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Karst Geology of Wellington Caves: a review

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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-

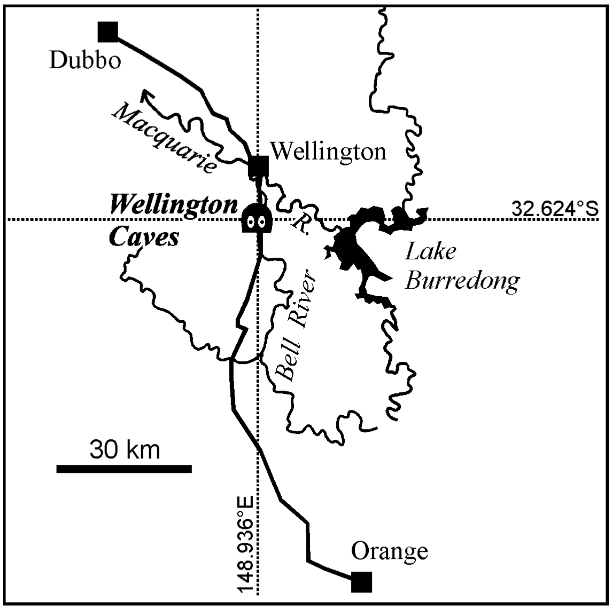

Figure 1: Location of Wellington Caves.

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

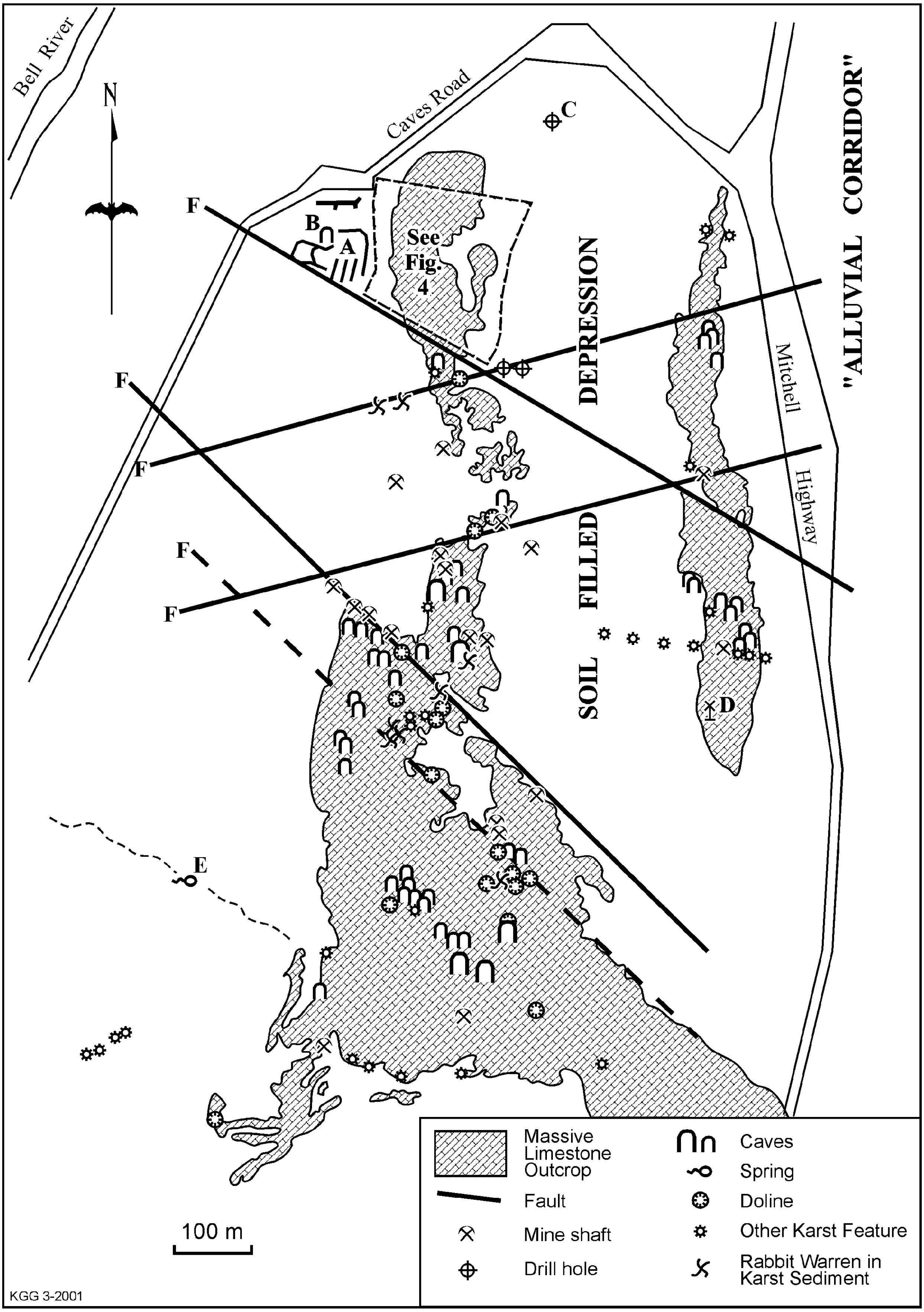

Figure 2: Simplified Karst Geology Map. Based on field mapping by R.A.L. Osborne and B. Scott, in 1999 and 2000. Initial cartography by B. Scott.
A: Caravan Park, **B:** Anticline Cave, **C:** Deepest drill-hole, **D:** Well in eastern limestone ridge,
E: Spring in thinly-bedded limestone, **F:** Faults.

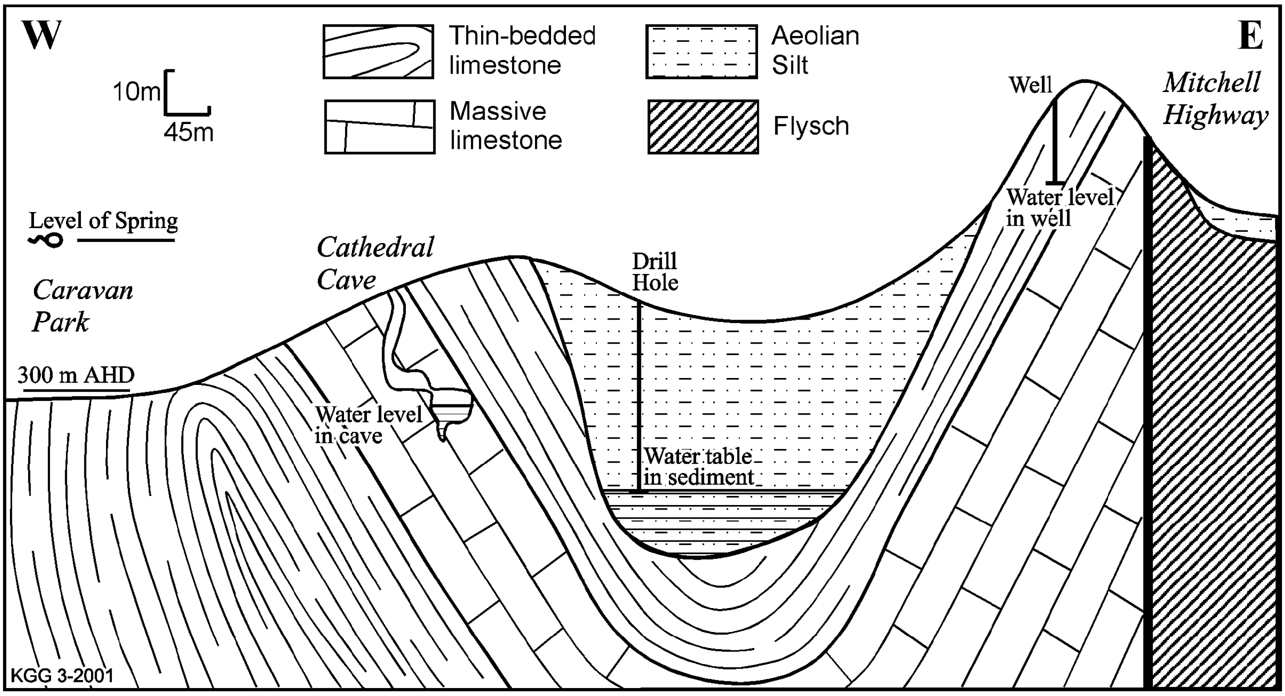

Figure 3: Diagrammatic cross-section, looking north, showing simplified structure and standing water levels. Vertical exaggeration 4.5 x

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**		

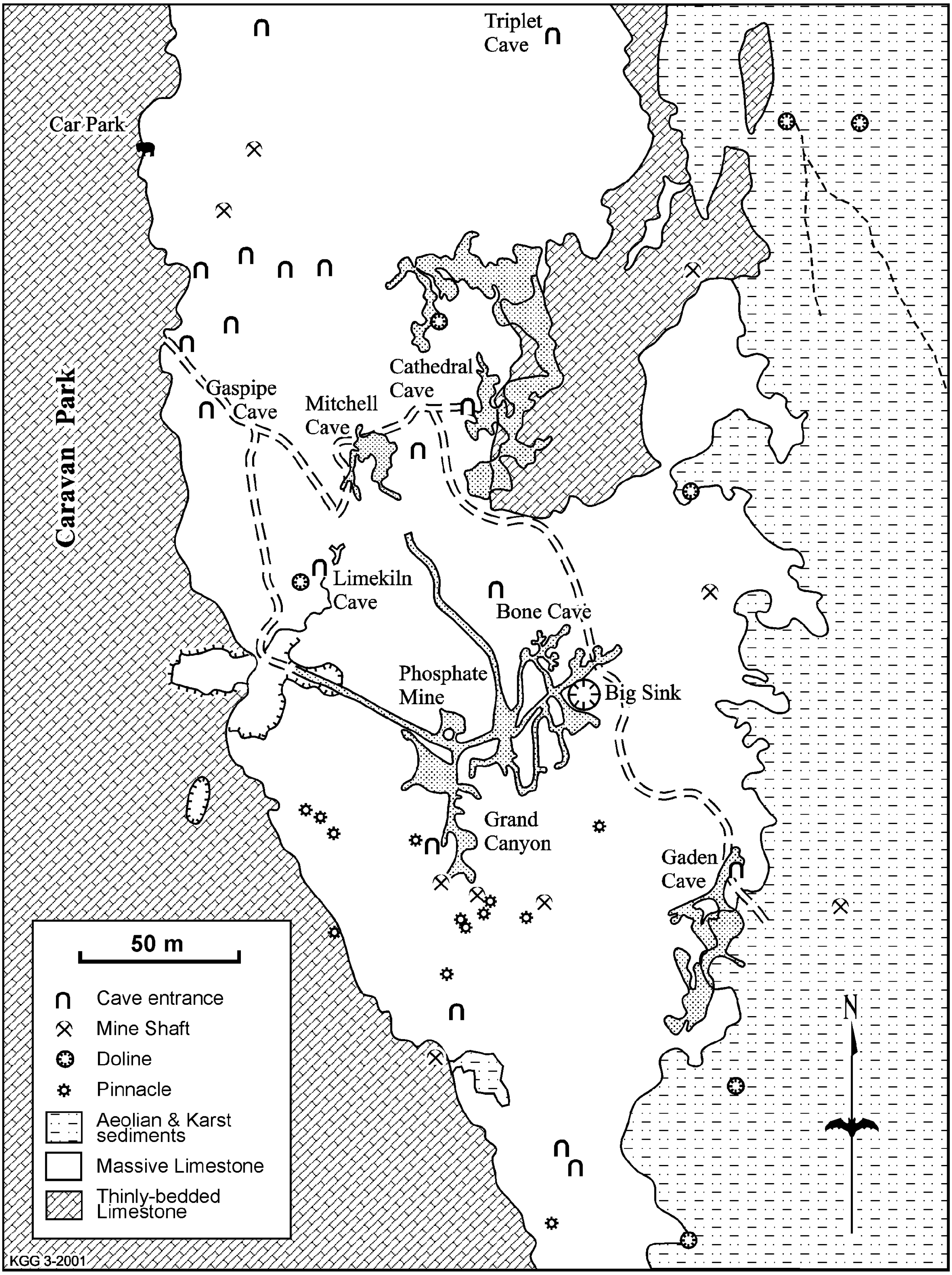

Figure 4: Detail of Show Caves Area. Based on field mapping by R.A.L. Osborne and B. Scott in 1999 and 2000. Cave plans modified from Frank (1971). Initial cartography by B. Scott.
The boundary between the massive and thinly bedded limestone dips to the east. Consequently, thinly bedded limestone crops 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:

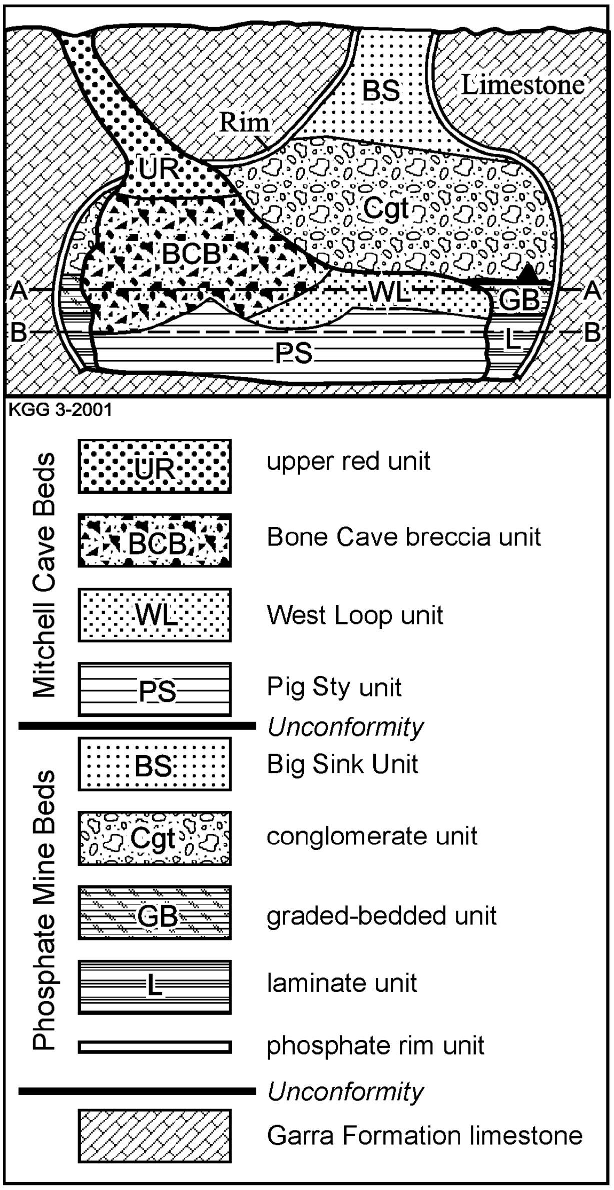

Figure 5: Rock relationship diagram for eastern part of the Phosphate Mine. A & B are roof and floor of mine.

"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.

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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.