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

Introduction

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

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

The abstracts have been arranged in alphabetical order by author.

Palaeontology of Wellington Caves

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Wellington Caves Fossil Studies Centre

I. Devonian fossils

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

II. Quaternary mammal fossils.

A. Historical collections

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

   Jameson – Edinburgh

   Clift - Royal College of Surgeons, London

   Cuvier -Paris (died 13 May 1832)

   Pentland – Paris

   Note: Lyle (1833) summarised the significance of the WC fossils

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

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

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

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

6. The phosphate mine (1913-1918)

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

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

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

5. Dehm and Schroeder 1939 - first attention to microfossils

6. The American era -

   Marcus (1952-54) collections reside at U. Cal.

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

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

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

9. Establishment of the Wellington Caves Fossil Studies Centre 1997

B. The fossils

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

2. There are two cohorts:

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

   b. Megafauna.

   c. Usually mixed; sometimes separate.

3. Probable sources:

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

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

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

C. Age

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

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

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

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

III. Current work

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

Interactive Marble Tombstone Deterioration Model

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

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

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

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

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

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

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

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

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Radon – Is there a need for badge programs?

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

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

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

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

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

Presenting World Heritage Values to the Visitor.

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

Condensation Corrosion in Tourist Caves, Case Study: Jenolan Caves

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

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

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

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

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

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

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

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

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

Palaeoclimatic Information from Biominerals in Odyssey Cave, Bungonia

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

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

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

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

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

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

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

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

Pottiaceae, Bryaceae and Fissidentaceae. The liverworts are composed mostly of thallose liverworts from the order Marchantiales.

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

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

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

Karst of Christmas Island (Indian Ocean)

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

The Caves

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

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

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

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

Karst Hydrology

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

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

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The Prominence Of Jenolan

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Abstract withheld.

What We Do Inside Caves

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

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

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

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

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

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

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

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

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

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

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

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

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

Calculations of SIc indicate that values exceeded 0.5 for late October to May, so precipitation of calcite was likely to be occurring for this time period, probably in the form of fine crystals in the water column. The waters are also supersaturated for the rest of the year, but because SIc < 0.5, precipitation is unlikely. As Pco_2 drops SIc increases. Both are related to surface water temperature, as temperatures over 15^0 C correspond with SIc = 0.5 and log Pco_2 = -2.5. As Pco_2 drops, so does the concentration of H_2CO_3 and this favours the precipitation of calcite according to reaction (2):

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

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

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

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

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New Concepts in Cave Atmosphere Studies

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

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

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

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

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

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

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

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Geology of the Wellington karst area

Armstrong Osborne

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

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

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

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

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

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

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

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

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

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

Notes

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

Karstic Groundwater Ecosystems In The Murray Darling And Otway Groundwater Basins

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

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

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

Diversity at Depth: The NSW Cave Invertebrate Story

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

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

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

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

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

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

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Origin of cenotes near Mt Gambier, South Australia

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

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

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

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

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

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Models of Speleogenesis: A Review

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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