to sites in the Naracoorte Caves World Heritage Area, and surrounds. The Pleistocene faunal record at the Naracoorte Caves is extensive, the caves having acted as pitfall traps, sampling the fauna of one geographic region over an extended period of time. Eighteen sites within eleven of the twenty-six caves within the World Heritage have yielded vertebrate bone material, spanning possibly the last 400,000 years (Ayliffe et al, 1998; Brown, 1998; Moriarty et al, 2000). When combined with recent climate and geochronological work, their potential for resolving palaeoecological and other contentious issues is considerable.

References

Ayliffe, L.K., Marianelli, P.C., Moriarty, K.C., Wells, R.T., McCulloch, M.T., Mortimer, G.E. and Hellstrom, J.C. (1998). 500 ka precipitation record from southeastern Australia: Evidence for interglacial relative aridity. *Geology*. **26(2):** 147-150.

Brown, S.P. (1998). *A geological and palaeontological examination of the Pleistocene Cathedral Cave fossil accumulation, Naracoorte, South Australia.* Unpublished Honours thesis, School of Biological Science, Flinders University of South Australia.

Moriarty, K.C., McCulloch, M.T., Wells, R.T. and McDowell, M.C. (2000). Mid-Pleistocene cave fills, megafaunal remains and climate change at Naracoorte, South Australia: towards a predictive model using U/Th dating of speleothems. *Palaeogeography, Palaeoclimatology, Palaeoecology*. **159:** 113-143.

Flood effects in McKeowns Valley and Mammoth Cave, Jenolan Caves, NSW.

Henry Shannon

319 Brisbane Street, West Launceston Tas 7250.

Email: r_shannon@hotmail.com

The creek bed in McKeowns Valley is normally dry but with sufficient rain attains the semblance of an ordinary creek. This disguises the real situation of leakage zones termed sinks or submergences through which water gets into caves below. The advance and breakup on retreat of the running portions of the creek reveals the locations of these sinking points but their actual capacity is determined by upstream to downstream flow loss measurement. Underground there is a response to these surface changes in the activation of overflow streams and increase in flow of the underground rivers.

Flow measurements have been taken over the years more or less on the run and often as an adjunct to dye tracing experiments. The potential in the measurements themselves to provide answers has been overshadowed by the emphasis on dye tracing. But after doing the sums on the available data set some pretty definite conclusions can be made, as follows.

Central River in Mammoth Cave has a source independent of Lower River. The river at First Crossing is fed not just from the river at Second Crossing, but from a larger and more permanent second source.

The water sinking outside Serpentine Cave reappears exclusively in the Northern River Passages in Mammoth Cave. The Serpentine Cave streamway is activated only at a high stage. In Mammoth Cave the water emerges mainly from the Infinite Crawl but also from the Central River at Second Crossing.

The Bow Cave takes water to Lower Level in Mammoth Cave but there is also a streambed submergence area outside the cave entrance, which would remain operational if all flow were diverted from Bow Cave itself. Reputedly the passage to Lower River remains dry in this situation so implying that water from the streambed sink goes directly to the Woolly Rhinoceros Cave.

The capacity of the streambed sinking points plus the baseflow of the Jenolan Underground River, as revealed by sudden flooding, is about 1000 litres per second. Given the baseflow is typically 200 l/sec or a little more this gives 800 l/sec for this somewhat variable number.

Notes

Publication of this material may occur in a talked-of new edition of *The Caves of Jenolan, 2: The Northern Limestone*, ed. Bruce R Welch. ISBN 0 9599622 6 3 (first edition 1976) published by SUSS, Sydney. The chapter "Notes on Geology, Geomorphology and Hydrology" by C. Henry Shannon, pp 5-9 in this book draws on the some of the same source material. The ultimate source is my trip report archive for which copies theoretically exist in the SUSS and UQSS records. Earlier material was never published but that for the 1970's was all published in *Down Under*, the UQSS magazine and most in the contemporary *SUSS Bulletin*.

Karstic Groundwater Ecosystems In The Murray Darling And Otway Groundwater Basins

Andy Spate[1], Jane Gough[1] and Mia Thurgate[2]

[1]NSW National Parks and Wildlife Service, P O Box 2115, Queanbeyan, NSW 2620.

[2]Jenolan Caves Trust, PO Box 1495, Bathurst, NSW 2795.

Email: karst@jenolancaves.org.au

A number of mainland locations in South Eastern Australia support diverse groundwater ecosystems. Small, impounded, karstic aquifers are found widely on the western fall of the South Eastern Highlands of New South Wales. Reconnaissance surveys of many of the aquifers indicate that they support highly significant, but little studied, invertebrate faunas, displaying high levels of endemism and diversity.

In contrast to the scattered archipelago of New South Wales karsts, the Otway Basin, around Mount Gambier, includes a very extensive contiguous groundwater system. There are many dependent ecosystems in the groundwaters of the Otway Basin. Highly diverse and extensive extant stromatolite populations are present in permanent karst lakes. The groundwater-dependent fauna is of moderate diversity, and includes endemic species.

This poster discusses aquatic ecosystems within the impounded karsts of the New South Wales portion of the Murray Darling Basin and of the Otway Basin. These ecosystems are centres of biodiversity for subterranean fauna and are dominated by freshwater amphipod and syncarid faunas. The faunas from both regions show ancient relictual distributions and Gondwanan affinities. The Wellington Caves aquifer in particular has many values including a significant and diverse, endemic aquatic invertebrate fauna and is considered worthy of recognition as a RAMSAR site. Some potential threats to these important ecosystems are identified, and some potential research directions are canvassed.

Diversity at Depth: The NSW Cave Invertebrate Story

Mia Thurgate[1], Andy Spate[2] and Alexander Herr[3]

[1]Jenolan Caves Reserve Trust, PO Box 1495, Bathurst, NSW 2795

[2]NSW National Parks & Wildlife Service, PO Box 2115, Queanbeyan, NSW 2620.

[3]Environmental Studies Unit, Charles Sturt University-Mitchell, Panorama Ave, Bathurst, NSW 2795.

Email: karst@jenolancaves.org.au

New South Wales contains some 450 carbonate rock outcrops of which 95 are known to be cavernous. Over 2200 individual caves are known in these karst environments. In 1994/95, Eberhard and Spate (1995) completed a major survey of cave macroinvertebrate fauna from over 130 caves. More than 1700 specimens from at least 360 taxa were collected. The results of this survey significantly increased the known subterranean fauna of NSW. Compared with the state of knowledge published prior to 1993, the number of orders was doubled (from 21 to 44), and the number of families recorded increased by almost two-thirds (from 61 to 177). Before 1993, 11 troglobitic species had been recorded, and this has since increased to 90 cave-dependent taxa, including many stygobites.

Although the mean number of taxa identified from individual karst areas in New South Wales (19 taxa) is low, a high number of taxa have been recorded for several individual karst areas in New South Wales. The richest karst areas include Jenolan (126 taxa), Wombeyan (83 taxa), Wee Jasper (62 taxa) and Stockyard Creek (55 taxa). The richness of these four sites may be due to their large size, topographic relief, and highly cavernous structure containing a wide variety of habitats. Most other NSW karst areas probably have a lower environmental buffering capacity (and hence fewer taxa) owing to their smaller size and lower relief, their fewer and smaller caves, or smaller range of available habitats.

Within the total taxa identified by the survey, the aquatic fauna is found to be very diverse, particularly within the highly endemic Crustacea. One taxonomic group, the Division Syncarida, are found with a single endemic species at each of 12 different karst areas. A new family and two new genera as well as the 12 new species of syncarids are currently being described. In the Order Amphipoda four new genera containing eleven new species have been described and a further nine species are awaiting taxonomic determinations. Both the syncarids and amphipods contain species of great biogeographical significance. They have survived in karst areas that were maintained as stable, moist refugia over a geologically long time period, thus facilitating the survival of relictual populations.

Karst faunas are valued for many reasons including high levels of endemicity, rarity and high taxa richness. Preliminary information from this survey suggests that the New South Wales cave fauna contain all of these elements. However, important information is still missing for taxa that have not been fully described to species level.

Using presence/absence data, we analysed the existing survey database to identify the proximity between karst areas in terms of taxonomic composition. The results confirm the importance of Jenolan, Wombeyan, Wee Jasper and Stockyard Creek based on high taxa richness and endemism. We used the lowest taxa-level identification as the basis for this analysis, because several groups could not be identified to species or even family level.

We conducted four separate multivariate analyses using 1) all taxa, 2) endemic taxa (i.e. taxa recorded from only one karst area), 3) taxa occurring at between two and seven karst areas and 4) ubiquitous taxa (i.e. taxa recorded from more than seven karst areas). Our preliminary analyses suggest that while the identification of all specimens to species level is highly desirable, karst areas that have outstanding biological values are likely to be identified even with a lower taxonomic resolution.

Reference

Eberhard, S. and Spate, A. P. 1995. *Cave Invertebrate Survey: Towards an Atlas of New South Wales Cave Fauna*. Report to the Department of Urban Affairs and Planning. NSW Heritage Assistance Program NEP 94 765. 120 pp.

Origin of cenotes near Mt Gambier, South Australia

John A. Webb[1], Ken G. Grimes[2], Roland Maas[1] and Russell Drysdale[3]

[1]Department of Earth Sciences, La Trobe University, Bundoora, Vic 3083

[2]P.O. Box 362, Hamilton, Vic 3300

[3]Department of Geography, University of Newcastle, Callaghan, N.S.W. 2308

The Southeast Karst Province of South Australia is notable for its cenotes, collapse dolines containing water-table lakes (Grimes 1994), up to 50m wide at the surface and extending down to 95m below the land surface. They are developed in the flat-lying Oligocene - Early Miocene Gambier Limestone, which is exposed at the surface over much of the province. The cenotes are all characterized by collapse; they have vertical and overhanging sides and are floored by large cones of rubble, which may be overlain by finer grained sediment. Exploration and diving have revealed no major phreatic passages extending off any of the cenotes, despite the fact that typical shallow phreatic joint maze caves, both dry and water-filled, are common in the Gambier Limestone throughout the Southeast Karst Province. Collapse dolines are associated with some of these phreatic caves, but are shallower than the cenotes in that they do not have deep lakes.

The distribution of the cenotes is uneven; they are concentrated in two small areas, each ~3km in diameter, located 5km W and 10km NW of Mt Schank (a few other cenotes are scattered through the province). Within these areas they are distributed along two joint sets, a dominant set trending 320° and a subsidiary one at right angles. These are the dominant regional joint directions.

Lewis (1984) noted that the depth of the cenotes indicates that they represent collapse into large caverns dissolved at or close to the base of the Gambier Limestone; the boundary between the Gambier Limestone and the underlying Tertiary siliciclastics lies at about 100m below ground surface around the cenotes west of Mt Schank. He suggested that the caverns had been dissolved by acidified groundwater containing large amounts of volcanogenic CO_2, which had ascended up fractures from deep-seated reservoirs related to the magma chambers that fed the Quaternary volcanoes Mt Schank and Mt Gambier. Approximately 10km east of Mt Schank is a CO_2-producing well (Caroline); the isotopic composition of the CO_2 identifies it as magmatic in origin, and it is probably related to the Quaternary volcanics in the area (Chivas et al. 1990).

Direct evidence for the influence of volcanogenic fluids on the cenotes comes from strontium isotope analyses of a stromatolite collected at ~8m depth from Black Hole, one of the larger cenotes. Stromatolites grow on the walls of many of the cenote lakes, and are large structures up to 4m long formed of calcite precipitated by the microbial communities growing on their surfaces (Thurgate 1996). In cross-section the calcite of the Black Hole stromatolite shows submillimeter-scale laminations, which may be annual. Detailed sampling of one section of this stromatolite showed that overall it has a $^{87}Sr/^{86}Sr$ ratio of around 0.7088, slightly greater than the isotopic composition of the host Gambier Limestone (0.7083, corresponding to the Early Miocene age of the limestone at this location). However, one sample has a lower ratio (0.7079), probably due to an input at this time of volcanic fluids, which have a much lower Sr isotopic ratio (0.7037-0.7058 for the Quaternary volcanics of the region; Price et al. 1997). The layer with the anomalous $^{87}Sr/^{86}Sr$ ratio has an age of ~6000 BP, from C_{14} dates on the stromatolite either side of the layer (Kelly 1998), and assuming a uniform rate of growth. This age corresponds to that of the eruption at Mt Schank (5000 BP, based on recent thermoluminescent dating).

Thus the Sr isotope data show the apparent influence of volcanogenic fluids within the cenote lakes during a time of eruption (although it must be noted that additional work is still needed to confirm the Sr isotope data and the dating). It is possible that larger amounts of fluid, including volcanogenic CO_2, could have been injected during previous eruptions, dissolving the caves that collapsed to form the cenotes.

References

Chivas, A.R., Barnes, L., Evans, W.C., Lupton, J.E. and Stone, J.O., 1990. Liquid carbon dioxide of magmatic origin and its role in volcanic eruptions. *Nature*, **326**, 587-589.

Grimes, K.G., 1994. The Southeast Karst Province of South Australia. *Environmental Geology*, **23**, 134-148.

Kelly, M.D., 1998. *Freshwater stromatolites as potential palaeoenvironmental indicators: a case study from lower southeast South Australia.* B.Sc. (Hons) thesis (unpubl.), Dept of Geography, University of Newcastle, 107 pp.

Lewis, I.D., 1984. *Cave and sinkhole morphology in the lower southeast karst region.* B.A. (Hons) thesis (unpubl.), Department of Geography, Flinders University, 119 pp.

Price, R.C., Gray, C.M. and Frey, F.A., 1997. Strontium isotopic and trace element heterogeneity in the plains basalts of the Newer Volcanic Province, Victoria, Australia. *Geochimica et Cosmochimica Acta*, **61**, 171-192.

Thurgate, M.E., 1996. The stromatolites of the cenote lakes of the lower southeast of South Australia. *Helictite*, **34**, 17-25.

Models of Speleogenesis: A Review

Susan White

Department of Earth Sciences, La Trobe University, Bundoora, VIC 3083

Email: geosw@popeye.latrobe.edu.au

The concepts involved in speleogenesis have undergone many advances over the past century. The general theory of speleogenesis describes how meteoric water sinks underground through the epikarst or dolines and stream sinks, and circulates through limestone without any confinement. Caves so formed, are genetically related to surface drainage and solutional conduits and fissures and their relationship to underground karst aquifers are fundamental to the understanding of speleogenesis. The integration of speleogenetic data is an important part of the development of speleogenetic models (White, 1999; Klimchouk et al, 2000).

However, there are many ways in which such models have been developed. Main groups of models can be identified and are briefly described with some examples.

Early models are summarised by Lowe (2000). At the start of the 20th century Grund and Cvijic (see citations in Lowe, 2000) recognised that karst relief is formed by water dissolving soluble rocks such as limestone but failed to explain water circulation through fractures. Lehmann (1932) linked the ideas of underground streams to groundwater.

Since 1940, kinetic, hydrogeological and the Four State models have dominated theoretical thinking. Kinetic models relate to the kinetics of the dissolution processes of carbonates, and were developed in particular by Dreybrodt (1988). The relationship of dissolution concepts to specific geological settings explains the variation in karst landscapes. These models develop cave evolutionary histories from an improved understanding of the chemical equilibria and chemical kinetics of carbonate rock dissolution.

Hydrogeological models interpret cave development in terms of flow paths of groundwater and surface streams and incorporate the laws of fluid flow and the chemistry of limestone solution. These include Vadose theories of cave formation where solution is seen as occurring above the water table; Deep Phreatic theories which propose cave development in the phreatic zone with vadose activity as a modification (Davis, 1930, 1931) Bretz (1942) and Water Table hypotheses (Swinnerton, 1932).

D.C. Ford and his coworkers developed the Four State Model throughout the 1970s, 1980s and 1990s (Ford & Ewers, 1978; Ford & Williams, 1988). This is a very useful model as it links hydrogeology to the surficial and underground karst landforms. This model has incorporated many of the ideas developed by Jennings such as the nothephreas.

These conventional models have been concerned with shallow and generally unconfined settings. There is an overall increased interest in the geological controls of karst areas and a similar increased recognition of caves as an important part of aquifer hydrogeology (White, 2000). The issues of hypogene karst in confined deep settings are now regarded of importance (Klimchouk, 1997). The revision of such artesian water speleogenetic concepts could be useful in areas such as the Otway Basin with its long flow paths and where calcite saturation has been assumed but not confirmed by observation.

The questions of ***how, when*** and ***why*** have generally been well covered by these models, but the issue of ***where*** continues to plague us all. Many of the models cited above avoid the issue, or deal with it briefly. However, Worthington (1991) has shown that flow in karst aquifers is primarily a function of the boundary conditions of the aquifer and that variation between karst aquifers is mainly a function of these same boundary conditions. Those of importance are catchment length, stratal dip, underflow and overflow, all of which are measurable, and show that karst development can therefore be predicted.

There is still a need to continually refine our ideas on how caves form as is the need to continually update the integration of the theoretical with field observations. Progress continues to be made but a complete model for karstic aquifers has not yet been attained.

References

Bretz, J.H. 1942 Vadose and Phreatic features of Limestone Caverns. *J. Geology* **50**: 675-679, 698-720.

Davis, W.M. 1930 Origin of Limestone caverns. *Geol. Soc. Am. Bull.* **41**: 475-628.

Davis, W.M. 1931 The origin of limestone caverns. *Science* **73**: 327-331.

Dreybrodt, W. 1988 *Processes in Karst Systems.* Berlin, Springer-Verlag.

Ford, D.C. and R.O. Ewers 1978 The development of limestone cave systems in the dimensions of length and depth. *Canadian J. Earth Sci.* **15**: 1783-1798.

Ford, D.C. and P.W. Williams 1989 *Karst geomorphology and hydrology.* London, Chapman & Hall.

Klimchouk, A. 1997 Artesian speleogenetic setting. *Proc. 12th Int. Congress Speleology*, La Chaux-de-Fonds, Switzerland, Speleo Projects, Basel, Switzerland.

Klimchouk, A. et al (eds) 2000 *Speleogenesis: Evolution of Karst Aquifers,* National Speleological Society, Alabama.

Lehmann, O. 1932 *Die Hydrographie des Karstes. Enzyklopädie der Erdkunde.* Leipzig, Franz Deuticke.

Lowe, D.J. 2000 Development of Speleogenetic Ideas in the 20th Century: The Early Modern Approach. *in* Klimchouk, A. et al (eds) *Speleogenesis: Evolution of Karst Aquifers,* National Speleological Society, Alabama.: 30-38.

Swinnerton, A.C. 1932 Origin of limestone caverns. *Geol. Soc. Amer. Bull.* **43**: 663-694.

White, W.B. 1999 Karst hydrology: Recent developments and open questions. *in* Beck B.F. et al (eds) *Hydrogeology and Engineering Geology of Sinkholes and Karst -1999. Proc. 7th Multidisciplinary conference on sinkholes and the engineering and environmental Impacts of Karst*, Balkema, Amsterdam. 3-21.

White, W.B. 2000 Development of Speleogenetic Ideas in the 20th Century: The Modern Period: 1957 to the Present. *in* Klimchouk, A. et al (eds) *2000 Speleogenesis: Evolution of Karst Aquifers,* National Speleological Society, Alabama: 39-43.

Worthington, S.R.H. 1991. *Karst Hydrogeology of the Canadian Rocky Mountains.* Dept of Geography. Hamilton, McMaster University Ph.D thesis, 380p.

Local climate reflected in radon concentrations in the Temple of Baal, Jenolan Caves

Stewart Whittlestone[1], Wlodek Zahorowski[1], Michael Hyde[1], Julia James[2] and Craig Barnes[2]

[1]Environment Division, ANSTO, PMB 1, Menai, NSW 2234

[2]School of Chemistry, F11, University of Sydney, NSW 2006

Email: swh@ansto.gov.au

Radon is an inert gas emitted by all soils and sediments. Its concentration in air depends on how much is able to escape from the soil, and on the rate at which it is diluted by radon-free air. Sometimes it is possible to design an experiment so that radon can be used as a tracer to provide insights into the movement of air and water.

In 1997, an intensive air quality monitoring system was established at Jenolan Caves to measure the seasonal variation of a number of parameters including radon gas. The Temple of Baal was originally selected as a site for radon monitoring because of its low ventilation rate and steady temperature. About 30 m wide, 35 m high and with a volume of about 10,000 m^3, the chamber has two natural entrances at the bottom and none at the top. A tunnel to gain access at the top has air-tight doors which are kept closed. It appeared to be a relatively simple system compared to Katies Bower, which can experience strongly varying radon concentrations on time scales as short as an hour.

In fact, the one year study of radon in the Temple of Baal has shown that its air flow patterns are complex and governed mainly by water in soil and cave passages. In the short term, less than a week, rain appears to reduce the permeability of the soil, and reduce the ventilation rate. This results in an increase in radon concentration. On a time scale of a month or more, prolonged rain can cause passages to block, and prevent radon laden air from entering the cave from the more distant sources. Radon concentrations in wet seasons are therefore low.

Correlations of radon with surface air pressure and temperature confirmed that different radon sources were predominant in different conditions. During Autumn, rainfall was very low, and radon concentrations varied by 50%, in strong anti-correlation with air pressure. This response to pressure indicates that the air in the Temple of Baal came from formations with large volume but limited permeability.

In winter completely different behaviour was observed. The radon levels were low and varied by only 5%. Such a steady radon concentration proves that the air exchange rate was very low, and the predominant source of radon was shallow sediments within the cave. Air flow within these sediments equilibrates so quickly that ambient pressure changes had no effect on the radon output.

Summer brought yet another regime. Radon levels were 50% higher and their variability, 10%, was double that in winter. The only climate variable correlating with radon was temperature with a time lag of two days. This can be explained by small exchanges of air with neighbouring chambers which have very high radon concentrations when the temperature is high.

BOOK REVIEW

FOREIGN TRAVELLERS IN THE SLOVENE KARST 1537-1900

Trevor R. Shaw (September 2000) Published by ZRC Publishing, Ljubljana, and Karst Research Institute, Postojna, Slovenia. ISBN 961-6182-12-X. 244 pp. 200 x 270 mm. 13 colour + 132 b&w illus., 422 refs, index, soft cover. Available from ZRC Publishing, PO Box 306, Ljubljana 1001, Slovenia.

In *Foreign Travellers* ... Dr Shaw carefully documents and annotates the records left by 93 visitors to the Classical Karst - from Leonberger in 1537 to Viré in 1900. Among these are 10 accounts from previously unpublished manuscripts. 48 of the travellers were British and a further 17 came from the USA. For those not written in English, Shaw has provided translations. Not included are writings by 'locals' like Baron Valvasor, scientists such as Schmidl or even resident foreigners – only itinerant travellers; what we would now call tourists, though many of them were, in fact, scientists or scholars in other fields.

Before presenting the travellers' descriptions, Shaw sets the scene, outlining why these people travelled, their sources of background information, the routes they most commonly took, the dangers they faced, their communication problems, guides, their behaviour, what they saw (mainly the caves and karst features; many were keen to see the blind salamander, *Proteus*) – even the accommodation they enjoyed. Shaw also gives us a brief introduction to the Karst, with its caves, dolines and other sites such as the disappearing lake Cirknica (Zirknitz). Each of the major attractions is described and those accounts which mention it are listed. Not surprisingly Postojna Cave features in no less than 55 of the accounts; perhaps surprisingly, only about 10 describe the spectacular Škocjanske Jame, though it had paths and guides from the 1850s.

The largest part of the book is taken up with 88 original accounts, reproduced verbatim (translated where necessary) and in many cases in facsimile. With each, Shaw gives background details on the writer (including, where possible, a portrait) and the reasons for his (or, in just four cases, her) visit. In many instances, Shaw describes the route taken and any known consequences of the visit. The signatures of many visitors after about 1820 are reproduced from the Postojna visitors books.

Among the better known travellers to the Karst were Sir Humphry Davy, English chemist and geologist (in 1818 and 1828); Sir Roderick Murchison, English geologist (after whom I presume Tasmania's Mt Murchison is named) (1829); Charles Latrobe, later Governor of Victoria (1830); King Frederick Augustus II of Saxony (1838); George Spottiswoode who, as head of the London publishing firm Eyre & Spottiswoode in 1889, was to publish the first book containing printed cave photographs, on Jenolan Caves (1860); Thomas Cook, originator of the 'Cook's tour', who organised many later excursions to Postojna (1868); Sir Richard Burton, explorer of Africa and the Middle East, translator of the *Kama Sutra* and British diplomat (5 visits between 1873 and 1889); the Prince of Wales (later George V) (1887) and Dr Sigmund Freud, psychoanalyst (1898). Shaw has edited some of their accounts to remove repetitious and irrelevant material. We are left with some charming descriptions of caves, including the usual superlatives, though many writers declared themselves lost for words. Through these narratives one can trace the development of the caves, particularly Postojna, including the improvements to the lighting, the pathways, the use of sedan chairs and the installation of a railway employing hand-pushed trolleys. In 1822 extra light was obtained in the large chambers by the guides igniting bundles of straw; for the Duke of Edinburgh and the Prince of Wales in 1887, 30,000 candles were lit, along with 8000 coloured lamps and 40 electric (arc) lights. The writers occasionally give insights into their own characters: Freud tells us he gave his "pickled" guide a generous tip "so he could drink himself to death all the faster" (despite this he lived another 31 years).

The index is thorough and there are useful lists of equivalent place names and old units of measurement. The references are presented as endnotes – the only element of the presentation with which I would differ (preferring the alphabetical Harvard system). However the citations are meticulous and all the necessary information is provided. The book is extremely well presented and bound. The colour photos are an unexpected bonus in such a reasonably priced production.

Dr Shaw has produced yet another volume destined to become a classic in the annals of cave history, an essential reference on the history of the Karst – and a fine companion volume to his *History of Cave Science*, the second edition of which was published by the Sydney Speleological Society in 1992.

Greg Middleton

NEWS and VIEWS

ASF Conference, Bathurst N.S.W. 29 Dec 2000 – 3 January 2001

A number of interesting scientific papers and posters were presented. These included papers on Cliefden area hydrology (Steve Lucas); the Bullita Cave system N.T. (Chris Bradley); Jenolan Hydrology (Henry Shannon); minerology and speleogenesis (Jill Rowling) and historical subjects (Darryl McDowell, John Dunkley, Norm Poulter, Albert Goede, Ian Curtis).

Proceedings should appear later this year.

Australasian Quaternary Association (AQUA) Conference, Port Fairy, Vic. 5 – 9 February 2001

Despite a preponderance of pollen diagrams, the AQUA conference in February 2001 had a number of papers and posters of speleological interest. These included vertebrate fauna from palaeokarst features at Barrow Island, W.A. (K. Aplin et al); McEachern's Cave fauna, Vic. (E. Budde and J. Hope); stable isotopes and geochemistry of speleotherms, Cliefden Caves, NSW (J. McDonald); Devil's Lair, W.A. dating issues (C. Turney et al); and the karst of Christmas Island (K. Grimes). A field trip included the lava caves at Byaduk and Mt Eccles and coastal karst and dune limestone sites.

No proceedings are planned. A book of abstracts was issued to registrants.

ACKMA Conference, Wombeyan Caves, NSW, 30 April – 4 May,2001

The 14th ACKMA Conference was a moving feast, with three days at the Wombeyan Caves followed by a day at each of Bungonia Gorge and Wee Jasper Caves. Although dominantly management oriented, a number of papers had scientific interest.

These included the introductory paper on the new scientific views of the Eastern Australian caves by Armstrong Osborne; an interpretation of two limestone knobs near Borenore (Ernst Holland & Mia Thurgate); karst vegetation in the Macquarie Catchment of NSW (Peter Dykes); Australian glow worms (Dave Merritt); microbial mantles in the submerged parts of the Nullarbor caves (Annalisa Contos & others) and calcite speleothems in a Korean lava cave (Soo Jin Kim).

The proceedings will be published primarily as a CD, if you want a hard-copy you should immediately contact the editor (Kent Henderson, PO Box 332, Williamstown, Vic 3016. Email: kenthen@optushome.com.au).

Information for Contributors to Helictite

Scope

Contributions from all fields of study related to speleology will be considered for publication. Suitable fields include Earth Sciences, Speleochemistry, Hydrology, Meteorology, Conservation, Biospeleology, History, Major Exploration (Expedition) Reports, Equipment and Techniques, Surveying and Cartography, Photography and Documentation. Comprehensive descriptive accounts of the exploration and morphology of individual caves will be welcomed, but simple trip reports and brief cave descriptions are not adequate. Papers overall should not exceed 20 printed pages in length. Contributors intending to write at greater length or requiring any advice on details of preparation are invited to correspond with the Editors. All manuscripts will be assessed by referees. "News and Views", "Short Notes" and "Letters to the Editor", expressing a personal view or giving a preliminary report of interesting findings, are welcomed, and will be given preference for speedy publication.

Manuscripts

Submitted manuscripts should initially be in printed form. Manuscripts should be typed, double spaced, on one side of the paper. Do not use multiple columns - this manuscript is for the editors and referees use and does not have to look like the final production.

The title should be upper case bold and the author's names and addresses should follow. A brief and explicit summary of the notable aspects of the paper, headed abstract, should precede the main text. Acknowledgements should be placed at the end of the text before the references.

Once authors have dealt with referees comments, they are requested to submit a copy of their final manuscript by email or on floppy disk as well as hard copy. Disks may be 3 ½" or 5 ¼" in either IBM or Macintosh format. If sending text as a word processing document (Microsoft Word etc.), please also send a copy as plain text on the same disk. Illustrations and tables are best sent in separate files, not embedded in the main document. Separate instructions concerning electronic layout are available.

References

References should be listed alphabetically at the end of the manuscript and cited in the text by the author's name and the year of publication, e.g. "(Grey, 1973)". Where there is more than one reference to the same author in one year the letters a, b, c, etc. should be added. If there are more than two authors, they should all be named at the first citation and in the reference list, but the first name followed by et al. should be used in subsequent citations. References should be checked particularly carefully for accuracy. If Journal titles are abbreviated, this should follow the "World List of Scientific Periodicals", which is available in most large libraries.

The following examples illustrate the style:

GREY, M.R., 1973 Cavernicolous spiders from the Nullarbor Plain and south-west Australia. *J. Aust. ent. Soc.* **12:** 207-221.

VANDEL, A., 1965 *Biospeleology. The Biology of the Cavernicolous Animals.* Pergamon, London. Pp. xxiv, 524.

WIGLEY, T.M.L. and WOOD, I.D., 1967 Meteorology of the Nullarbor Plain Caves. *In:* J.R. DUNKLEY and T.M.L. WIGLEY (eds), *Caves of the Nullarbor. A Review of Speleological Investigations in the Nullarbor Plain. Southern Australia:* 32-34. Speleological Research Council, Sydney.

Illustrations

For papers that have a geographical location we will provide a small location map in a standardised style (typically a map of Australia with a dot, rectangle or arrow - see recent issues for examples). Figures and photographs should not duplicate information in tables or other material. Photographs should be relevant to the text, and supplied as clear black and white prints with sharp focus. Figures should be supplied as Laser prints or drawn in Indian ink on white card, heavy paper or tracing material and lettered using stencils or stick-on lettering. Ink-jet prints should be enclosed in plastic to reduce the risk of water damage in transit. Most computer drawn documents and photographic images can also be handled. Please ask for additional instructions on file formats, pixel widths and photo "enhancements".

All illustrations should be designed to fit within a full page print area of 170 x 258 mm and ideally should be a column width (80mm) or double-column width (170 mm). They may be supplied larger provided that these proportions are maintained, but allowance for reduction must be made when choosing letter sizes and line thickness.

Foldouts or colour photographs and maps will be subject to negotiation, and the authors may be asked to make a contribution to the production costs.

Figures and plates should be numbered in a single sequence and specifically referred to in the text. The numbers should be marked lightly in pencil on the margin or back of each illustration. An arrow and the word "top" should be used if orientation is not obvious. Captions should be typed on a separate sheet (or supplied at the end of the text file).

Units

The S.I. system (Australian Standard AS 1000) should be used unless citing historical data, in which case the original units should be quoted and appropriately rounded metric equivalents added; 100 feet (30 m).

Offprints

Twenty free offprints of papers will be supplied after publication. Additional offprints can be arranged at the author's expense. The number required should be stated when submitting the final manuscript.

VOLUME 37 (1) 2001

Helictite

Journal of Australasian Speleological Research

Contents

Helictite Commission, Australian Speleological Federation Inc.

Printed by Campus Graphics, La Trobe University, 3086, Victoria.