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Helictite

Journal of Australasian Speleological Research

Thylacoleo carnifex, Victoria Fossil Cave, Naracoorte. Ken Grimes

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Helictite was established in 1962 by Edward A. Lane and Aola M. Richards, 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. Stefan Eberhard joined the editorial team in 2003.

In 2000 ownership was transferred to the Australian Speleological Federation, Inc. (ASF) and is administered 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.

Helictite

Journal of Australasian Speleological Research
VOLUME 39 (1) 2006

Contents

Cover: *Thylacoleo carnifex* from Victoria Fossil Cave, Naracoorte. Assembled by Ed Bailey. Photo by Ken Grimes.

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This issue is published in March 2006.

Editorial

Ken Grimes

This issue's cover photo of the *Thylacoleo* skeleton that is on display at Victoria Fossil Cave, Naracoorte, was chosen for two reasons: firstly to compliment the paper by Liz Reed on the taphonomy of a bone site within the cave, and, secondly, as a memorial to the man who assembled the skeleton: Ed Bailey. The following is based on notes provided by Ian Lewis of CEGSA (Cave Exploration Group, South Australia).

Ed was an engineer at the Defence Research Establishment. He therefore got along very well with Rod Wells who also had an engineering background, and they applied their technical and analytical talents to deducing the functional relationships and interconnections of the bone fragments being extracted from Victoria Fossil Cave. This quickly turned to practical assembly of skeletons as the vast amount of fossil material allowed them to do accurate reconstructions.

These assemblies made an incredibly important contribution to our knowledge of Australian mammal evolution, as whole prehistorical skeletons were virtually unknown to Australian palaeontology before Ed's work with Rod.

Ed retired from engineering and devoted his time to patiently and delicately building skeletons from casts in the old fossil lab at Naracoorte (which is now the Parks Office). The two skeletons displayed on the Fossil Dig Table in the cave are his handywork, which is viewed by thousands of people each year and brings the fossil discoveries to life for the general public, adding a special dimension to educating them about the past in Australia. For example, the Guides explain about the hands, bone structure and teeth and jaws of these creatures, from which details palaeontologists can deduce their behaviour, past vegetation types and climates at Naracoorte. The detail which Ed put into the skeleton reconstructions allows such conclusions to be made.

In October 2005 a commemorative plaque was placed on one of the new limestone walls at the entrance to the Victoria Fossil Cave in which Ed worked so thoroughly for many years. On the opposite wall is a matching plaque in memory of Ern Maddock, another CEGSA member whose senior role in SA Tourism in the 1970s ensured that Victoria Fossil Cave received the development attention, funding and national promotion which it deserved.

Other matters

We have been negotiating with other karst journals for an exchange of contents of recent issues, and will include those in future issues of Helictite. We will also reproduce abstracts from those journals which we feel are relevant to Australasian readers, as has been done on page 16.

Helictite web page

The *Helictite* web page is maintained by our Business Manager, Glenn Baddeley.
The URL is: http://home.pacific.net.au/~gnb/helictite/

The web site provides subscription information, contact details, information for contributors, and contents and abstracts for all issues of *Helictite*.

Helictite, (2006) **39(1):** 3-4

The first Australian record of subterranean guano-collecting ants

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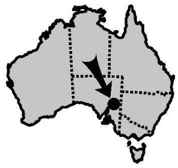

Abstract

An arthropod community was found in guano of the inland cave bat (*Vespadelus findlaysoni*) roosting in the abandoned Eregunda mine, a 25 m adit located east of Blinman in the central Flinders Ranges, South Australia. This guano community is remarkable because meat ants (*Iridomyrmex purpureus* Smith) were observed to enter the mine, collect fresh guano, and carry it back to the nest. This opportunistic behaviour has not previously been reported in Australian or overseas hypogean guano communities. Bat guano is eaten directly by many guanobitic and guanophilic invertebrates as high nitrate food, or, more commonly the more readily digested glycogen rich bacteria and fungus are eaten. Although not strictly a cave, the lack of suitable bat roosts in nearby caves, and the stable environmental conditions present, make this site locally important as a representative hypogean guano arthropod community.

Keywords: Ant, biospeleology, Flinders Ranges, Formicidae, guano.

Introduction

The presence of ants in a hypogean environment is interesting as few species have been recorded from cave habitats, with only limited numbers exhibiting troglomorphies recorded worldwide (Wilson 1962). No ants were recorded by Hamilton-Smith (1967) in his checklist of Australian cavernicolous arthropods and relatively few have been recorded since. Humphreys (1998) records a possibly cave-adapted species of *Paratrechina* attending meenoplids (Homoptera) in caves in the Cape Range peninsula and the Kimberley region, Western Australia. Humphreys and Eberhard (2001) record a guanophilic species of *Pachycondyla* from Upper Daniel Roux Cave (6CI-56), Christmas Island, but it possesses no troglomorphies. Several ant species including *Camponotus ?obniger* (*consobrinus* complex Erichson), *Cerapachys ?edentatus* Forel and *Rhytidoponera metallica* Smith, have all been recorded from the maternal chamber of Bat Cave (5U-2), Naracoorte, although these species are considered to be accidental to the cave environment (T. Moulds, unpubl. data).

A small population of the inland cave bat (*Vespadelus findlaysoni* Kitchener, Jones & Caputi) roosts in the abandoned Eregunda mine, east of Blinman in the central Flinders Ranges, South Australia. The population of approximately 20-30 individuals was observed in October 2002 and April 2003. The horizontal mine adit, approximately 25 m in length (Figure 1), is the most significant bat roost in the region (E. Rubessa, pers. comm. 2003). The current roosting area is nearest to the entrance, although two older, drier guano deposits, deeper into the adit provide evidence of movement of the bat roost during previous periods of occupation. This mine is an important site for hypogean guano arthropods in the Flinders Ranges as few other active bat roosts remain, due to disturbance from past guano mining.

Observations

In April 2003 I collected arthropod specimens from the small guano deposit under the active roost and from the surrounding walls. A sample of guano was also collected for extraction in a Tullgren funnel. Specimens have been sorted to family level and beyond where possible.

This guano arthropod community is interesting due to the presence and behaviour of common meat ants (*Iridomyrmex purpureus* Smith). A trail of meat ants was observed from the entrance of the mine adit leading to the fresh guano under the active bat roost. At the active roost site, ants were observed collecting fresh guano in their

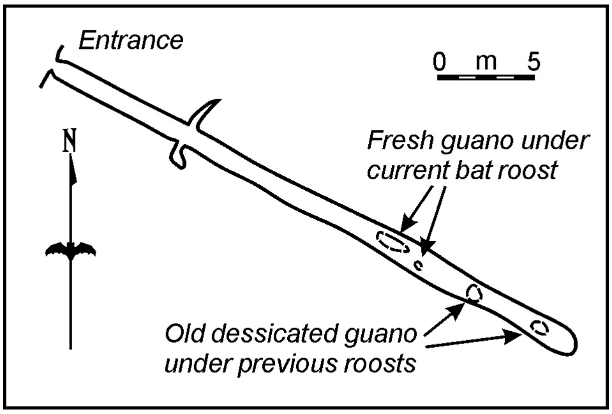

Figure 1. Plan view of Eregunda mine, central Flinders Ranges, South Australia.

mandibles and carrying it out of the mine to their nest entrance, approximately 30 m from the mine entrance. Approximately 10 ants were collecting guano at any one time, with groups of two to four individuals spaced every 30-40 cm traveling along the adit. This accounted for a large proportion of the fresh guano falling to the mine floor. This is the first record of the systematic gathering of bat guano by ants in an Australian mine or cave. The ants possess no troglomorphies, as would be expected given the opportunistic exploitation of the guano resource. No ants were observed attacking guanophilic arthropods.

The remainder of the guano arthropod community exhibits a standard structure, with a range of predatory species including pseudoscorpions, beetle adults and larvae, and spiders consuming psocids, fly larvae and other guanivore/fungivore species (*sensu* Gnaspini and Trajano 2000; Moulds 2004). No guanivore species were observed during April, although further sampling during summer months will undoubtedly reveal their presence. Several psocids were observed *in situ* although no specimens were collected. Despite the bats being in torpor, and the associated lack of fresh guano, the arthropod community was still active. Older drier guano piles, located deeper in the adit (Figure 1) supported few arthropods compared with the guano under the active roost.

Discussion

The collection of guano by a single colony of *I. purpureus* is noteworthy as it demonstrates the opportunistic nature of this species. It is unknown if this behaviour is more widespread than the single example reported and further observations in other guano caves throughout Australia will aid in determining the extent of this behaviour in this and other ant species. The lack of ants exploiting this rich resource may be due to a number of reasons. The accessibility of guano may be a factor as the active guano pile is located in the twilight zone of the mine while the majority of guano is located well into the dark zone at Naracoorte. Guano in Eregunda mine is a relatively short distance from the entrance (Fig. 1), while sizeable guano deposits in Bat Cave are situated approximately 100-150 m from the entrance. The most important factor is probably the quantity and quality of resources available to ants outside both caves. Guano may be eaten directly for its relatively high nitrate content (Hutchinson 1950). Alternatively bacteria and fungus growing upon guano as it ages is also eaten by guanobitic and guanophilic invertebrates. It is unknown why this colony of *I. purpureus* was collecting fresh guano. Further observations are needed to clarify if guano is being used as a food source or for another purpose.

Acknowledgements

I would like to thank Department of Environment and Heritage, South Australia and The University of Adelaide for funding this project. I would like to thank Eddie Rubessa of the Cave Exploration Group, South Australia for field assistance and knowledge of local bat populations. Additional field assistance was provided by Alice Shields and Matilda Thomas. Andy Austin and John Jennings provided editorial comments. Terry Reardon aided in the identification of the bat species and provided useful discussions. Alan Anderson, Sylvia Clarke and Travis Gotch provided ant and spider identifications. Comments by the two reviewers greatly improved this paper.

References

GNASPINI, P. and TRAJANO, E., 2000: Guano communities in tropical caves. *Ecosystems of the world. Subterranean ecosystems*. WILKENS, H., CULVER, D.C. and HUMPHREYS, W.F. Amsterdam, Elsevier. **30:** 251-268.

HAMILTON-SMITH, E., 1967: The Arthropoda of Australian caves. *Journal of the Australian Entomological Society* **6:** 103-118.

HUMPHREYS, W.F., 1998: *Phaconeura* (Homoptera: Meenoplidae) attended by ants of the genus *Paratrechina* (Hymenoptera: Formicidae) in caves. *The Australian Entomologist* **25:** 23-27.

HUMPHREYS, W.F. and EBERHARD, S., 2001: Subterranean fauna of Christmas Island, Indian Ocean. *Helictite* **37:** 59-73.

HUTCHINSON, G.E., 1950: Survey of contemporary knowledge of biogeochemistry. 3. The biogeochemistry of vertebrate excretion. *Bulletin of the American Museum of Natural History* **96:** 1-554.

MOULDS, T.A., 2004: Review of Australian cave guano ecosystems with a checklist of guano invertebrates. *Proceedings of the Linnean Society of New South Wales* **125:** 1-42.

WILSON, E.O., 1962: The Trinidad cave-ant, *Erebomyra* (*Spelaeomyrmex*) *urichi* (Wheeler), with a comment on cavernicolous ants in general. *Psyche* **69:** 62-72.

In Situ Taphonomic Investigation of Pleistocene Large Mammal Bone Deposits from The Ossuaries, Victoria Fossil Cave, Naracoorte, South Australia

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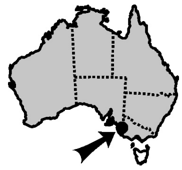

Abstract

The Ossuaries within the Victoria Fossil Cave (5U-1) contain a large, virtually untouched deposit of Pleistocene vertebrates. Discovered in the early 1970s, the chamber has been left unexcavated as a ‘reference’ section of the cave and contains taphonomic features analogous to the formation of other large deposits such as the Fossil Chamber. This paper presents the results of an *in situ* taphonomic investigation of large mammal fossils from The Ossuaries. The results suggest The Ossuaries acted as a pitfall trap for a range of large Pleistocene mammals, in particular kangaroos. Once accumulated, the skeletons of these animals were subject to burial and dispersal by water and modification by trampling and termite gnawing. The presence of articulated material suggests many animals survived their initial fall, only to wander further into the cave and perish at some distance from the entrance.

Keywords: karst, cave, taphonomy, palaeontology, mammal, Pleistocene.

Introduction

The caves within the Naracoorte Caves World Heritage Area are renowned for their large deposits of Pleistocene vertebrates (Reed & Bourne, 2000). Among these, the Victoria Fossil Cave (5U-1) stands out for the number and size of Pleistocene deposits it contains. Discovered in 1969, the Fossil Chamber within this cave has been the focus of research for more than thirty years (Wells *et al.*, 1984; Reed & Bourne, 2000; Reed, 2003). In the years following its discovery other large deposits were found within the cave, including the chamber known as The Ossuaries which was discovered in the early 1970s (Reed & Bourne, 2000).

The Upper and Lower Ossuaries consist of scatters of large Pleistocene vertebrate bones lying on the clayey-sand sediment floors of the chamber. The important nature of these deposits was recognised early and only a small number of specimens were collected for taxonomic identification, with the deposit left un-excavated for future reference (Reed & Bourne, 2000). The chamber is classified in the Park’s management plan as a ‘Reference’ section of Victoria Fossil Cave (Department for Environment and Heritage, 2001). The management plan states that “Reference Caves will be protected against further disturbance as far as is practicable, and access will be only with written approval for research specifically related to the baseline functions of the cave, and where such research cannot reasonably be carried out elsewhere in the State” (Department for Environment and Heritage, 2001).

Taphonomic investigation of deeply stratified deposits such as those in the Fossil Chamber of Victoria Fossil Cave is complex and requires the identification of the full range of processes that have operated to produce the deposit. The Ossuaries deposits provide an important opportunity to study large surface scatters of Pleistocene bones in a relatively undisturbed (by humans) fossil deposit, one that is analogous in many ways to the larger Fossil Chamber and many other Pleistocene pitfall deposits at Naracoorte and the South East of South Australia in general. Several features evident on the surface of The Ossuaries deposit provide useful analogues for the depositional stages of the Fossil Chamber including evidence of hydraulic action.

This paper reports the results of a taphonomic investigation of The Ossuaries deposit. As there are no other ‘un-disturbed’ deposits of this size and age known at Naracoorte, permission was granted to conduct research in The Ossuaries with the condition that all data collection was made on bones remaining *in situ* with no excavation or disturbance to the sediment floors.

Materials and methods

Mapping The Ossuaries

Prior to this project there had been no detailed maps produced of The Ossuaries chambers, due largely to access restrictions and the logistical problems of mapping a chamber when most of the floor cannot be crossed. As part of this project, plan maps of the chambers were produced using laser surveying equipment which

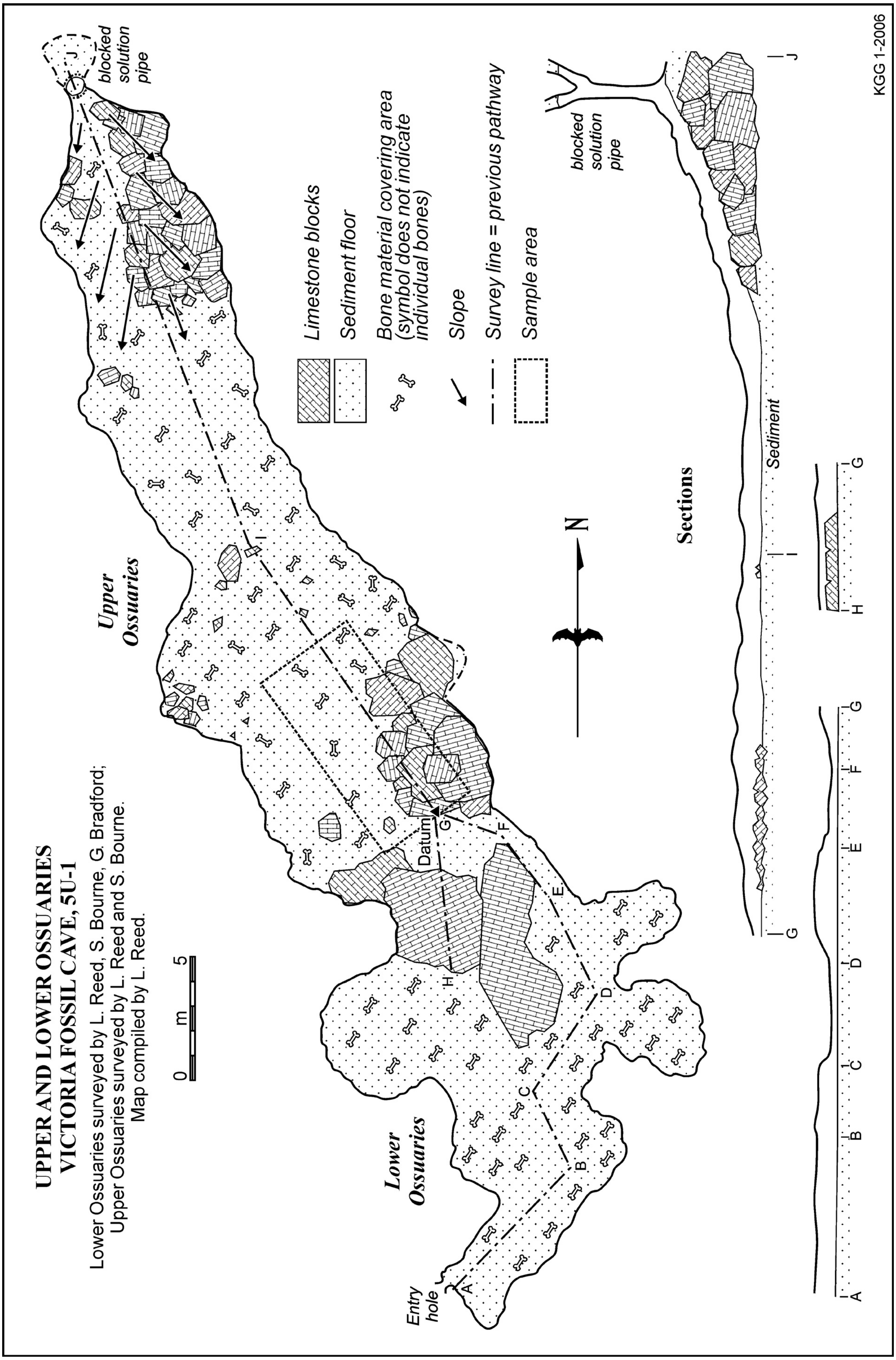

Figure 1. Map and sections of The Ossuaries, Victoria Fossil Cave (5U-1), Naracoorte.

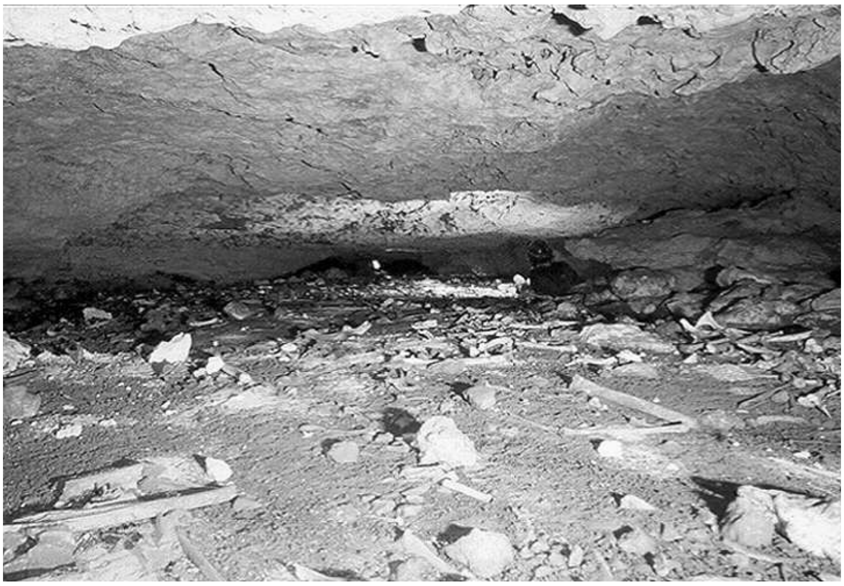

Figure 2. View of The Upper Ossuaries chamber looking Northwest. Note caver's light in distance.

obviated any need to cross the undisturbed floor. The chambers were surveyed by running a tape along the centre-line (following the established narrow pathway) and measuring the distance to the walls and the roof height with a laser rangefinder at every 0.50 m along bearings defined by a digital compass. The mapping data were used to draw maps by hand. The topography of the floor was not surveyed, as access to most of the floor was restricted.

Four data collection trips were made, each lasting up to eight hours. The first trip was to photograph and map the entire chamber and to plan a strategy for the project. The survey of bone material was restricted largely to The Upper Ossuaries, as the roof height in The Lower Ossuaries was extremely low making work in that area practically impossible; nevertheless, the area was mapped and photographed. A datum point (small steel peg) was surveyed in and used on subsequent trips. Following the initial trip a map of The Upper Ossuaries chamber was completed and a grid overlain onto it to be used as a guideline for documenting bone material within the chamber for future trips. The grids used were 2 m square (with some variation resulting from difficulties accessing some areas of extremely low roof height) and were given X and Y co-ordinates for reference (eg. A2, B4).

Documenting bone material

Large, visible bones in The Upper Ossuaries were plotted onto the grid map, with cranial and post cranial material distinguished on the map. A few bones near the far walls of the chamber were omitted from the map as they were too far away to be easily identified, although some identifications were made after photographing using a zoom lens on a camera. No physical markers were used to define the limits of each grid and all data recording was done from the existing pathway. Grid boundaries were established by sight using the laser rangefinder, a tape measure (for distance along centre line), and compass (for bearings). A portable halogen light was used to provide strong light. Two people were involved in collecting data. One person plotted the position of bones onto the grid map as communicated by the other person who made element identifications and recorded positional data (measured at centre-point of bone). Due to the difficulties of recording bones in this manner, there is likely to be some degree of error in the accuracy of plotted locations of bones (particularly smaller elements), despite the care taken during the data gathering.

Other features such as rock piles, visible water-cut channels, associated and articulated sub-assemblies, modified bones and any other features of interest were noted on the map. These features were also extensively photographed using an SLR camera and a range of lenses. In addition, the entire Ossuaries were photo-documented for management reference. The Lower Ossuaries was also mapped and the survey tied in to that for The Upper Ossuaries. The maps produced from the study will be integrated with the entire cave survey currently being completed by CEGSA (Cave Exploration Group, South Australia).

Bone material within a 40 m^2 area adjacent to the pathway (representing 13.5% of the total floor area, see Figure 4), was sampled for taphonomic data. A total of 269 bones was examined and where practical, details such as element type, taxon (at least to family), bone orientation, modifications, associations and articulations recorded. The orientations of 182 bones (accessible from the pathway) with a long axis were measured using a digital compass mounted with a spirit level.

Analysis of bone material

Taphonomic data was catalogued using a spreadsheet. Statistical analyses were completed using SPSS™ version 11. Rose diagrams were created using the program Stereographic Projections version 1.00. The number of identifiable specimens (NISP) within the sampled area was calculated by counting all specimens identifiable to anatomical element and taxon. The minimum number of individuals (MNI) from this sample was determined by counting the relative proportions of left and right specimens of the most abundant element type, in this case the tibia.

Following counting and grouping of specimens the relative abundances (Ri) of elements was determined using the equation of Andrews (1990):

$$\text{Ri}\,\% = \frac{\text{Ni} \times 100}{(\text{MNI})(\text{Ei})}$$

where Ni indicates the number of specimens per element type counted, MNI being the minimum number of individuals determined for the relevant taxon or stratigraphic unit and Ei the expected number of each element type in a complete skeleton.

The index of skeletal representation (Ir) was calculated using the equation:

$$\text{Ir} = \frac{(\text{NISP} \times 100)}{(\text{NE} \times \text{MNI})}$$

where NISP is the number of identified specimens recovered, NE is the number of elements in a single skeleton and MNI is the minimum number of individuals in the assemblage (method follows Arribas & Palmqvist, 1998). This figure gives an indication of the degree of element 'loss' (i.e. transport, dispersal) from that expected should the bones of all skeletons initially deposited in the assemblage still be present. It was used as it may offer some insight into the degree of dispersal and preferential burial within the sample.

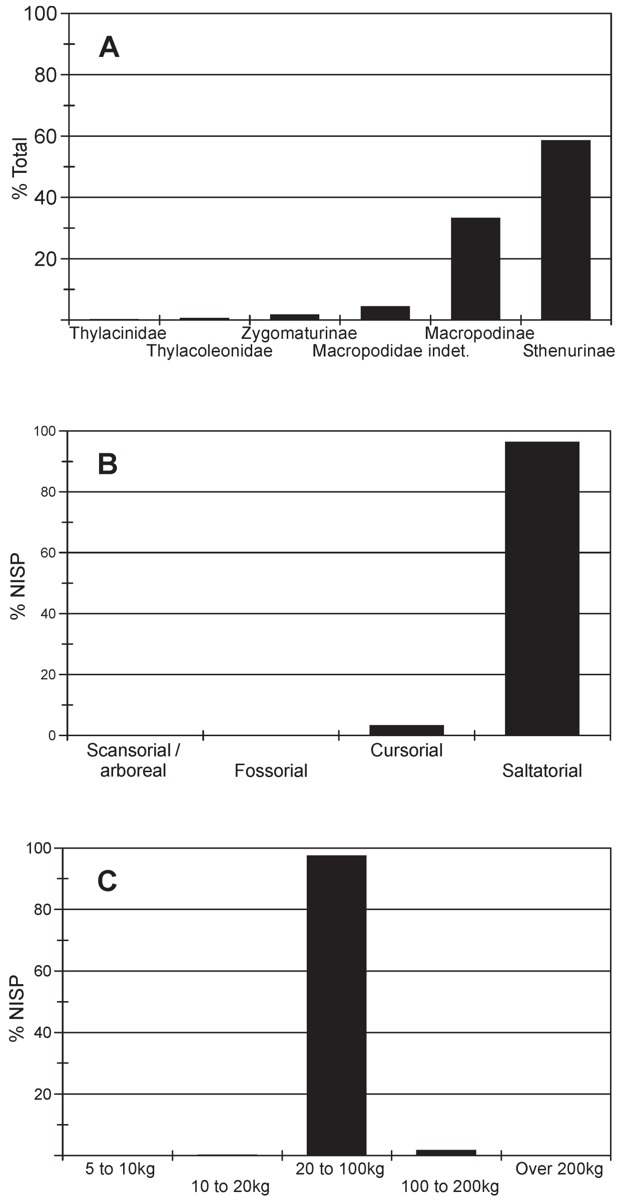

Figure 3. **A:** Relative abundances of the large mammalian families (or sub-families) based on NISP values for bones *in situ* in The Upper Ossuaries. N = 269; **B:** Locomotory mode class representations for the Ossuaries sample based on NISP (N = 269); **C:** Body size class representations for the Ossuaries sample based on NISP (N = 269).

Results

Chamber morphology and geological features

Description of the chamber

Although designated The Lower and Upper Ossuaries, The Ossuaries forms a single, large chamber with areas of rock collapse separating the two areas (Figure 1). The combined Upper and Lower Ossuaries chamber is approximately 63 metres long and 18 metres at its widest point. The floor surface area is around 475 m^2 and roof height is generally less than one metre (Figure 1). The chamber extends from the area of the Victoria Fossil Cave known as the Main Leg and is entered via a small dug hole. The Lower Ossuaries area is low and flat with a floor of clayey sediment littered with bone material. The Upper Ossuaries is much larger, although the chamber is still low with an average roof height of around one metre. The sediment floor is littered with bone material (Figure 2) with some roof fall limestone boulders and smaller pebbles in several areas. Limestone dust and evidence of minor roof fretting is obvious across the sediment floor. The depth of sediment is unknown as probing or coring has not been undertaken due to sensitivity of the floor. Both chambers of The Ossuaries are devoid of calcite speleothems.

Entry point for sediment and animals

The only discernible point in the chamber for entry of sediment and animals is a solution pipe in the northern end of The Upper Ossuaries (Figure 1). The pipe is 70 to 80 cm in diameter on average and extends upwards as a single pipe for four metres before branching into twin pipes that continue for approximately another two metres until constrictions are reached. The depth below the land surface at this point is not known, but it is likely

Table 1. Large mammal species recorded for The Ossuaries, Victoria Fossil Cave (5U-1). See also Reed & Bourne (2000). *† = extinct during Pleistocene, ** = extinct since European settlement

Class / sub-class & order	Family	Genus & species
MAMMALIA		
MONOTREMATA	Tachyglossidae	*† *Megalibgwilia ramsayi*
MARSUPIALIA		
DASYUROMORPHIA	Thylacinidae	***Thylacinus cynocephalus*
	Dasyuridae	*Sarcophilus* sp. cf. ***S. laniarius*
DIPROTODONTIA	Diprotodontidae	*† *Zygomaturus trilobus*
	Thylacoleonidae	*† *Thylacoleo carnifex*
	Macropodidae	*Macropus* sp. cf. *M. giganteus*
		M. rufogriseus
		*† *Simosthenurus browneorum*
		*† *Simosthenurus gilli*
		*† *Simosthenurus maddocki*
		*† *Simosthenurus occidentalis*
		*† *Sthenurus andersoni*

to be several metres. The sediment cone slopes steeply up to the base of the solution pipe suggesting this as the sediment source. Other evidence supporting this conclusion is the presence of sediment adhering to the inner portions of the pipe and bone material at its base.

Evidence of water action

Evidence of past water channelling is obvious across the sediment floor of the chamber, although the chamber is now dry. Water flow appears to have originated at the solution pipe, with evidence of flow over a large rock pile and branching micro-channel systems, generally less than 5 cm across and a few millimetres deep, extending 30 m beyond the pipe across the fan. At least one area within the chamber shows evidence of water ponding and there are desiccation cracks evident on the sediment surface in places. Deviations in channels occur where flows met rocks and large bone material. Within the micro-channels, pebbles (15-30mm; mostly carbonate) form obvious lag deposits with winnowing of finer grains having occurred suggesting a relatively low energy water flow. Some staining is present on bone specimens attesting to partial inundation of the bones and many bones are partially buried by sediment washed down the cone and fan. The chamber is now completely dry with evidence of recent water flows.

The bone assemblage

Species composition

Table 1 presents a list of large mammal species identified from The Upper and Lower Ossuaries chambers based mainly on identifications of specimens collected in the 1970s when the pathway was defined and material identified during this project. Species represented include: *Megalibgwilia ramsayi* (extinct, giant, long-beaked Echidna), *Thylacinus cynocephalus* (Tasmanian Tiger), *Sarcophilus laniarius* (extinct giant Devil), *Zygomaturus trilobus* (extinct, cow-sized marsupial), *Thylacoleo carnifex* ('Marsupial Lion'), *Macropus rufogriseus* (Red-necked Wallaby), *Macropus giganteus* (Eastern Grey Kangaroo) and the extinct browsing kangaroos *Simosthenurus browneorum*, *Simosthenurus gilli*, *Simosthenurus maddocki*, *Simosthenurus occidentalis* and *Sthenurus andersoni*. Of these species, 69% are megafaunal taxa that became extinct during the Pleistocene with the remaining species either extant in the region today or extinct since European settlement as shown in Table 1. As no excavation has been conducted in the chamber, this is undoubtedly an incomplete list particularly with regard to small vertebrates. However, it does give an indication of the large mammal diversity within the deposit. In addition to the large mammal remains, Emu (*Dromaius novaehollandiae*) bones from several individuals are visible on the sediment surface. There is a definite bias toward large species in the surface sample and this may be related to preferential burial of smaller bones, hiding them from view of the surface survey.

The sample of bones recorded *in situ* during this study is composed primarily of kangaroos (96.9%), with the sthenurines the most numerous (58.8%). Other species recorded include *Thylacinus cynocephalus* (0.4%), *Thylacoleo carnifex* (0.8%) and *Zygomaturus trilobus* (2.0%) (Figure 3a). Carnivores make up just 1.2% of the total with the remainder herbivorous species. Of the herbivores, 60.8% are browsing species.

Body size and locomotion

The largest animal recorded from the sampled area is *Zygomaturus trilobus* (300-500 kg – Murray,

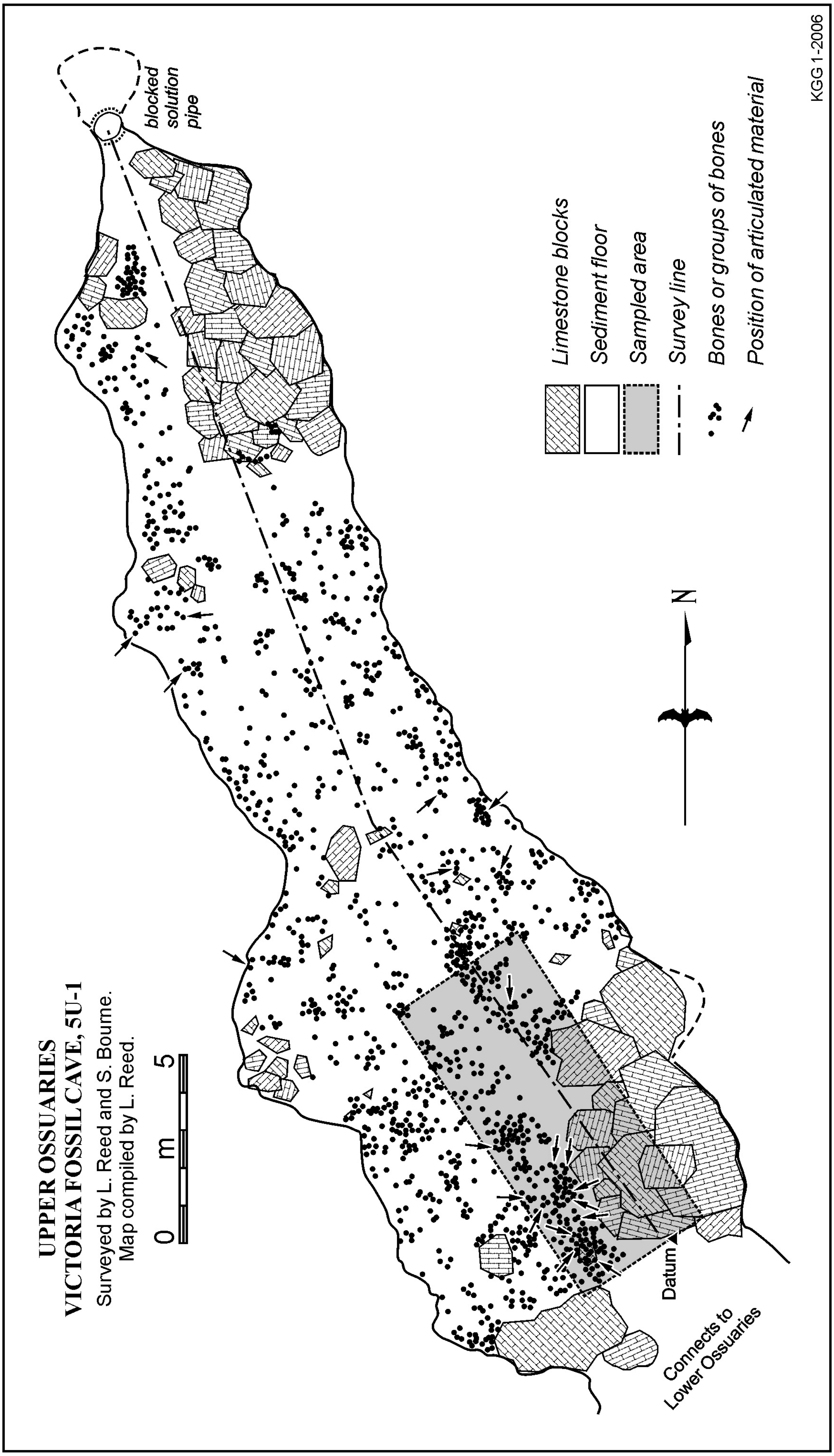

Figure 4. Map showing the distribution of bone material across the floor surface of The Upper Ossuaries.

Table 2. Total numbers (Ni), % total Ni and relative abundances (Ri%) for the bone sample from The Upper Ossuaries. N = 269, MNI = 34 (determined from the most abundant element type for each family or sub-family represented).

Element type	**Ni**	**% Total**	**Ri%**
Cranium	8	2.97	23.53
Dentary	12	4.46	17.65
Atlas	1	0.37	2.94
Axis	0	0.00	0.00
Cervical vertebrae	6	2.23	2.94
Thoracic vertebrae	13	4.83	2.94
Rib	10	3.72	2.26
Lumbar vertebrae	16	5.95	7.84
Sacrum	2	0.74	5.88
Caudal vertebrae	35	13.01	4.68
Chevron	1	0.37	0.13
Clavicle	0	0.00	0.00
Sternebrae	0	0.00	0.00
Scapula	2	0.74	2.94
Humerus	4	1.49	5.88
Radius	3	1.12	4.41
Ulna	1	0.37	1.47
Carpal	0	0.00	0.00
Metacarpal	1	0.37	0.29
Phalanges - manus	0	0.00	0.00
Pelvis	32	11.90	47.06
Epipubic	2	0.74	2.94
Femur	50	18.59	73.53
Tibia	60	22.30	88.24
Fibula	3	1.12	4.41
Tarsals	3	1.12	1.10
Metatarsals	4	1.49	1.47
Phalanges - pes	0	0.00	0.00
Total	269		

1991). Remains of this animal are not evident on the distal portions of the cone. A few isolated remains of a juvenile individual were observed at around 24 and 29 metres from the solution pipe and bones of an associated skeleton lie near the base of the pipe. The body size classes for all individuals (based on NISP) reflect the abundances of the macropodidae. Animals less than 20 kg and over 100 kg are poorly represented (Figure 3c). The sample is dominated by saltatory animals, but that is not surprising given kangaroos were a dominant feature of the palaeocommunity and the mode of locomotion increases susceptibility to trapping via pitfall (Figure 3b).

Skeletal element abundance and spatial patterning

Most element types were recorded from the surface sample, with the exception of the axis, clavicle, sternebrae, carpals and phalanges of the manus and pes. The dominant element types are the bones of the hindlimb and the larger vertebrae (caudal, lumbar). Most specimens visible on the surface are large, with a mean length of 20.7 cm for the sample recorded. Analysis of the relative abundances (Ri%) of the various element types show that for the individuals represented in the sample (MNI = 34), the tibia, femur and pelvis are very well represented, with crania and dentaries (including mandibles) moderately well represented (Table 2). All other element types have relative abundance values of less than ten percent (the majority <5%), indicating substantial loss from the surface. The index of skeletal representation (Ir = 3.10) reflects this.

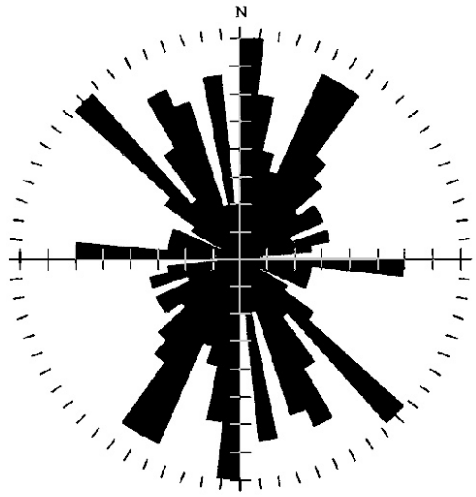

Figure 5. Orientations of bones for the area sampled from the floor surface of The Upper Ossuaries chamber. N = 182, Mean = 172.56°, standard deviation = 106.54.

In the area sampled, 269 large bones representing 34 individuals (MNI calculated from the most numerous element type) were recorded, giving a density of 0.85 individuals /m^2. The mean spatial density of bone material for the area sampled is 6.75 bones /m^2, and spatial distribution is patchy. Across the floor of The Upper Ossuaries concentrations of bones are interspersed with areas of sparse bone material, with a greater concentration of bone material on the distal portions of the fan (Figure 4). The orientations of 182 bones from the sampling area were measured and the results show a non-random orientation (X^2 = 29.97, N = 182, d.f. = 18, p = 0.04), with some tendency for alignment of bones with the longitudinal axis of the chamber (Figure 5). Some bones are plunging almost vertically.

Articulation and association

Several articulated sub-assemblies (Table 3) are visible on the floor surface of The Upper Ossuaries mostly on the distal portions of the fan or adjacent to cave walls, but some are present on the proximal cone and others near large limestone rocks (Figure 4). The elements that remain articulated tend to be those that separate late in the disarticulation sequence of Reed (2001). In the sampled area several associations were recorded (N = 19 matched pairs of elements). The mean distance separating these elements was 32.4 cm.

Taphonomy

Table 3. Composition of the various articulated sub-assemblies visible on the floor surface of The Upper Ossuaries chamber. Sthe = sthenurine, Macn = macropodine.

Articulated sub-assembly	**Taxon**	Rank order of disarticulation (from Reed 2001)
Pelvis, Lumbar vertebrae x 2	Sthe	27
Femur & Tibia	Macn	26
Pelvis, Lumbar vertebrae x 2	Sthe	27
Lumbar vertebrae x 2	Macn	30
Pelvis, Lumbar vertebrae x 2	Sthe	27
Pelvis, Lumbar vertebrae x 2	Macn	27
Pelvis, Lumbar vertebrae x 2, Sacrum, Lumbar vertebrae x 6, Thoracic vertebrae x 1	Sthe	25 to 30
Tibia, Femur	Sthe	26
Lumbar vertebrae x 2	Sthe	30
Tibia, Femur	Sthe	26
Pelvis, Lumbar vertebrae x 2, Sacrum	Sthe	27
Lumbar vertebrae x 5	Sthe	30
Caudal vertebrae x 4	Sthe	22
Caudal vertebrae x 2	Sthe	22
Lumbar vertebrae x 3	Sthe	30
Thoracic vertebrae x 3	Sthe	25
Thoracic vertebrae x 2	Sthe	25

Bone modification

The bones from The Upper Ossuaries are generally in an excellent state of preservation; however, some examples of bone modifications are observable. Insect gnawing consistent with termite modification (Watson and Abbey, 1986; Reed, 2003) is evident on numerous bones as are dirt tunnels and minor sediment disturbances. Many bones display very fine longitudinal cracking and some specimens have more extensive cracking. Access limitations severely restricted assessment of the degree of surface modification to bones other than those adjacent to the path. However, scratch marks, similar to those produced by trampling (Oliver, 1989; Reed, 2003) are discernible on some specimens. Similarly, fracturing is evident on some specimens with impact, irregular perpendicular and spiral fractures represented. The highest degree of fracturing is present on a pile of bones (representing at least one complete *Macropus* kangaroo skeleton) near the base of the entrance pipe. Many of these bones display impact, spiral and irregular fractures as well as termite damage. Bones not covered by sediment display a 'chalky' texture.

Discussion

Chamber morphology and geological features

The Ossuaries is essentially a large collapse chamber separated by a large rubble pile and accessible via a low passage. The depth of the sediment infill is difficult to ascertain (no probing or coring was permitted); however, the chamber has almost been filled to the roof in places. The entry point for bones and sediments appears to have been the single solution pipe evident and dispersion was via a complex series of water-cut micro channels emanating from the cone adjacent to the pipe. The pattern of water channelling evident in The Upper Ossuaries is very similar to that observed for currently active caves at Naracoorte (Reed, 2003), and is suggestive of low energy water flow. Other features similar to those observed in the modern analogue caves (Reed, 2003) include the lag of coarser limestone pebbles, winnowing of finer-grained material in the channels and the apparent movement of saturated sediment and slow burial of bones. The staining of bone material suggests water flow over the bones. The surface layer of The Ossuaries provides a good example of the processes proposed by Wells *et al.* (1984) and Reed (2003) for the formation of some sedimentary units of the Fossil Chamber, which show sedimentary evidence of low energy water flow (Wells *et al.*, 1984; Reed, 2003).

Numerous white, chalky, angular, un-stained limestone flakes/rocks spread over the floor of The Upper Ossuaries probably result from roof fretting. Wells *et al.* (1984) suggest that the amount of fretting might give some indication of exposure time of the floor surface, and as accumulation of The Ossuaries deposit ceased thousands of years ago (evidenced by the presence of extinct megafauna), this appears to support such a conclusion.

The bone assemblage

The fauna

The faunal composition of the large mammal assemblage from The Ossuaries is a subset of that of the Fossil Chamber of Victoria Fossil Cave (Wells, *et al.* 1984; Reed & Bourne, 2000; Reed, 2003). The smaller number of species recorded from The Ossuaries is probably an artefact of the limited sample size. The fauna is dominated by the macropodidae, as in the Fossil Chamber assemblage and other major Pleistocene deposits in the region (Reed & Bourne, 2000). This is also the case for modern caves at Naracoorte with solution pipe entrances (Reed, 2003), and the entrance for The Ossuaries chamber was very likely a narrow solution pipe. Kangaroos appear to be particularly susceptible to pitfall entrapment, predominantly where the entrance is small or a solution pipe (Reed, 2003). As macropodids were a highly speciose group with a high local faunal diversity (at least 7 species of 12 in the sample) it is probable they were dominant in the palaeocommunity as well. One very interesting feature of The Ossuaries sample is that sthenurine remains are more prevalent than those of macropodines and this may reflect relative abundances in the community and habitat proximal to the cave. Alternatively, this feature may also be related to sample size or other palaeoecological factors. Overall, the composition of the large mammal fauna suggests a habitat composed mainly of open woodland to sclerophyll forest with areas of shrub land, heath land and grass land.

Body size and locomotion

The largest animal recorded from the assemblage is the cow-sized *Zygomaturus trilobus*. This animal is also the largest recorded for other pitfall deposits at Naracoorte (Brown & Wells, 2000; Reed & Bourne, 2000). *Diprotodon optatum*, the biggest mid to late Pleistocene marsupial recorded from the Naracoorte region is absent. This may reflect actual abundances of diprotodontids in the habitat near the cave, or alternatively, it could reflect a body size filtering effect due to the entrance size and susceptibility of diprotodontids to entrapment. The solution pipe entrance to The Ossuaries is narrow and branches into two narrower pipes about half-way up its length. The majority of *Zygomaturus* material is found only on the more proximal portions of the cone, with bones found on the fan representing a younger individual. The largest concentration of *Zygomaturus* material is approximately five metres from the entrance and may represent the remains of an adult animal that was wedged in the pipe with its bones entering the chamber following decomposition. As with the Fossil Chamber, The Ossuaries assemblage is dominated by saltatorial kangaroos, with cursorial species poorly represented and fossorial and scansorial species absent. This may be related to sample size, but is more likely to reflect the nature of the entrance and the susceptibility of kangaroos to entrapment (Reed, 2003).

Skeletal element representation and spatial patterning

The majority of skeletal element types are present in the sampled assemblage, suggesting the animals entered the cave as whole entities. The higher relative abundances for the larger elements of the skeleton, notably the limb elements (particularly the hindlimbs) and cranial elements is probably related to differential transport and more rapid burial of the smaller, compact elements. This pattern has been observed for recent surface assemblages from water-washed sediment cones at Naracoorte (Reed, 2003). Smaller elements would no doubt be recovered with excavation.

The spatial distribution of bones across the floor surface of The Upper Ossuaries is patchy and uneven, a pattern also observed for the Fossil Chamber (Reed, 2003). The concentration of bones on the distal portions of the fan and against the walls of the chamber is probably related to the higher potential for disturbance nearer the entrance and the initial position of deposition of carcasses. In the areas of the chamber that are clearly micro-channelled by water, there are fewer bones apparent and this may be related to burial of smaller elements and transport due to sediment movement induced by water run-off from the cone. Within the sampled area, bones display a preferred orientation. However, this is an area with no surface evidence of water flow. Taphonomic study of modern caves at Naracoorte has shown that the overall pattern of orientation can be overprinted by subsequent disturbance and trampling by trapped animals (Reed, 2003). Oliver (1989) also noted a similar situation for a pitfall cave in North America. Therefore, it is difficult to ascertain whether this represents the 'real' pattern indicating water transport or not.

Articulation and association

The presence of articulated sub-assemblies on the floor surface of the fan suggests animals survived the fall into the cave and perished away from the entrance, further supporting a pitfall accumulation analogous to the Fossil Chamber and other large pitfall deposits at Naracoorte (Wells *et al.*, 1984; Brown and Wells, 2000; Reed, 2003). With only one exception, all articulated and associated remains are found on the distal portions of the cone or in some 'sheltered' location such as against the cave walls or behind large rocks (Figure 4). This pattern was observed for modern Naracoorte pitfall deposits and the Fossil Chamber (Reed, 2003); suggesting the position of skeletons within a cave has a strong influence on the range of taphonomic processes they will be exposed to, particularly dispersal by trampling and water action. All bones remaining articulated in The Ossuaries are those elements that separate late in the disarticulation sequence for kangaroos (Reed, 2001). During disarticulation, joints with the strongest soft tissue and muscle structure generally remain articulated longer (Reed, 2001). In the kangaroo this includes the joints of the hind limb, vertebrae and in particular the caudal vertebrae (Reed, 2001). Those elements that disarticulate earlier in the sequence (ie. the cranial bones, forelimb, hand and foot bones) would be susceptible to dispersal and transport earlier. The Ossuaries data suggest that disarticulation is primarily influenced by the anatomy of the animal regardless of depositional environment.

Bone modification

Despite methodological and sampling restrictions, some general patterns of modification were detectable. The presence of spiral fracturing which is indicative of 'green' or 'fresh' bone fracturing suggests some modification occurred at or shortly after death. A lack of fracturing, or fracturing resembling that seen for 'fresh' bones, has been suggested as a characteristic of pitfall deposits by some authors (Andrews, 1990; Baird, 1991). Spiral fracturing could be attributable to trampling or the fall into the cave. The 'pile' of fractured kangaroo bones (largely from one individual) found near the base of the solution pipe may represent the remains of an individual that was killed by the fall into the cave and was subsequently trampled by other trapped animals as they fell into the cave. Termite use of bone as a food source is evidenced as gnawed tunnels both in the bones themselves and across the floor. Termites are known to prefer 'fresh' bone so this indicates some modification took place relatively early in the taphonomic history as described in Watson and Abbey (1986) and Reed (2003).

Scratch marks indicative of trampling and also impact fractures suggest additional modification occurred to bones lying on the floor surface following deposition. Similar damages have been noted for other pitfall caves (Oliver, 1989; Andrews, 1990). Longitudinal cracking of the outer surface of bones is probably related to within-cave processes, with variations in moisture content over time weakening the bone structure. There is no exfoliation associated with the cracking as is the case in sub-aerial weathering on the land surface (Behrensmeyer, 1978), suggesting the bones were not washed into the cave from outside. Therefore, all modification occurred after the animals entered the cave.

Conclusions

The taphonomic data presented suggest a taphonomic history that followed four broad stages.

1. Accumulation of remains and resulting modification produced by the mode of accumulation ie. pitfall entrapment, the most prevalent accumulating mode for large mammal bone deposits at Naracoorte (Reed & Bourne, 2000).

2. Decomposition and disarticulation of carcasses leading to secondary modification eg. termite modification, trampling, fracturing.

3. Dispersal, transport and incorporation of bones into the cave sediments eg. burial and/or dispersal of bones by hydraulic re-working of proximal cone sediments.

4. Modification occurring after burial in sediment eg. re-working and diagenesis. Stage 4 was largely unobserved during this study as no excavation of buried material was conducted; however, some evidence of re-exposure of bones following water flow was observed.

The composition of the large mammal fauna shares similarities with other deposits at Naracoorte including the Fossil Chamber, and is indicative of open woodland to sclerophyll forest with areas of shrub land, heathland and grassland. The age of the deposit is Pleistocene as indicated by the presence of extinct megafauna, but the precise age is unknown. The pattern of skeletal element representation and spatial patterning of bones suggests differential burial and/or hydraulic transport of small element types. The presence of articulated remains on the distal fan indicates some animals survived the fall into the cave, their remains accumulating away from the entrance where disturbance was limited. Due to the constraints of the project, sample size is limited. Further taphonomic investigation of The Ossuaries would increase sample size and allow more in-depth interpretation.

The Ossuaries deposits provided an important opportunity for investigation of a relatively undisturbed Pleistocene fossil site that is analogous taphonomically to other large pitfall deposits at Naracoorte and the wider South East region of South Australia. There are also taphonomic similarities with results published for other pitfall caves (see Oliver, 1989). The spatial distribution of the bones and the taphonomic features of the surface of this deposit could be studied virtually as they were found. Such an investigation was not possible for most of the Fossil Chamber deposit, as it had been the subject of decades of excavation prior to the commencement of this project. An *in situ* investigation of bones lying on the floor of The Ossuaries allowed analysis of a surface unit, providing further insight into interpreting the processes influential in the formation of deep, multi-layered deposits such as the Fossil Chamber.

The results of this study are not only interesting from a scientific perspective, but also for fossil site management. Useful information was collected with little impact to the fossil site and in the case of a deposit such as The Ossuaries this should be a priority. The scientific importance of The Ossuaries has been noted in the management plan for the Naracoorte Caves National Park in which it is categorised as a 'Reference' area of Victoria Fossil Cave (Department for Environment and Heritage, 2001). Reference areas are set aside in order to protect them from disturbance, with access only given for "research specifically related to the baseline functions of the cave" (Department for Environment and Heritage, 2001). Effective management of a site such as The Ossuaries requires more than simply categorising it and denying access. Park managers should have a thorough knowledge of the resources they are protecting. Prior to this project there was little or no information available to assist managers with decision-making regarding access to the site. This project has provided critical baseline data for management and will also aid in planning future research strategies for the park. Fossil deposits in caves are finite resources and the benefits of research and other activities should be carefully weighed against impact to the resource. Excavation of The Ossuaries deposits would undoubtedly reveal a greater body of data than this study has and it could certainly be done in such a way as to limit impacts to the site. Relatively undisturbed Pleistocene large mammal sites such as The Ossuaries are rare. In this particular case one could argue that the intrinsic values outweigh the scientific benefits that would be provided by excavation using current methods.

Acknowledgements

This work was undertaken during my PhD studies and I thank my supervisor Rod Wells for his advice during the project. Special thanks must go to Steven Bourne, manager of the park, for many hours assistance with mapping, photography and documentation of bone material. The author would also like to thank George Bradford, Andrew Hansford and Steven Brown for assistance with mapping and documenting bones for this project. Ken Grimes assisted with drafting of some figures.

References

ANDREWS, P. 1990: *Owls, Caves and Fossils*. University of Chicago Press, Chicago.

ARRIBAS, A. and PALMQVIST, P. 1998: Taphonomy and palaeoecology of an assemblage of large mammals: hyaenid activity in the lower Pleistocene site at Venta Micena (Orce, Guadix-Baza basin, Granada, Spain). *Geobios* **31**: 3-47.

BAIRD, R.F. 1991: The taphonomy of late Quaternary cave localities yielding vertebrate remains in Australia pp. 267-309 *in* Vickers-Rich, P., Monaghan, J. M., Baird, R. F. & Rich, T. H. (Eds) *Vertebrate palaeontology of Australasia.* Pioneer Design Studio, Lilydale.

BEHRENSMEYER, A.K. 1978: Taphonomic and ecologic information from bone weathering. *Paleobiology* **4**: 150-162.

BROWN, S.P. and WELLS, R.T. 2000: A middle Pleistocene vertebrate fossil assemblage from Cathedral Cave, Naracoorte, South Australia. *Trans. Roy. Soc. Sth. Aust.* **124**: 91-104.

DEPARTMENT FOR ENVIRONMENT AND HERITAGE 2001: *Naracoorte Caves National Park Management Plan.* Department for Environment & Heritage, Adelaide.

MURRAY, P.F. 1991: The Pleistocene megafauna of Australia. pp. 1071-1164 *in* P.V. RICH, J.M. MONAGHAN, R.F. BAIRD and T.H. RICH (eds), *Vertebrate Palaeontology of Australasia*. Pioneer Design Studio, Lilydale.

OLIVER, J.S. 1989: Analogues and site context: Bone damages from Shield Trap Cave (24CB91), Carbon County, Montana, U.S.A. pp. 73-98 *in* Bonnichsen, R. & Sorg, M.H. (Eds.) *Bone modification*. University of Maine Center for the study of the first Americans, Orono.

REED, E.H. 2001: Disarticulation of kangaroo skeletons in semi-arid Australia. *Aust. J. Zool.* **49**: 615-632.

REED, E.H. 2003: *Vertebrate taphonomy of large mammal bone deposits, Naracoorte Caves World Heritage Area*. Unpublished PhD thesis, the Flinders University of South Australia.

REED, E.H. and BOURNE, S.J. 2000: Pleistocene fossil vertebrate sites of the South East region of South Australia. *Trans. Roy. Soc. Sth. Aust.* **124**: 61-90.

WATSON, J.A.L. and ABBEY, H.M. 1986: The effects of termites (Isoptera) on bone: some archeological implications. *Sociobiology* **11**: 245-254.

WELLS, R.T., MORIARTY, K.C. and WILLIAMS, D.L.G. 1984: The fossil vertebrate deposits of Victoria Fossil Cave Naracoorte: an introduction to the geology and fauna. *Aust. Zool.* **21:** 305-333.

Abstracts of some recent papers in other karst journals

Sasowsky, I. D. and Dalton, C. T. 2005: Measurement of pH for field studies in karst areas
Journal of Cave and Karst Studies, **67(2)**, 127–132.

The determination of pH in karst waters is important for evaluating such chemical processes as cave growth, speleothem deposition, and overall water chemistry. Relatively small errors in pH readings can result in significant misinterpretations of the chemical processes taking place. For example, a pH error of 0.5 units would produce a correlative error in SIcalcite of 0.5. To ensure accuracy, pH must be measured in the field, but the conditions in karst settings make this hard to accomplish, and there is minimal published guidance available. Actions that help to improve data quality include: use of a good meter/electrode (accurate to 2 decimal places), careful preparation before field activities, cautious transport of instruments, frequent calibration, measurement in a beaker (not the water body), and allowance of time for equilibration. Instrumentation that allows measurement of very small samples, samples in wells, or continuous monitoring are available, but are more expensive and usually not as accurate. [An excellent reference for anyone using pH meters in karst, *Ed*]

Worthington S.R.H. 2005: Hydraulic and geological factors influencing conduit flow depth
Speleogenesis and Evolution of Karst Aquifers **3(1)**, www.speleogenesis.info, 19 pages, re-published from *Cave and Karst Science* 2004, **31(3)**, 123-134.
http://www.speleogenesis.info/pdf/SG7/SG7_artId3273.pdf

There has much been speculation as to whether cave formation should occur at, above, or below the water table, but a satisfactory explanation has been lacking until recently. The last 50 years has seen extensive mapping of caves both above and, more recently, below the water table. It is now becoming apparent that there are systematic differences in depth of flow between different areas and that conduit flow to depths >100m below the water table is not uncommon. Such deep flow is facilitated by the lower viscosity of geothermally heated water at depth. Analysis of data from caves shows that depth of flow is primarily a function of flow path length, stratal dip and fracture anisotropy. This explains why conduits form at shallow depths in platform settings such as in Kentucky, at moderate depths (10-100m) in folded strata such as in England and in the Appalachian Mountains, and at depths of several hundred metres in exceptional settings where there are very long flow paths.

Osborne R.A.L. 2005: Dating ancient caves and related palaeokarsts
Speleogenesis and Evolution of Karst Aquifers **3(1)**, www.speleogenesis.info, 15 pages, re-published from *Acta Carsologica* 2005, **34(1)**, 51-72.
http://genet-server.ibtm.tuwien.ac.at/speleo/art/SG7/SG7_artId3274.pdf

There are few cases of open caves that have been reliably dated to ages greater than 65 Ma. This does not mean that such caves are extremely rare, rather it is difficult to reliably establish that a cave, or palaeokarst related to a cave, is this old. Relative dating methods such as: regional stratigraphic, lithostratigraphic, biostratigraphic, relative climatic, relative isotopic, morphostratigraphic, and regional geomorphic are very useful. They suffer however from significant difficulties, and their results lack the impact of a crisp numerical date. While many of the methods used to date younger caves will not work over the required age range, some isotopic methods and palaeomagnetic methods have been applied with varying degrees of success. While finding something to date and having it dated is difficult enough, producing the date is rarely the end of the story. The difficult issue is not the date or relative correlation itself, but what the date or correlation means. Demonstrating that caves are ancient seems to rapidly become beset with the old adage that “extraordinary claims require extraordinary proof”. The presence of a well-dated or correlated sediment in a cave does not necessarily mean that the cave is that old or older. Perhaps the dated material was stored somewhere in the surrounding environment and deposited much more recently in the cave. A lava flow in a cave must be demonstrated conclusively to be a flow, not a dyke or a pile of weathered boulders washed into the cave. It must be conclusively shown that dated minerals were precipitated in the cave and not transported from elsewhere. There seems little doubt that in the future more ancient caves, or ancient sections of caves, will be identified and that as a result our perception of the age of caves in general will change.

Osborne R.A.L. 2003: Partitions, compartments and portals: Cave development in internally impounded karst masses
Speleogenesis and Evolution of Karst Aquifers **1(4)**, www.speleogenesis.info, 12 pages.
http://genet-server.ibtm.tuwien.ac.at/speleo/art/SG4/SG4_artId3256.pdf

Dykes and other vertical bodies can act as aquicludes within bodies of karst rock. These partitions separate isolated bodies of soluble rock called compartments. Speleogenetically each compartment will behave as a small impounded-karst until the partition becomes breached. Breaches through partitions, portals, allow water, air and biota including humans to pass between sections of caves that were originally isolated.

Helictite, (2006) **39(1):** 17-20

A small cave in a basalt dyke, Mt. Fyans, Victoria, Australia

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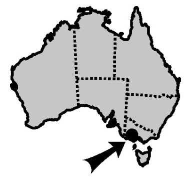

Abstract

A small but unusual cave has formed within a large dyke that intrudes a scoria cone at the summit of Mount Fyans, western Victoria. Draining of a still-liquid area, after most of the dyke had solidified, left an open cavity. Features within the cave mimic those of conventional lava caves, and suggest that the lava levels oscillated within the cave. Some smaller fingers of lava that intruded the scoria also have hollow, drained, cores.

Keywords: pseudokarst, volcanic caves, dyke.

The Volcano

Mount Fyans is a volcano within the Western District Province of western Victoria, Australia (Figure1. Price & others, 2003, Joyce & Webb, 2003). The age of the province dates back at least 5 million years, but Mount Fyans is a relatively youthful eruption, undated, but possibly less than 500,000 years old – judging by the well preserved “stony rises” (remnants of the original hummocky lava surface) and minimum soil development (Joyce, 1998; MacInnes, 1985). The volcano is a broad gently-sloping shield of basaltic lava with a low scoria cone at the summit and possibly once had a small crater – though an extensive quarry in the scoria makes the original form difficult to deduce!

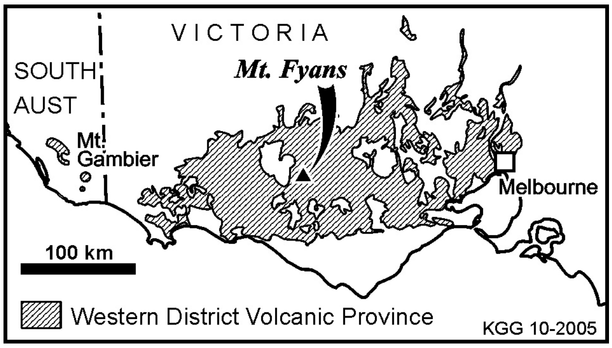

Figure 1: Location of Mt Fyans within the Western District Volcanic Province of Victoria, Australia.

The scoria at the summit has a thin cap of basaltic lava, and ropy patterns on the underside of this are well-exposed on the southern margin of the quarry. The loose scoria has been intruded by two large basalt dykes up to 12 m across (which would have fed the lava cap) and a number of smaller pipe or finger-like basalt bodies, some of which have been partly drained to leave small cavities. Figure 2 is a view of the quarry and the main

Figure 2: View of Mt. Fyans Quarry, looking north towards the large dyke. C = cave, P = pipe, W = witch’s hats.

dyke. An inset map in Figure 3 shows the location of the various features described here. The quarry operations have worked around the large dykes, but damaged the smaller intrusive features (which is how we know they are hollow!). Minor quarrying activity appears to be continuing.

Mount Fyans Cave, 3H-105

A small horizontal cave occurs within the largest dyke. It lies close to the west edge of the dyke and runs parallel to the dyke wall (Figure 3). Entry is via a small hole broken into the roof by the quarry operation. The cave is about 17 m long and generally less than one metre high. The roof and walls have numerous lava drips (Figure 4). The floor is a horizontal ropy pahoehoe surface which rises gently towards the northern end – but the ropy structures suggest a final flow direction from south to north. The drainage points for the lava are not obvious; but there is a very small hole in the floor at the southern end. Both roof and floor have common patches of pale-cream coatings over the basalt – possibly fumerolic alteration? There are well-developed rolled benches (10 cm diameter) along the edges of the floor (Figure 5). These suggest that the lava rose and fell within the cavity at least once after its initial draining. One small hole in the ceiling, near the entrance, opened into broken scoriaceous material.

Related features

As well as the cave, the main dyke also has a drained hollow vertical pipe at its southern end – this has been broken into by the quarry operation and we found the upper part lying on its side 20 m to the NE (see inset map, Figure 3). This pipe had spatter and dribble patterns on its inside walls (Figure 6). Elsewhere in the quarry there are intrusive pipes and smaller fingers of basalt that have pushed up through the loose scoria. Several of these have drained back after the outside had solidified so as to leave a hollow core, some with lava drips. Probably the most distinctive are conical “witch’s hat” structures (Figure 7).

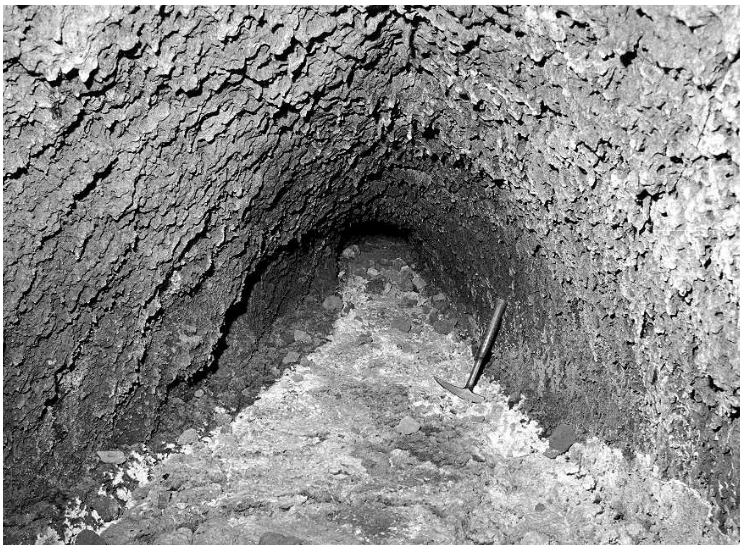

Figure 4: View looking north from the cave entrance.

Figure 5: Looking south from section X4. Note the small rolled bench against the foot of the wall and the pale patches on the wall. Notebook is 18 cm long.

Figure 6: Spatter and drips in a vertical pipe.

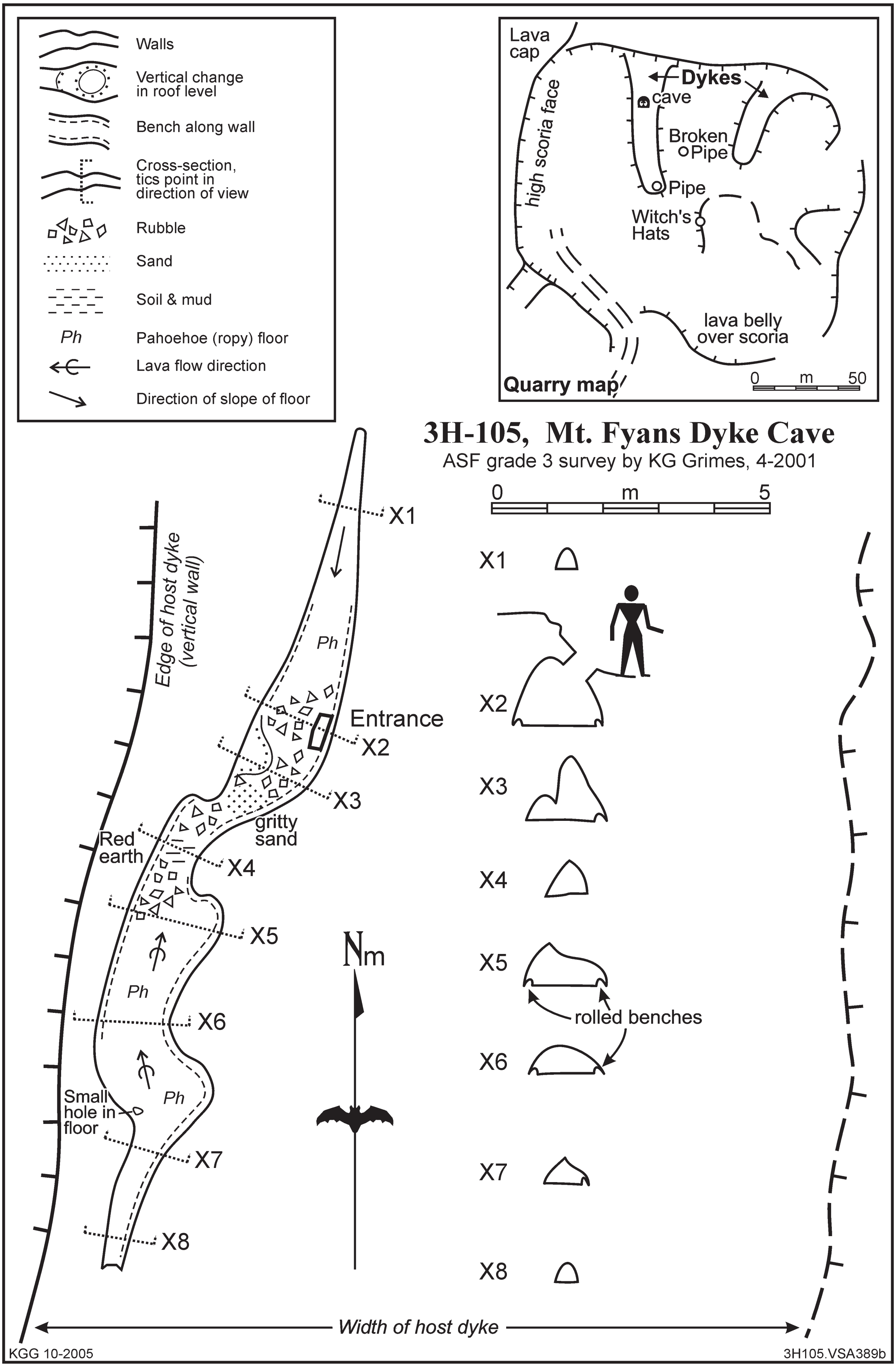

Figure 3: Map of Mt Fyans Cave, 3H-105. The inset map shows the volcanic structures within the quarry.

Mt. Fyans dyke cave

Figure 7: A conical "witch's hat" formed by a finger of lava that intruded the loose scoria, then drained back to leave a hollow core. Stereopair.

The area has other features of both geological and historic interest and warrants preservation. For example, the underside of the lava flow capping the scoria is exposed in several places and shows a wrinkled "belly" with fragments of the loose scoria stuck to it. The surrounding "stony rises" have some particularly elegant and distinctive dry-stone walls that were constructed by early European settlers.

No other volcanic caves formed in dykes have been reported in Australia – a cave described by Hale & Spry (1964) in dolerite in Tasmania was produced by solution of secondary minerals formed in an alteration zone. Elsewhere in the world, a larger, but apparentlysimilar, dyke cave has been reported from the Canary Islands (Socorro & Martin, 1992).

Genesis

The dykes and other bodies would have been intruded into the loose scoria towards the end of the eruption, where they would have cooled and partly solidified. Then, as pressure was lost those liquid parts that were still connected to the main feeder channels would have drained a little way back to leave the cavities. There may have been some oscillation in lava levels to form the rolled benches in the dyke cave.

Acknowledgements

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References

Hale, G.E., & Spry, A., 1964: A cave in dolerite at Wayatinah, Tasmania. *Journal, Geol. Soc. Aust.* **11(2):** 213-216.

Joyce, E.B., 1998: A new regolith landform map of the western Victorian volcanic plains, Victoria, Australia. *in* Taylor, G. & Pain, C., [eds] *Regolith '98: New Approaches to an Old Continent*. Cooperative Research Centre for Landscape Evolution & Mineral Exploration, Perth. pp. 117-126.

Joyce, E.B., & Webb, J.A. (co-ordinators), 2003: Geomorphology (section 18.10.1, Volcanic Plains). *in* Birch, W.D., [ed] *Geology of Victoria*. Geological Society of Australia, Special Publication, **23**. 553-554.

MacInnes, K.J., 1985: *The Newer Volcanics of the Mt. Hamilton region in Western Victoria*. Unpublished B.Sc. (Hons) thesis, School of Geology, University of Melbourne.

Price, R.C., Nicholls, I.A., & Grey, C.M., 2003: Cainozoic igneous activity (section 12.4.6, Western District Province). *in* Birch, W.D., [ed] *Geology of Victoria*, Geological Society of Australia, Special Publication, **23**. 366-370.

Socorro, JS., & Martin, JL., 1992: The Fajanita Cave (La Palma, Canary Islands): A volcanic cavity originated by partial draining of a dyke, *in* Rea, GT., [ed] *6th International Symposium on Volcanospeleology*. National Speleological Society, Huntsville. pp 177-184 [*in Spanish*].

Ecology and hydrology of a threatened groundwater-dependent ecosystem: the Jewel Cave karst system in Western Australia

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Extended Abstract

Groundwater is a significant component of the world's water balance and accounts for >90 % of usable freshwater. Around the world groundwater is an important source of water for major cities, towns, industries, agriculture and forestry. Groundwater plays a role in the ecological processes and 'health' of many surface ecosystems, and is the critical habitat for subterranean aquatic animals (stygofauna). Over-abstraction or contamination of groundwater resources may imperil the survival of stygofauna and other groundwater-dependent ecosystems (GDEs). In two karst areas in Western Australia (Yanchep and Leeuwin-Naturaliste Ridge), rich stygofauna communities occur in cave waters containing submerged tree roots. These aquatic root mat communities were listed as critically endangered because of declining groundwater levels, presumably caused by lower rainfall, groundwater abstraction, and/or forest plantations. Investigation of the hydrology and ecology of the cave systems was considered essential for the conservation and recovery of these threatened ecological communities (TECs). This thesis investigated the hydrology and ecology of one of the TECs, located in the Jewel Cave karst system in the Leeuwin-Naturaliste Ridge. A multi-disciplinary approach was used to explore aspects pertinent to the hydrology and ecology of the groundwater system.

Thermoluminescence dating of the limestone suggested that development of the karst system dates from the Early Pleistocene and that caves have been available for colonisation by groundwater fauna since that time. Speleogenesis of the watertable maze caves occurred in a flank margin setting during earlier periods of wetter climate and/or elevated base levels. Field mapping and leveling were used to determine hydrologic relationships between caves and the boundaries of the karst aquifer. Monitoring of groundwater levels was undertaken to characterize the conditions of recharge, storage, flow and discharge. A hydrogeologic model of the karst system was developed.

The groundwater hydrograph for the last 50 years was reconstructed from old photographs and records whilst radiometric dating and leveling of stratigraphic horizons enabled reconstruction of a history of watertable fluctuations spanning the Holocene to Late Pleistocene. The watertable fluctuations over the previous 50 years did not exceed the range of fluctuations experienced in the Quaternary history, including a period 11,000 to 13,000 years ago when the watertable was lower than the present level.

The recent groundwater decline in Jewel Cave was not reflected in the annual rainfall trend, which was above average during the period (1976 to 1988) when the major drop in water levels occurred. Groundwater abstraction and tree plantations in nearby catchments have not contributed to the groundwater decline as previously suggested. The period of major watertable decline coincided with a substantial reduction in fire frequency within the karst catchment. The resultant increase in understorey vegetation and ground litter may have contributed to a reduction in groundwater recharge, through increased evapotranspiration and interception of rainfall. To better understand the relationships between rainfall, vegetation and fire and their effects on groundwater recharge, an experiment is proposed that involves a prescribed burn of the cave catchment with before-after monitoring of rainfall, leaf-area, ground litter, soil moisture, vadose infiltration and groundwater levels.

Molecular genetic techniques (allozyme electrophoresis and mitochondrial DNA) were used to assess the species and population boundaries of two genera and species of cave dwelling Amphipoda. Populations of both species were largely panmictic which was consistent with the hydrogeologic model. The molecular data supported the conclusion that both species of amphipod have survived lower watertable levels experienced in the caves during the Late Pleistocene. A mechanism for the colonization and isolation of populations in caves is proposed.

Multi Dimensional Scaling was used to investigate patterns in groundwater biodiversity including species diversity, species assemblages, habitat associations and biogeography. Faunal patterns were related to abiotic environmental parameters. Investigation of hydrochemistry and water quality characterized the ecological water requirements (EWR) of the TEC and established a baseline against which to evaluate potential impacts such as groundwater pollution.

The conservation status of the listed TEC was significantly improved by increasing the number of known occurrences and distribution range of the community (from 10 m^2 to > 2 x 10^6 m^2), and by showing that earlier perceived threatening processes (rainfall decline, groundwater pumping, tree plantations) were either ameliorated or inoperative within this catchment. The GDE in the Jewel Cave karst system may not have been endangered by the major phase of watertable decline experienced 1975-1987, or by the relatively stable level experienced up until 2000. However, if the present trend of declining rainfall in southwest Western Australia continues, and the cave watertable declines > 0.5 m below the present level, then the GDE may become more vulnerable to extinction.

The occurrence and distribution of aquatic root mat communities and related groundwater fauna in other karst catchments in the Leeuwin-Naturaliste Ridge is substantially greater than previously thought, however some of these are predicted to be threatened by groundwater pumping and pollution associated with increasing urban and rural developments. The taxonomy of most stygofauna taxa and the distribution of root mat communities is too poorly known to enable proper assessment of their conservation requirements. A regional-scale survey of stygofauna in southwest Western Australia is required to address this problem. In the interim, conservation actions for the listed TECs need to be focused at the most appropriate spatial scale, which is the karst drainage system and catchment area. Conservation of GDEs in Western Australia will benefit from understanding and integration with abiotic groundwater system processes, especially hydrogeologic and geomorphic processes.

Cave Aragonites of New South Wales

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Extended Abstract

Aragonite is a minor secondary mineral in many limestone caves throughout the world. It has been claimed that it is the second-most common cave mineral after calcite (Hill & Forti 1997). Aragonite occurs as a secondary mineral in the vadose zone of some caves in New South Wales. Aragonite is unstable in fresh water and usually reverts to calcite, but it is actively depositing in some NSW caves.

A review of current literature on the cave aragonite problem showed that chemical inhibitors to calcite deposition assist in the precipitation of calcium carbonate as aragonite instead of calcite. Chemical inhibitors work by physically blocking the positions on the calcite crystal lattice which would have otherwise allowed calcite to develop into a larger crystal. Often an inhibitor for calcite has no effect on the aragonite crystal lattice, thus aragonite may deposit where calcite deposition is inhibited.

Another association with aragonite in some NSW caves appears to be high evaporation rates allowing calcite, aragonite and vaterite to deposit. Vaterite is another unstable polymorph of calcium carbonate, which reverts to aragonite and calcite over time. Vaterite, aragonite and calcite were found together in cave sediments in areas with low humidity in Wollondilly Cave, Wombeyan.

Several factors were found to be associated with the deposition of aragonite instead of calcite speleothems in NSW caves. They included the presence of ferroan dolomite, calcite-inhibitors (in particular ions of magnesium, manganese, phosphate, sulfate and heavy metals), and both air movement and humidity.

Aragonite deposits in several NSW caves were examined to determine whether the material is or is not aragonite. Substrates to the aragonite were examined, as was the nature of the bedrock. The work concentrated on Contact Cave and Wiburds Lake Cave at Jenolan, Sigma Cave, Wollondilly Cave and Cow Pit at Wombeyan and Piano Cave and Deep Hole (Cave) at Walli. Comparisons are made with other caves. The study sites are all located in Palaeozoic rocks within the Lachlan Fold Belt tectonic region. Two of the sites, Jenolan and Wombeyan, are close to the western edge of the Sydney Basin. The third site, Walli, is close to a warm spring. The physical, climatic, chemical and mineralogical influences on calcium carbonate deposition in the caves were investigated. Where cave maps were unavailable, they were prepared on site as part of the study.

At Jenolan Caves, Contact Cave and Wiburds Lake Cave were examined in detail, and other sites were compared with these. Contact Cave is located near the eastern boundary of the Late Silurian Jenolan Caves Limestone, in an area of steeply bedded and partially dolomitised limestone very close to its eastern boundary with the Jenolan volcanics. Aragonite in Contact Cave is precipitated on the ceiling as anthodites, helictites and coatings. The substrate for the aragonite is porous, altered, dolomitised limestone which is wedged apart by aragonite crystals. Aragonite deposition in Contact Cave is associated with a concentration of calcite-inhibiting

ions, mainly minerals containing ions of magnesium, manganese and to a lesser extent, phosphates. Aragonite, dolomite and rhodochrosite are being actively deposited where these minerals are present. Calcite is being deposited where minerals containing magnesium ions are not present. The inhibitors appear to be mobilised by fresh water entering the cave as seepage along the steep bedding and jointing. During winter, cold dry air pooling in the lower part of the cave may concentrate minerals by evaporation and is most likely associated with the "popcorn line" seen in the cave.

Wiburds Lake Cave is located near the western boundary of the Jenolan Caves Limestone, very close to its faulted western boundary with Ordovician cherts. Aragonite at Wiburds Lake Cave is associated with weathered pyritic dolomitised limestone, an altered, dolomitised mafic dyke in a fault shear zone, and also with bat guano minerals. Aragonite speleothems include a spathite, cavity fills, vughs, surface coatings and anthodites. Calcite occurs in small quantities at the aragonite sites. Calcite-inhibitors associated with aragonite include ions of magnesium, manganese and sulfate. Phosphate is significant in some areas. Low humidity is significant in two areas.

Other sites briefly examined at Jenolan include Glass Cave, Mammoth Cave, Spider Cave and the show caves. Aragonite in Glass Cave may be associated with both weathering of dolomitised limestone (resulting in anthodites) and with bat guano (resulting in small cryptic forms). Aragonite in the show caves, and possibly in Mammoth and Spider Cave is associated with weathering of pyritic dolomitised limestone.

Wombeyan Caves are developed in saccharoidal marble, metamorphosed Silurian Wombeyan Caves Limestone. Three sites were examined in detail at Wombeyan Caves: Sigma Cave, Wollondilly Cave and Cow Pit (a steep sided doline with a dark zone). Sigma Cave is close to the south east boundary of the Wombeyan marble, close to its unconformable boundary with effusive hypersthene porphyry and intrusive gabbro, and contains some unmarmorised limestone. Aragonite occurs mainly in a canyon at the southern extremity of the cave and in some other sites. In Sigma Cave, aragonite deposition is mainly associated with minerals containing calcite-inhibitors, as well as some air movement in the cave. Calcite-inhibitors at Sigma Cave include ions of magnesium, manganese, sulfate and phosphate (possibly bat origin), partly from bedrock veins and partly from breakdown of minerals in sediments sourced from mafic igneous rocks. Substrates to aragonite speleothems include corroded speleothem, bedrock, ochres, mud and clastics. There is air movement at times in the canyon, it has higher levels of CO_2 than other parts of the cave and humidity is high. Air movement may assist in the rapid exchange of CO_2 at speleothem surfaces.

Wollondilly Cave is located in the eastern part of the Wombeyan marble. At Wollondilly Cave, anthodites and helictites were seen in an inaccessible area of the cave. Paramorphs of calcite after aragonite were found at Jacobs Ladder and the Pantheon. Aragonite at Star Chamber is associated with huntite and hydromagnesite. In The Loft, speleothem corrosion is characteristic of bat guano deposits. Aragonite, vaterite and calcite were detected in surface coatings in this area. Air movement between the two entrances of this cave has a drying effect which may serve to concentrate minerals by evaporation in some parts of the cave. The presence of vaterite and aragonite in fluffy coatings infers that vaterite may be inverting to aragonite. Calcite-inhibitors in the sediments include ions of phosphate, sulphate, magnesium and manganese. Cave sediment includes material sourced from detrital mafic rocks.

Cow Pit is located near Wollondilly Cave, and cave W43 is located near the northern boundary of the Wombeyan marble. At Cow Pit, paramorphs of calcite after aragonite occur in the walls as spheroids with minor huntite. Aragonite is a minor mineral in white wall coatings and red phosphatic sediments with minor hydromagnesite and huntite. At cave W43, aragonite was detected in the base of a coralloid speleothem. Paramorphs of calcite after aragonite were observed in the same speleothem. Dolomite in the bedrock may be a source of magnesium-rich minerals at cave W43.

Walli Caves are developed in the massive Belubula Limestone of the Ordovician Cliefden Caves Limestone Subgroup (Barrajin Group). At the caves, the limestone is steeply bedded and contains chert nodules with dolomite inclusions. Gypsum and barite occur in veins in the limestone. At Walli Caves, Piano Cave and Deep Hole (Deep Cave) were examined for aragonite. Gypsum occurs both as a surface coating and as fine selenite needles on chert nodules in areas with low humidity in the caves. Aragonite at Walli caves was associated with vein minerals and coatings containing calcite-inhibitors and, in some areas, low humidity. Calcite-inhibitors include sulfate (mostly as gypsum), magnesium, manganese and barium.

Other caves which contain aragonite are mentioned. Although these were not major study sites, sufficient information is available on them to make a preliminary assessment as to why they may contain aragonite. These other caves include Flying Fortress Cave and the B4-5 Extension at Bungonia near Goulburn, and Wyanbene Cave south of Braidwood. Aragonite deposition at Bungonia has some similarities with that at Jenolan in that dolomitisation of the bedrock has occurred, and the bedding or jointing is steep allowing seepage of water into the cave, with possible oxidation of pyrite. Aragonite is also associated with a mafic dyke. Wyanbene cave features some bedrock dolomitisation, and also features low grade ore bodies which include several known calcite-inhibitors. Aragonite appears to be associated with both features. Finally, brief notes are made of aragonite-like speleothems at Colong Caves (between Jenolan and Wombeyan), a cave at Jaunter (west of Jenolan) and Wellington (240 km NW of Sydney).

Karst and Landscape Evolution in parts of the Gambier Karst Province, Southeast South Australia and Western Victoria, Australia

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A PhD thesis submitted to La Trobe University, Bundoora, Victoria. October 2005

Abstract

Despite interest in the palaeontology, groundwater and tourist caves of the karst of the western Otway Basin, limited investigation of the karst landscape development and its processes has occurred. This study documents the overall features of the Gambier Karst Province and delineates its boundaries. The province comprises extensive areas where cave and karst development is limited, interspersed with areas of atypical karst development. Two such karst sub-regions are distinguished in the karst in the Tertiary limestones (Naracoorte and Glenelg River). These sub-regions contain karst assemblages with distinctive combinations of karst landform and process.

At Naracoorte the caves are concentrated and range from simple single passages to complex multi-level caves. The cave passages trend northwest/southeast and contain a range of fossiliferous clastic sediments and dated speleothems. Cave walls retain evidence of solutional features. Dolines, uvalas and blind valleys characterise the surface karst. In the Glenelg area, despite similarities such as the orientation of cave passages, the caves are smaller, less complex and more strongly associated with the main surface drainage—the Glenelg River.

The syngenetic aeolianite karst is hosted within a different lithology; the Pleistocene dunes and their interdune swales that dominate the surface karst landscape. These shallow, predominantly horizontal caves vary from large maze type systems to short single caves, and have formed under a hardened cap rock in the dune. It is widespread across the province where favourable conditions occur.

This study includes the development of a model for the landscape history of the karst landscapes of Naracoorte and Glenelg River areas of the western Otway Basin since the Pliocene. This model integrates the cave morphology and processes with groundwater and long term landscape data. This extends the current knowledge of the Gambier Karst Province and potentially contributes to more effective management of the karst of the province.

Another Abstract

Osborne R.A.L. 2004. The troubles with cupolas

Speleogenesis and Evolution of Karst Aquifers **2 (2)**, www.speleogenesis.info, 17 pages, re-published from: *Acta Carsologica*, 2004, **33 (2)**, 9-36.
http://genet-server.ibtm.tuwien.ac.at/speleo/art/Sg6/SG6_artId3269.pdf

Cupolas are dome-shaped solution cavities that occur in karst caves, and have been described in both limestone and gypsum karst. While there has been considerable discussion in the literature concerning the likely origin and significance of these features, there has been little in the way of detailed description of the features themselves and little attention has been given to the definition of the term. Consequently, there are a number of troubles with cupolas: - What is a cupola? Where do cupolas occur? What are cupolas like? Do cupolas occur with particular types of speleogens? Are Cupolas features of ceilings or features intersected by ceilings? How do cupolas form? But how can these troubles be resolved? Tentative answers are given here to many of these questions but a great deal of basic field observation and theoretical work is required to solve them. The most important step would be more field observation and measurement of cupolas and of the particular suite of speleogens that occur with them. The troubles with cupolas can be solved and in the process we will come to understand a great deal more about the unusual caves in which they occur.

INQUA meeting near Cape Range. August 2006

The International Union for Quaternary Research (INQUA) is holding an International Field Meeting on Sub-aerially exposed continental shelves since the Middle Pleistocene climatic transition, from August 13-18, 2006 at Exmouth and Ningaloo Reef, Western Australia. One of the sponsors is the IGCP 513 Global study of karst aquifers and water resources and there will be a session on karst deposits including coral reefs and speleothems. For details see the website http://www.inqua.curtin.edu.au/.

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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.

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