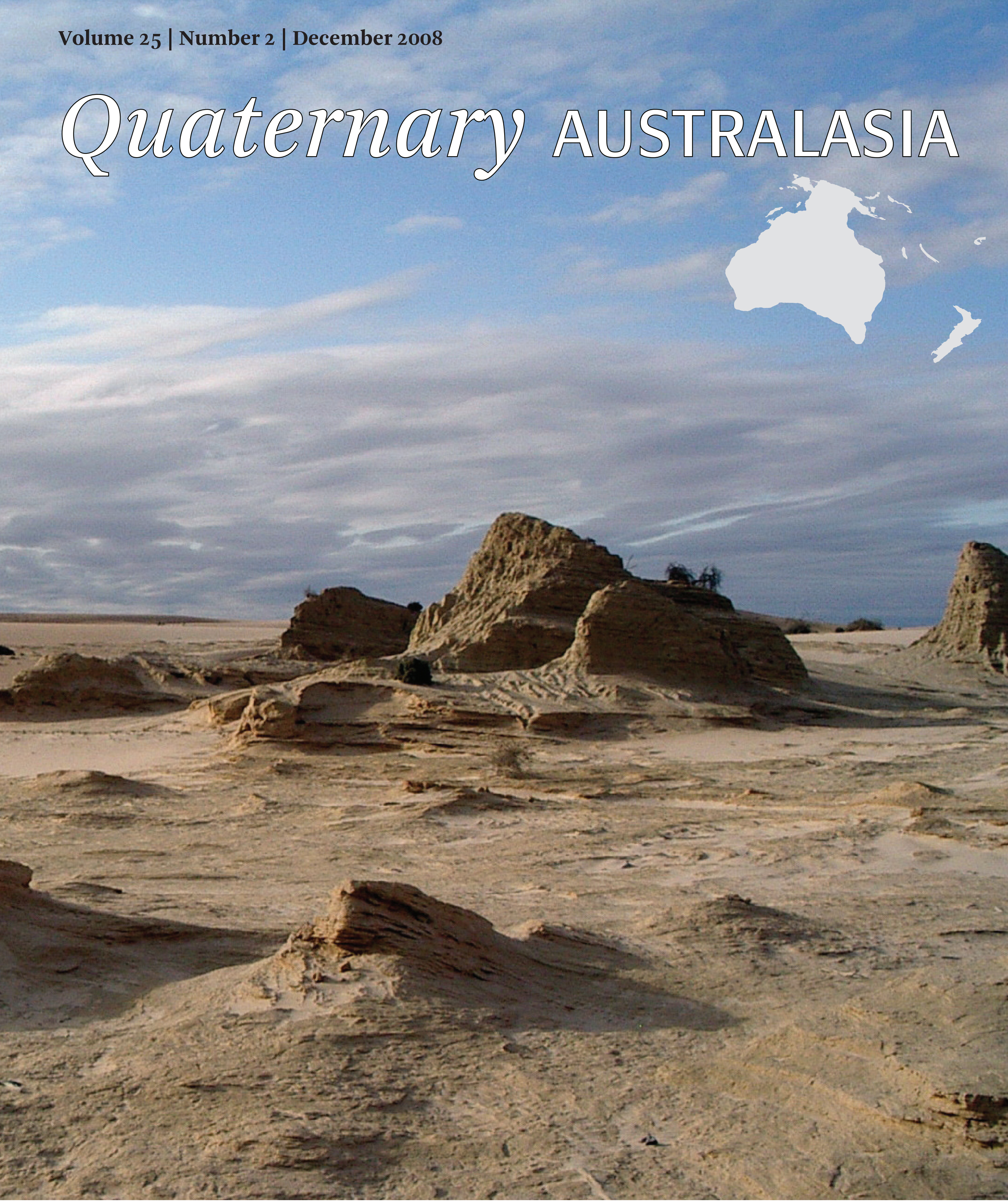
Volume 25 | Number 2 | December 2008

Quaternary AUSTRALASIA



- PINNING DOWN THE PITFALL IN THE NARACOORTE CAVES
- INVESTIGATING NEW APPLICATIONS FOR PALAEOBOTANY
- SPELEOTHEM RESEARCH UNLOCKING RAINFALL ARCHIVES
- AUSTRALASIAN INTIMATE MEETING
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Volume 25 | Number 2 | December 2008 | ISSN 0811-0433

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COVER: Erosional remnants on the Lake Mungo Lunette. Severe erosion of the lunette has exposed layers of sediment providing an unparalleled insight into the lake level history and its early occupation by people. Photo: Tim Barrows.

BELOW: Dust storm approaching, SW Queensland 22nd September 2008. This photograph was taken approx. 40 km from Birdsville, where wind gust speeds reached 85 km per hour. As the front hit, visibility was reduced to less than about 10 metres, and sand was transported at least 1.5 m above the ground onto the front of our car. This region is a significant dust source area within Australia, and the importance of dust transport processes in Australia is well documented (e.g. Hesse and McTainsh, QSR 22:2007-2035, 2003). Photo: Kathryn Amos.

Editorial

Dear Fellow Quaternarists,

It has been another busy year for Quaternary science in the Australasian region. This issue of *Quaternary Australasia* goes to press shortly after the AQUA meeting in Victor Harbour which highlighted the extensive research being undertaken in our region, particularly by students. It was wonderful to be attending a meeting right on the doorstep of the Coorong, a fascinating Quaternary site and an area subject to substantial political attention. Despite the distinctly Australian focus of the meeting, it was good to see research also being presented from sites as far afield as Indonesia, China and Europe.

In this issue, two research papers examine aspects of Quaternary research in Australia. Liz Reed investigates cave sedimentation and its implications for palaeontological assemblages in the Naracoorte Caves, a World Heritage Site. Mark Scarr and colleagues delve into the frequency and variation of stomata within several commonly occurring plant species to assess the utility of these characteristics as palaeoenvironmental proxies. I would like to thank the reviewers of these manuscripts for their constructive and timely reviews.

The Quaternary research community has indeed been busy this year. In addition to the recent AQUA meeting, many Quaternary scientists, particularly those based in New Zealand, attended the INTIMATE meeting in Onekaka to discuss various palaeoenvironmental archives and ponder the glacial landscapes of the South Island. Undergraduate Quaternarists-in-training got their hands dirty attending the archaeology field school in northern Queensland, organised by Flinders University. Finally, Pauline Treble and Janece McDonald provide a case in point for increased interaction between Quaternary science and policy bodies with their Land and Water Australia-sponsored research on rainfall archives.

This issue has a distinctly Australian focus, and I would like to strongly encourage New Zealand Quaternarists to consider more actively contributing to future issues of *Quaternary Australasia*.

Best wishes

Kathryn Fitzsimmons

President's Pen

Dear Quaternarists,

I have just returned from the recent AQUA biennial conference in Victor Harbor, South Australia, and I must say it was a highly successful meeting with strong presentations across the broad spectrum of Quaternary science. In particular, the quality of the student presentations was a highlight and provides me with a great deal of confidence in the future of Quaternary research throughout Australasia. On behalf of the AQUA executive, I would again like to express our gratitude to the University of Adelaide Quaternarists for the organisation of the meeting. They did an amazing job with just six months notice. In particular I would like to acknowledge Jennie Fluin, Ashley Natt, Rachel Skinner, John Tibby, Deborah Haynes and Eric Nicholson. In addition, I would also like to thank our sponsors Land and Water Australia and ANSTO for their financial support, as well as our three keynote speakers Patrick De Deckker, Jim Bowler and Colin Murray-Wallace. Finally, I would like to thank all of the conference participants for their support and ensuring a meeting in the best traditions of previous AQUA meetings.

Now for the key news from the conference: Three amendments to the AQUA constitution were passed at the extraordinary meeting (more details in this issue). It was also decided that the next AQUA biennial meeting will be held in June/July 2010 on North Stradbroke Island, Southeast Queensland - please keep an eye out for more details in the near future. Financially, AQUA is in a good position, but the executive is well aware of the potential impacts of the Global Financial Crisis and increased costs associated with the production of QA, which may require a response in the future. Discussion was held to increase AQUA's presence in the broader world, particularly focusing on engagement with government and industry. We are well on our way to meeting this goal, with recent submissions to the Australian House of Representatives inquiry into climate change and environmental impacts on coastal communities, and the Australian Department of Climate Change draft national framework for Climate Change Science, as well as the involvement of our two sponsors in the recent meeting. Any further suggestions to improve our profile will be gratefully received by the executive.

Finally, I would like to highlight the student awards at the meeting. Four students received awards:

- FASTs Science Meets Parliament Award to Rachel Skinner, The University of Adelaide.
- Financial Award for Best Presentation to Romina Belli, University of Newcastle
- Best Poster Award to Lydia Mackenzie, The University of Queensland
- Highly Commended Award to Raquel Lopes dos Santos, Royal Netherlands Institute for Sea Research.

Expect to see more details of their research in future issues of QA.

Best Wishes

Patrick

Pinning down the pitfall

Entry points for Pleistocene vertebrate remains and sediments in the Fossil Chamber, Victoria Fossil Cave, Naracoorte, South Australia

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Abstract

The Naracoorte Caves National Park was World Heritage listed in 1994 for its extensive Quaternary vertebrate fossil deposits. The Fossil Chamber within Victoria Fossil Cave is the most well known of these deposits. The deposit accumulated via pitfall entrapment during the Middle Pleistocene. A previous interpretation of the site proposed that the original entry point for sediments and vertebrates was a large section of roof collapse leading to a wide entrance hole. Recent research contradicted this interpretation. The type of cave entrance has a significant influence over the mode of accumulation, which in turn affects the faunal composition and taphonomic history of the resultant fossil deposit. Therefore, it is important to determine the nature of the original entrance of a cave site to fully understand the biases that may have influenced the faunal assemblage. The aim of the current paper is to elucidate the nature of the original entry points for sediment and bones into the Fossil Chamber. This was achieved via thorough mapping and surveying of the chamber and the corresponding area on the land surface. The results show that the original entry points for the Fossil Chamber were a series of narrow solution pipes, not the large collapse entrance previously proposed. This is reflected in the distinct sediment and bone distribution found in this chamber.

Introduction

The caves of Naracoorte, South Australia, have preserved an extensive record of Quaternary sediments and associated vertebrate remains (Reed and Bourne, 2000). The Fossil Chamber within the Victoria Fossil Cave is the most well known of these deposits and was central to the World Heritage listing of the Naracoorte Caves National Park in 1994. Discovered in 1969, the Fossil Chamber consists of a large sediment deposit containing abundant, well preserved fossils from over 100 vertebrate species (Wells *et al.*, 1984; Reed and Bourne, 2000). Estimates based on the spatial density of bones excavated from the deposit suggest over 45,000 medium to large sized mammals (>5kg) are preserved in this vast deposit (Reed, 2003). The numbers of small mammals, amphibians, reptiles and birds would increase this figure even substantially.

The sediment deposit consists predominantly of fine to very fine, moderately sorted, sub-rounded siliceous sands and has been subdivided into eight major units (Reed, 2003). Visual differences between units are attributable to variations in clay and carbonate content within the sediments (Reed, 2003; Forbes and Bestland, 2007). Grain size of the siliceous sand component is consistent throughout the deposit as are strontium isotope ratios (Forbes and Bestland, 2007), suggesting little variation in sediment source throughout the time span of deposition. Cave sediments were derived locally from remnant early Pleistocene dune systems with a wind-blown component of coarse silts originating from the Murray Basin (Forbes and Bestland, 2007). The age of the Fossil Chamber deposit is constrained by a U-series date of 212 ± 6.7 ka (Ayliffe *et al.*, 1998; Moriarty *et al.*, 2000) obtained from flowstone within a small secondary cone overlying the main sediment cone deposit. Electron Spin Resonance dates range between 282 ± 24 ka and 478 ± 22 ka (Grün *et al.*, 2001). Optically Stimulated Luminescence has yielded ages of 157 ± 16 ka and 171 ± 14 ka for the same deposits (Roberts *et al.*, 2001).

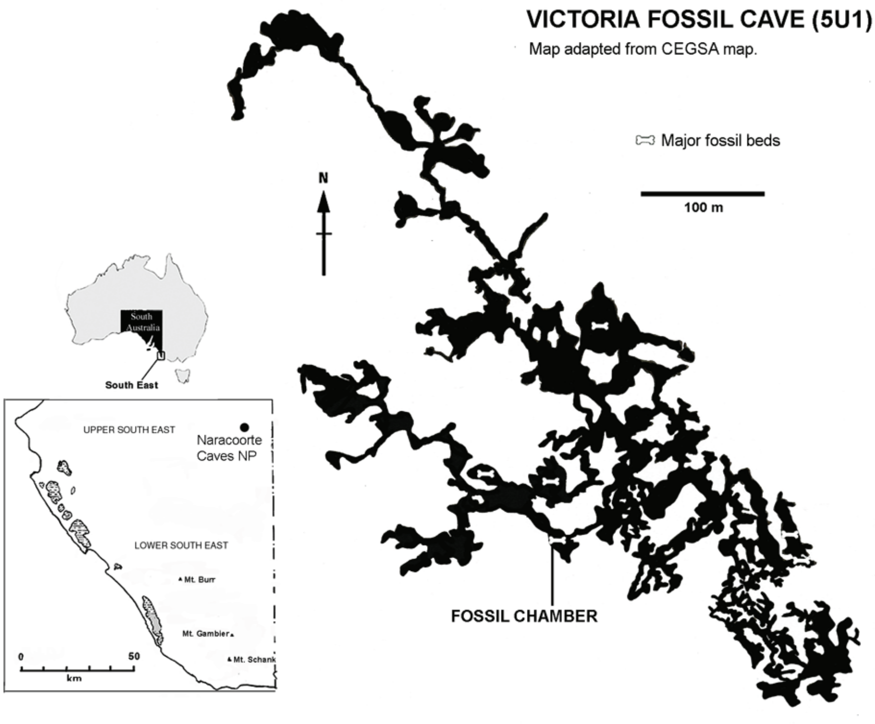


Figure 1. Map of Victoria Fossil Cave showing location of the Fossil Chamber. Map of Australia and the South East of South Australia show location of Naracoorte Caves.

Wells *et al.* (1984) concluded that the animals represented in the deposit were accumulated via pitfall entrapment through a large section of roof collapse leading to a 10 m wide entrance. Research on actively accumulating caves at Naracoorte today (Reed, 2003), contradicted this description of the original entrance and suggested a narrow solution pipe entrance type was more likely. The type of entrance has a significant influence over the way animal remains and sediments are accumulated in caves at Naracoorte (Reed, 2003). 'Modern' solution pipes at Naracoorte are highly effective pitfall traps and produce a collection bias towards fast-moving ground-dwelling animals, particularly kangaroos (Reed, 2003). The abundance of kangaroos within the Fossil Chamber deposit is very high, representing over 80% of the medium to large mammals (>5 kg) in the deposit and matches very closely the proportions for assemblages from modern solution pipe pitfalls at Naracoorte (Reed 2003). Large roof collapse entrances at Naracoorte are not nearly as effective pitfall traps, with the majority of remains in these caves derived from the activities of cave-dwelling animals such as owls (Reed, 2003). These differences in accumulation mode produce biases in the resultant faunal composition and as the goal of much of the research at Naracoorte is to reconstruct the palaeoecology of the area, it is critical to understand these biases and how they affect information preserved in the deposits. As the taphonomic history of a cave deposit starts with the accumulation of the animals through the cave entrance, it is logical to determine the exact nature of this 'starting point'.

The aim of this study was to elucidate the entry point/s for sediment and bone for the Fossil Chamber via a thorough and detailed topographic survey of the chamber and the land surface above it and in conjunction with a taphonomic analysis of the vertebrate fossils from the Fossil Chamber (Reed, 2003). The conclusions of Wells *et al.* (1984) regarding the entrance type would then be evaluated against these data.

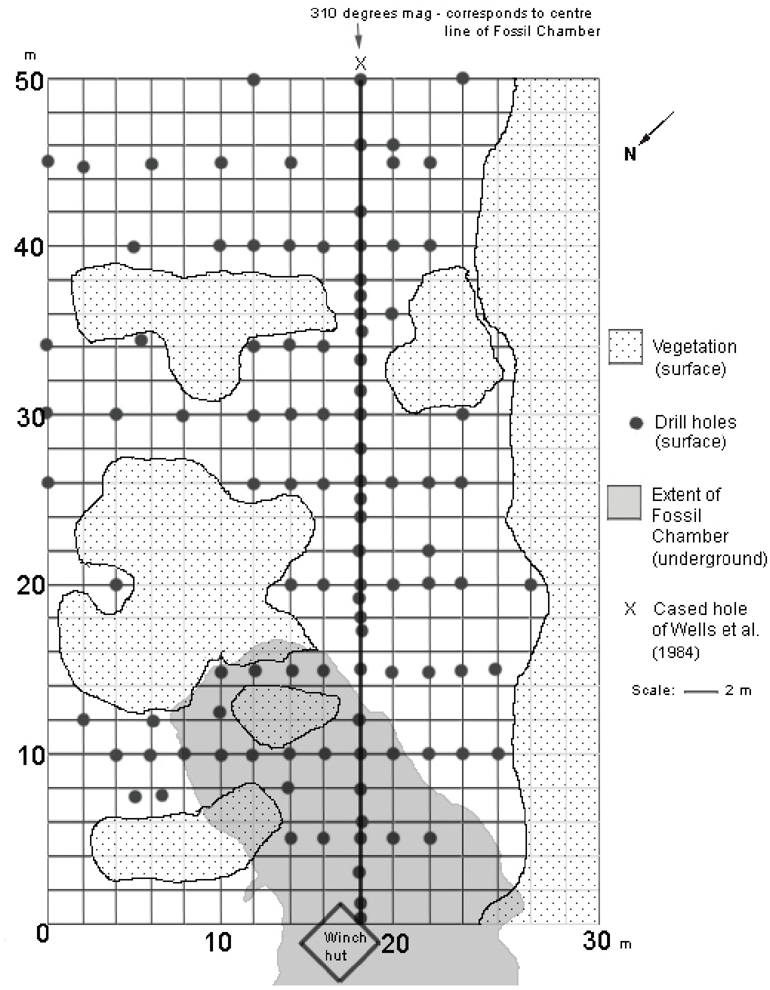


Figure 2. Layout of the grid system used for coring on the land surface above the Fossil Chamber. Major features are indicated.

Methods

Study site – Main Fossil Chamber, Victoria Fossil Cave

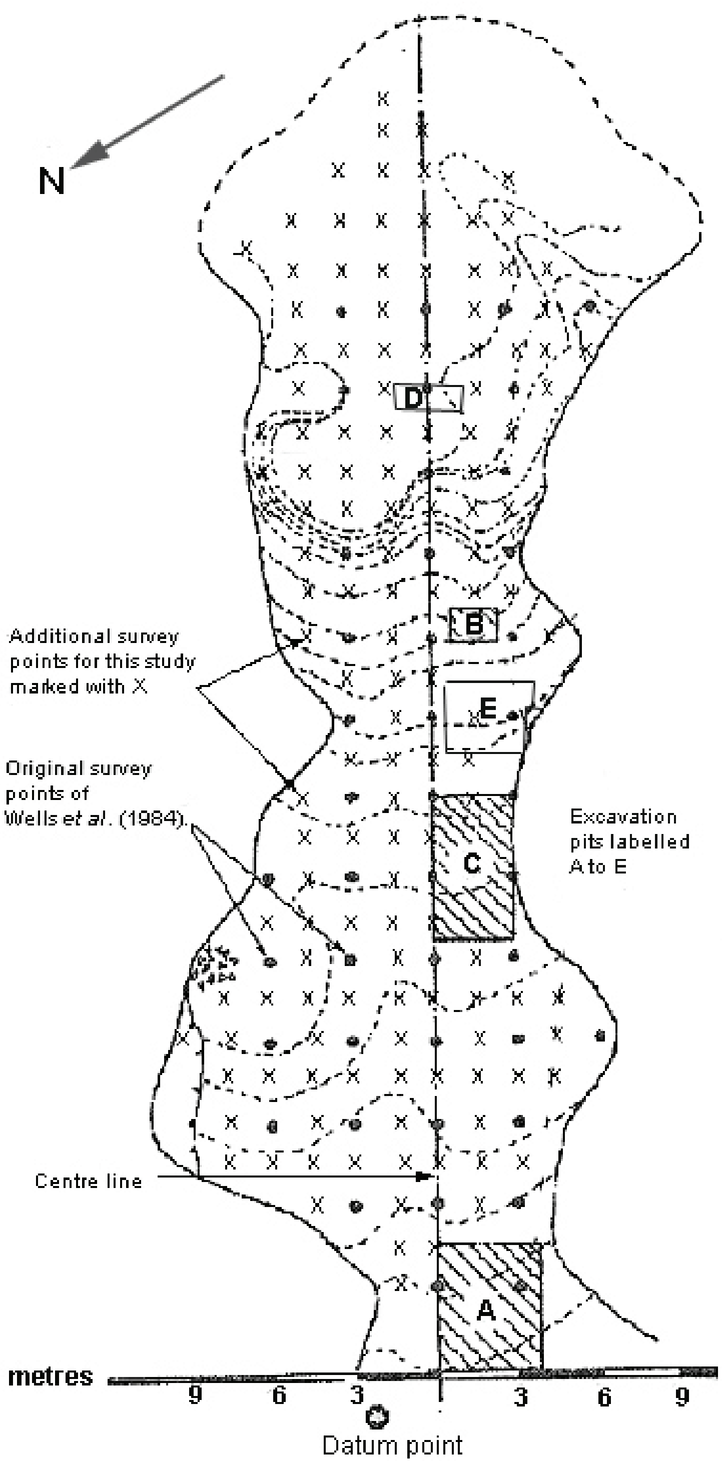
Victoria Fossil Cave is a large phreatic maze cave (Figure 1), formed within the Tertiary Gambier Limestone. It consists of around 4,000 metres of mapped passages and chambers (Reed and Bourne, 2000; Reed, 2003). The cave was discovered in 1894 by William Reddan who developed it as a tourist cave, opening it to the public in 1897. In 1969 a team of cavers from the Cave Exploration Group of South Australia led by Grant Gartrell and Rod Wells discovered a new section of the cave with a large chamber containing an enormous sediment and bone bed (Wells, 1975; Wells and Pledge, 1983; Wells *et al.*, 1984; Reed and Bourne, 2000). This chamber became known as the Fossil chamber and is the focus of this paper. Wells *et al.* (1984) provide a summary of the fauna and the geology of the chamber.

Surveying the surface above the cave

A survey of the land surface above the cave was conducted to determine the topography of the area and to provide a reference grid for an additional survey of the sub-surface limestone. A grid of 2x2 metre squares was pegged out on the land surface corresponding to the area beyond the south-eastern end of the Fossil Chamber (Figure 2). The grid extended to a cased core hole installed by Wells *et al.* (1984). The centre-line of the Fossil Chamber had previously been located and pegged out on the surface by Wells *et al.* (1984) and this was confirmed and used as a reference line (Figure 2). A datum point was established adjacent to the winch hut which houses the opening to an access shaft leading down to the Fossil Chamber (Figure 2). To determine the land surface topography, points were surveyed using a laser dumpy level within the grid at one metre intervals, along nine transects (two metres apart and 50 metres long – Figure 2).

The sub-surface topography of the limestone bedrock was determined by coring and probing on the same grid system (Figure 2). Holes were drilled until rock was reached at various points along the grid using a Case Uniloader 1840 fitted with a hydraulic auger and 15 cm diameter drill bit. Where access was hindered by trees or large rocks the area was probed using a steel rod or dug by hand. Some areas were too restricted by vegetation and were not cored. The depth (m) to the limestone reached at each of the 82 holes and additional points was recorded and tied in to the ground surface survey and datum point.

Figure 3. Map of the Fossil Chamber showing original survey points (filled circles) and contour lines (dotted lines) of Wells *et al.* (1984) and additional points (x) used for this study. Map adapted from Wells *et al.* (1984).



Mapping and surveying within the Fossil Chamber

A fixed datum point and a grid system of 3 x 3 metre squares had previously been established within the Fossil Chamber by Wells *et al.* (1984). During this study a grid system of 1.5 x 1.5 metre squares (incorporating the original survey points) was established and the topography was surveyed using a laser dumpy level (Figure 3). The existing pathway, rock material and foam mats were used to gain access to survey points so that the chamber floor was protected. The extremely low roof height (<0.5 m in places) at the far end of the chamber (>44 m from datum) necessitated a different approach with a string line, compass and spirit level was used to survey the last accessible portion of the chamber. This portion of the chamber had not been mapped previously. The chamber wall outline was mapped using a laser rangefinder by measuring the distance to the wall at 90 degrees from the centre-line at 1.5m intervals. Roof heights above floor level were also recorded at each of these points using the rangefinder. An outline map and cross-sections of the chamber were drawn by hand, with key features, including solution pipes, plotted in.

Results

The surface survey

Along the transect corresponding to the centre-line of the Fossil Chamber the land surface drops 1.64 m gradually over 51 metres (Figure 4). The limestone rock also slopes gradually with a 1.11 metre drop over the same distance (Figure 4). The source for the deeper measurements recorded by Wells *et al* (1984) is a solution pipe (70 cm diameter) which was located during the current survey. The maximum depth (reached by coring) of the limestone rock beneath the land surface was 1.48 m. The depth of limestone from the surface to the cave ranges from 10 to 12 m. The depth of the access shaft was 10.6 m from the land surface to the chamber roof. An additional solution pipe was located 12 m from the access shaft on an 85 degree (magnetic) transect where there is a large tree growing, the roots of which can be seen in the chamber below. The edges of part of the pipe were detected during coring and it is immediately below the large tree. The diameter of this pipe is estimated to be around 90cm from probing.

Chamber morphology and topography

The longitudinal axis of the chamber runs north-west to south-east and the accessible part of the chamber is approximately 54 m long from the datum point to the south-eastern wall and around 16 m at its widest point (Figure 5). Roof height along the centre-line ranges between 2 to 2.5 m, decreasing to less than one metre at the south-eastern end (Figure 6). Beyond this, the true extent of the chamber is unknown as it continues under the south-western wall and is too constricted to access. The north-western end of the chamber leads to a large outer chamber. At the south-eastern end a low area leads up 12 metres over a large, roof-collapse limestone boulder. Collapse has choked off several small tunnels leading from this area.

The sandy sediment floor of the main chamber consists of around 30 m of gently sloping surface and 19 m of more steeply sloping surface which eventually chokes off in the south-eastern corner. The floor on the south-western side of the chamber dips gradually underneath the wall, giving the floor a subtle south-western dipping slope, leading to an as yet unknown section of cave. Bone material is evident on the floor surface and roof fretting is evident in the form of limestone 'dust' and larger rocks ranging from pebble size to large boulders.

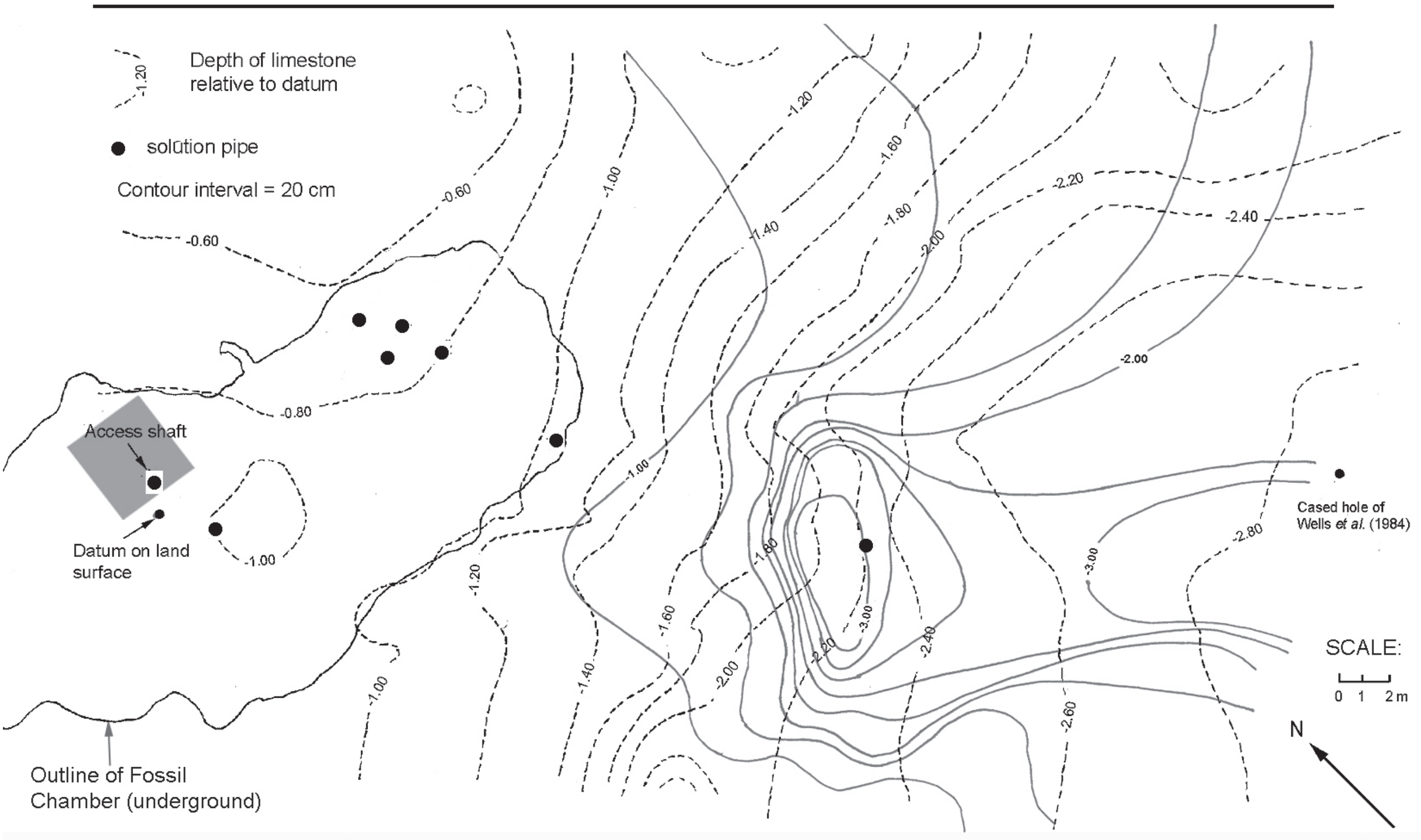


Figure 4. Contour diagram showing the sub-surface topography of the limestone above the Fossil Chamber at the land surface. The position of solution pipes located during this study is indicated. Dashed contour lines are those from the survey conducted during this study. Solid contour lines super-imposed onto the diagram are those from the original survey of Wells *et al.* (1984), drawn here from the original raw data (supplied by R. Wells).

Calcite formation is sparse in the chamber with only a few small areas of inactive straws and stalactites.

Sediment sources and pitfall entrances

There are four areas within the chamber that may have been entry points for sediment and bone. None are currently open. On the northern side of the chamber there is a small pile of roof-collapse limestone blocks and sediment on the floor surface associated with a corresponding bell-shaped hole in the roof above (Figure 5). There is no visible blocked solution pipe in the roof hole and no associated sediment staining. As the section of the roof clearly collapsed after the sediment floor was in place, this is unlikely to have been a major source of sediment input into the chamber.

In the south-eastern corner of the chamber an existing blocked solution pipe has been opened for use as an access shaft for removing excavated sediment (Wells *et al.*, 1984). This pipe is a potential source for sediment input as there is bone-bearing sediment adhering to the lower portions of the pipe. However, the relatively gentle depositional dip of the major deposits suggests a more distant source. Another blocked solution pipe is visible in the vicinity of the access shaft and is associated with calcite formation and the Pit D excavation site which includes dated flowstone (~213 ka - Ayliffe *et al.*, 1998). Beneath the pipe is a small secondary cone, formed on top of the sediment floor, which differs slightly from the main section in sediment colour and texture. Sediment staining is obvious at the base of this pipe providing evidence of water and sediment influx in the past.

The exact nature of the entrance/s through which the main fill (sediment and bones) accumulated is difficult to ascertain from within the chamber due largely to access restrictions to the area beyond the south-eastern end. However, the most likely source for the main fill is in the eastern corner of the chamber (~48 m from the distal fan) where the cone steeply inclines to a cluster of five blocked solution pipes. Bone material is present on the surface of the cone suggesting it has also been a source for animal remains. This area corresponds to a solution pipe located during the surface coring. The roots of the tree that grows in part of this pipe can be seen in the chamber below. The size of this solution pipe and its position above the apex of the cone suggest it was a major entry point for the deposit. The depth of this pipe is approximately 11 metres.

The topography of the sediment floor of the chamber (Figure 5), particularly the south-westerly dip of the sediment floor away from this cone, further suggest that this was the major sediment source for the chamber. Four additional solution pipes are evident in this area, all <40 cm in diameter. These pipes are also located on the surface. There is evidence of water action and sediment flow, including sediment staining of roof collapsed limestone, a lag of sub-angular limestones and a stream-cut channel. The channel has an

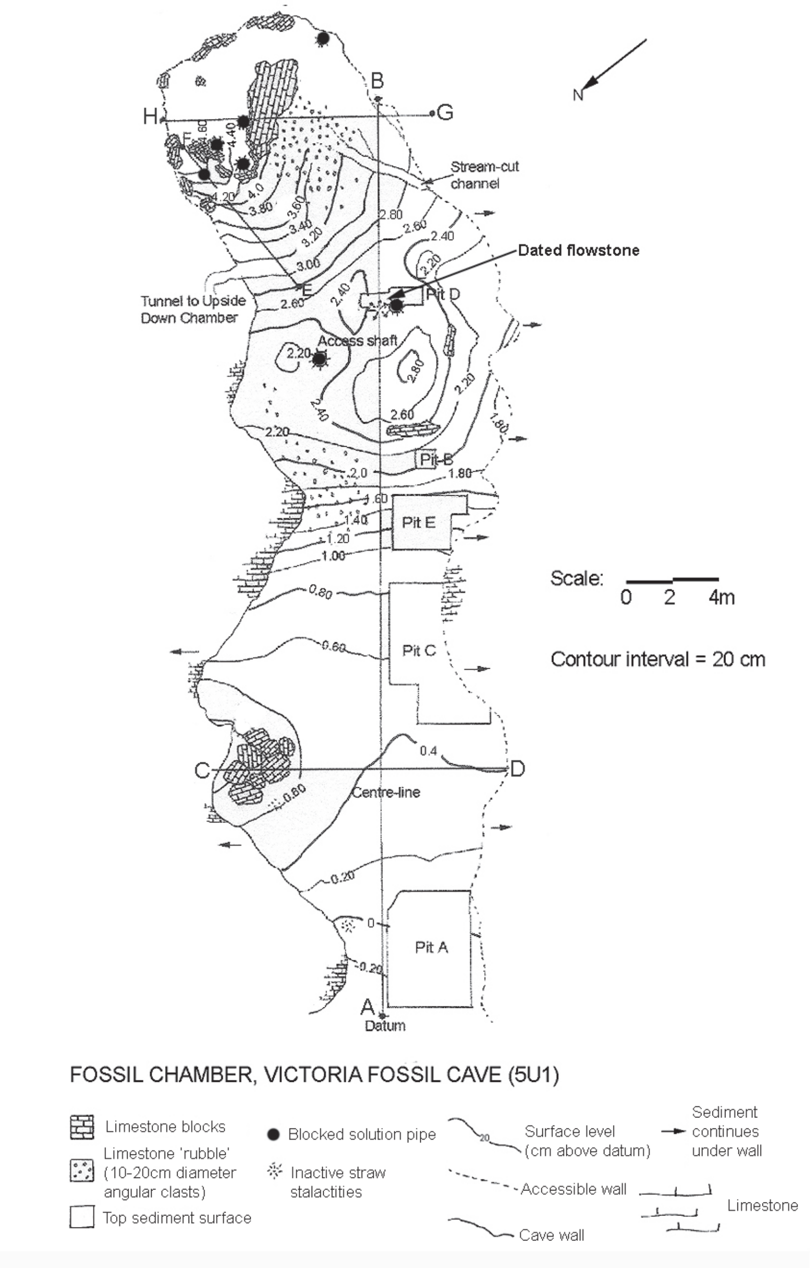


Figure 5. Map of the Fossil Chamber showing surface topography of the sediment floor of the chamber, the location of excavation pits and other features discussed in this paper. Transects from which section diagrams were produced are indicated (see figure 6).

average width of one metre and depth of around 30 cm. Bones are visible in the channel and have likely been uncovered following removal of the surrounding sediment by water. The channel continues under the south-west wall of the chamber and then north-west for several metres and is visible at the Pit C area under the wall.

Discussion

Chamber morphology, sediment sources and pitfall entrances

The Fossil Chamber is a long roof-collapse chamber filled almost entirely with sediment. Coring indicates that the limestone floor is around two metres below the datum level, giving the chamber a former roof height of as much as seven metres in places prior to sedimentary in-fill. Longitudinally, the nature of the cave beyond the south-eastern end of the chamber is unknown. However, the slope and depth of the farthest wall beneath the sediment suggest the roof height decreases. Beyond this the cave may continue as low phreatic passage as is typical of areas adjacent to the Fossil Chamber, or it may open up into another chamber.

There are at least three areas that have been entrances for sediment and bone accumulation into the chamber during the Pleistocene. These are the solution pipe expanded as the access shaft, the solution pipe above the pit D area with dated flowstone, and the cluster of solution pipes in the eastern corner of the chamber. Beyond the farthest accessible portion of the chamber are additional solution pipes (discovered by surface coring) which are too distant to have had a significant input. The results of this study suggest the major entry point for the bulk of the sediment and animal remains in the chamber was the series of solution pipes above the eastern corner of the chamber, in particular one pipe that has a diameter of around 90 cm. The slope of the sediment cone at this point and the topography of the sediment floor display a general trend away from this area. Furthermore, there is distinct evidence of water and sediment influx from solution pipes in this corner of the chamber.

It is not possible to say whether these holes were open during the same episodes of accumulation. Dating of the deposit indicates that accumulation of the main fill occurred over a considerable period of time (Ayliffe *et al.*, 1998; Moriarty *et al.*, 2000; Grün *et al.*, 2001) and there may have been many episodes where solution pipes have opened and closed over time. The presence of multiple entry points in the Fossil Chamber would increase the chances of at least one of these being open at any given time and may help to explain the prolonged period of accumulation and volume of the deposit. Wells *et al.* (1984) proposed a model for sediment infill in caves by which a cone forms beneath the entrance with subsequent saturation and slumping to form a fan and eventual blockage of the hole by sediment. The pipes would then back-fill and remain closed until the sediment 'plug' was eroded by water (Wells *et al.*, 1984).

Reed (2003) noted that there are two major types of cave entrances at Naracoorte ie. large roof collapse windows and solution pipes. The former develop via collapse where the limestone roof is relatively thin; whereas solution pipes form in limestone generally thicker than 5 metres (Reed, 2003). At Naracoorte, the vast majority of solution pipes are <1 m in diameter while roof windows can reach 10 m diameter. Roof windows do not block from sediment infill alone and potentially remain open over extended periods of time without ever blocking. The model of Wells *et al.* (1984) is relevant only to the solution pipe entrances and is a good model for sediment infill for the Fossil Chamber.

Wells *et al.* (1984) suggested the nature of the original pitfall entrance and sediment source was:

> "....a 50 m long section of the chamber exposed by roof collapse, and was at the base of a doline some 159 m wide possibly caused by erosion of the limestone by water flowing towards the entrance. Laterally the entrance was steep to vertical with an average width of 10 m".

As the grid on which the original survey was conducted was fairly coarse (10 x 10 metre squares), due to the difficulties of coring this area by hand and the impracticalities of coring on a finer scale at that time, the true nature of the original entrance/s was not revealed by that survey. Attempts were made by Wells *et al.* (1984) to drill cores into these possible entrance holes but were hindered by obstructions such as tree roots and limestone blocks (R. Wells, pers. comm). However, depths of up to 13 m were reached indicating that the cores were penetrating sediment filled cavities which were very likely, in light of the current survey, to indicate additional solution pipes. The more finely resolved survey conducted during this study has shown that the corresponding area on the surface above the Fossil Chamber could best be described as

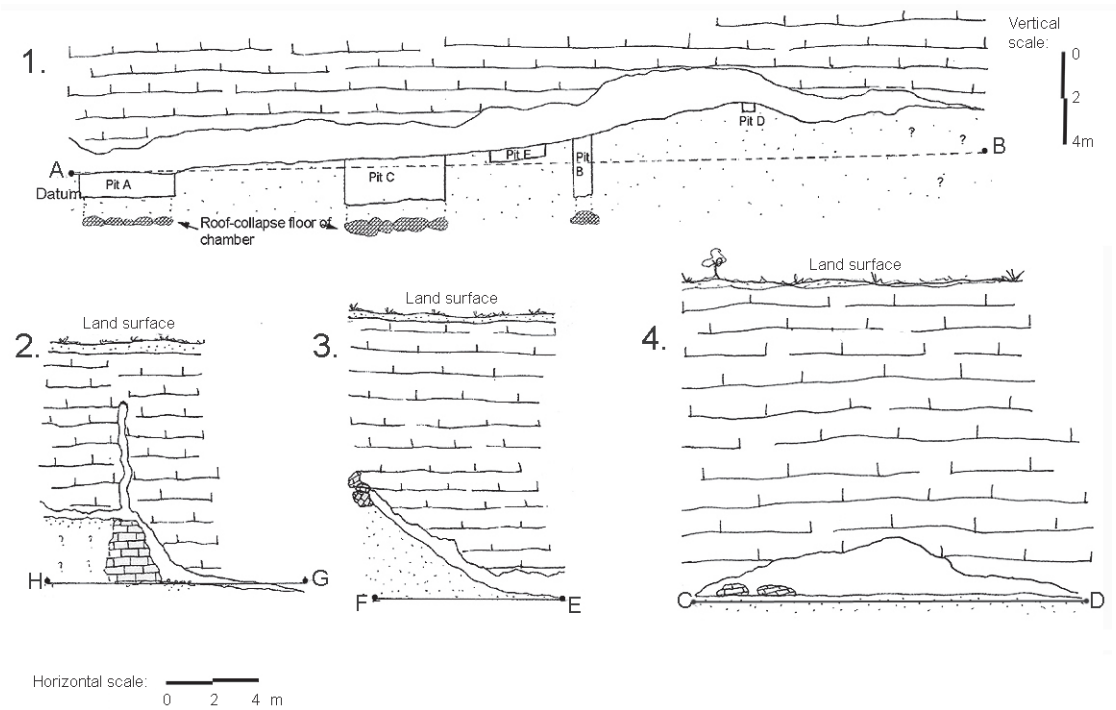


Figure 6. Longitudinal section and cross-section diagrams of the Fossil Chamber. Transects correspond to those indicated in Figure 5.

a shallow 'valley' or erosional channel in a low point amongst a series of undulating limestone hills. The area would have been subject to surface water run-off with sediment and limestone clasts being washed into solution pipes formed in the limestone. Evidence of water action within the Fossil Chamber is visible in the form of water staining of the ceiling and limestone blocks, lag deposits of limestone clasts and eroded channel.

The largest animals present in the Fossil Chamber deposit are *Zygomaturus trilobus* and *Palorchestes azael* (Wells *et al.*, 1984; Reed, 2003); however, they are very poorly represented with less than 4% of the total individuals (Reed, 2003). The estimated maximum body weight for these species is around 500 kg (Johnson, 2006). *Diprotodon optatum* with an estimated maximum weight of up to 2,700 kg (Johnson, 2006) is absent from the Fossil Chamber and also similar pitfall deposits within the Naracoorte Caves National Park (Brown and Wells, 2000). As *D. optatum* is known from contemporaneous deposits elsewhere in the region (Pledge, 1990), it is possible that it's absence within the Fossil Chamber relates to the small size of the solution pipe pitfall entrances which may have acted as body size 'filters' resulting in a biased representation of the largest species. This may also account for the rarity of the other large herbivores. A similar scenario has been proposed for deposits in Cathedral Cave (Brown and Wells, 2000) and the Upper Ossuaries (Reed, 2006). Partially articulated remains of a single *Z. trilobus* have been found near the farthest end of the Fossil Chamber deposit indicating that this animal was able to fall through the entrance and move further into the cave. The individuals preserved in the Fossil Chamber may have been smaller than the maximum estimate of 500kg or sub-adult. Observations of actively accumulating solution pipe entrances at Naracoorte have shown that relatively large animals such as cows can become trapped in small diameter entrances (Reed, 2003).

Conclusions

The results of this study shows that a large collapse entrance (as described by Wells *et al.*, 1984) is not present in the area above the Fossil Chamber and that previous entrances to the chamber were a series of relatively narrow solution pipes in a shallow limestone 'valley', all or some of these having contributed to the main sediment and fossil fill. Comparison with the entrances of other caves at Naracoorte suggests that at the limestone depths such as that above the Fossil Chamber (e.g. >10 m), solution pipes are the sole entrance type (Reed, 2003). A series of solution pipes such as the ones proposed here would serve as effective animal traps, particularly if concealed by vegetation cover or the topography of the hillside. These would also provide numerous openings for the influx of sediment via wind and water into the cave over an extended time period. Given the high faunal diversity at Naracoorte during the Pleistocene, the effectiveness of solution pipes as traps for animals and the span of time represented by the deposit, it is not surprising that the Fossil Chamber accumulated such a vast assemblage of remains.

Acknowledgements

The author wishes to thank R. Wells for supervising this work as part of a larger PhD project. Special thanks go to S. Bourne for assistance with field work and the staff of Naracoorte Caves National Park for continuing support with the Naracoorte research.

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Intrinsic variation associated with stomatal frequency within Victorian specimens of *Acacia melanoxylon*, *Acmena smithii* and *Eucalyptus obliqua*

A preliminary study: implications for palaeoclimatological reconstructions.

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Abstract

Intrinsic variation in stomatal frequency, density and index, was assessed in 3 Australian tree species, *Acacia melanoxylon*, *Acmena smithii* and *Eucalyptus obliqua* to determine the applicability of these leaf characters to be applied as palaeoclimatological tools. Intrinsic variation was assessed among leaves, over the leaf surface, across the leaf surface and between leaf surfaces. Stomatal index in *A. melanoxylon* did not show any significant intrinsic variation in any of the test factors, stomatal density of *A. melanoxylon* varied significantly among leaves and over the leaf. Stomatal density and index in *A. smithii* only varied significantly among leaves, while *E. obliqua* exhibited significant variation in stomatal density and index among leaves, and between leaf surfaces. Stomatal index of *A. melanoxylon* is a potential candidate for the use in palaeoclimatological reconstructions.

Introduction

Stomates or stomata are pores upon the leaf surface that allow gas exchange between the leaf and atmosphere. It is the movement of carbon dioxide [CO_2] from the atmosphere into the leaf, via these pores, that permits the photosynthetic reaction to occur (Beerling and Chaloner, 1992; Royer, 2001). Stomatal frequency refers to the number of stomata distributed across the leaf surface and it may be defined as a density count, stomata density per mm^2, or expressed as an index which calculates the ratio of stomata to epidermal cells (Salisbury, 1927; Greenwood et al., 2003).

Leaf morphological characters, such as stomatal frequency, have been found to respond to changing environmental variables, such as, temperature, rainfall, irradiance and [CO_2] (Givnish, 1978; Greenwood, 1992; Royer, 2001). If stomatal frequency is able to respond to a particular environmental or climatic variable in a predictable manner, this character holds the potential to be applied as a palaeoclimatological tool; thus potentially providing past climate estimates (Woodcock, 1992; Wing and Greenwood, 1993). The applicability of such a relationship is dependent upon the selected characters ability to accurately track a changing environmental variable and the characters ability not to be obscured by other factors. Therefore, documenting a range of factors that can affect the efficiency of utilising a chosen characteristic (i.e. stomatal frequency) to document past climate change is crucial.

Intrinsic variation is a factor that may obscure the potential use of stomatal frequency as a palaeoclimatological tool (Körner, 1988; Wagner et al., 2005). In terms of stomatal frequency, intrinsic variation is the variability in stomatal distribution across a leaf surface (Poole and Kürschner, 1999), and has the potential to be large in angiosperms (Poole *et al.*, 1996 & 2000, Kouwenberg et al., 2004; Uhl and Kerp, 2005). Typically, variation in stomatal frequency has been found to vary from the base to tip, midrib to margin, between surfaces of a leaf, within a leaf fragment and between individual leaves; with stomatal density exhibiting greater intrinsic variability than stomatal index (Salisbury, 1927; Sharma and Dunn, 1968; James and Bell, 1995; Ferris et al., 1996; Smith et al., 1989; Zacchini et al., 1997; Stancato et al., 1999; Royer, 2001). So if stomatal frequency is to be used as a proxy-estimator of some past climate parameter, the degree of intrinsic variation needs to be determined, as will be undertaken in this paper.

Australia fossil leaves, including the use of stomatal frequency, have been employed to estimate palaeoclimatic parameters, such as, temperature, precipitation and [CO_2] (Greenwood and Wing, 1995; Atchison and Head, 1999; Atchison et al., 2000; Greenwood et al., 2003; Carpenter et al., 2004; Greenwood et al., 2004). Greenwood et al. (2003) is the only Australian study to use stomatal index from fossil specimens, *Litsea* a tropical rainforest tree, to estimate Eocene [CO_2]. The use of stomatal frequency analysis

Species	Latitudinal Range (°S)	Altitudinal Range (m)	Annual Temperature Range (°C)	Annual Precipitation Range (mm)
Acacia melanoxylon	14 – 43	0 – 1500	1 – 30	750 – 7500
Acmena smithii	11 – 39	0 – 1200	5 – 32	700 – 2000
Eucalyptus obliqua	28 - 43	0 – 1200	-4 – 29	500 – 2400

Table 1: Physical and climatic parameters associated with distributions of *Acacia melanoxylon, Acmena smithii* and *Eucalyptus obliqua*. Source: Boland *et al.*, 1984.

has the potential to provide valuable information on past [CO_2], this information may be used to provide an insight into how future atmospheric [CO_2] may affect the Australian landscape.

The species to be examined in this study include two mesic species, *A. melanoxylon (R. Br.)* and *E. obliqua (L'Hér.)*, and one warm temperate rainforest species, *A. smithii (Poiret) Merr. & Perry var. smithii.* These species were chosen based on their broad environmental range in Victoria (Table 1), which allows establishment of wide environmental transects, thus permitting the assessment of stomatal frequency response to changing environmental and climatic parameters. *Acacia melanoxylon* does have a fossil record (Jordan, 1997),

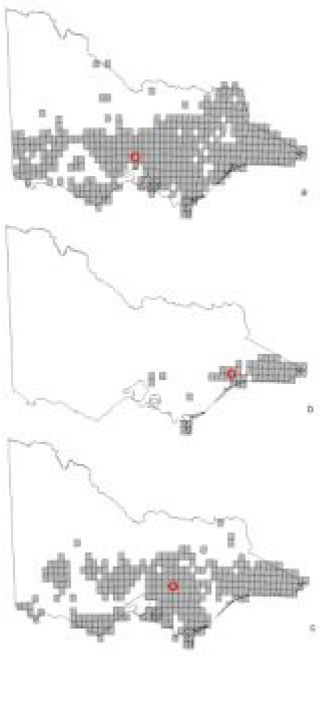

Figure 1: Victorian distribution and collection sites of a) *Acacia melanoxylon*, b) *Acmena smithii* and c) *Eucalyptus obliqua* (Source: Gullan, 1998).

while *A. smithii* and *E. obliqua* have not currently been identified in the fossil record, although *Eucalyptus* and *Acmena* specimens do exist, so there is potential for these species to be described in the future (Greenwood et al., 1997; Blackburn and Sluiter, 1994). Identification of fossil specimens to species level may be achieved by the use of, or combination of bark / wood, seeds, fruit, pollen, leaf architecture, cuticle morphology and DNA analysis (Hickey, 1979; Christophel and Rowett, 1996; Ladiges et al, 2003; Hopper and Gioia, 2004; Basinger et al, 2007). Currently, there is only one study examining the response of stomatal frequency in *A. melanoxylon* to increasing atmospheric [CO_2] (Scarr, 2000). The use of stomatal frequency analysis in *A. smithii* and *E. obliqua* has not been reported. If stomatal frequencies in *A. melanoxylon*, *A. smithii* and *E. obliqua* are found to be stable, that is, exhibit low intrinsic variation this will make stomatal frequency analysis in these selected species ideal for palaeoclimatological reconstructions, based on stomatal frequency analysis.

The aim of this study is to determine the intrinsic variation associated with stomatal frequency in specimens of *A. melanoxylon*, *A. smithii* and *E. obliqua*, in order to assess their applicability to be applied in the palaeobotanical realm. This will be achieved by examining stomatal frequency for significant variation among leaves, across the leaf surface from base to tip, mid lamina to leaf margin (i.e. within a leaf fragment) and between adaxial (upper) and abaxial (lower) leaf surfaces in leaves of specimens from *A. melanoxylon*, *A. smithii* and *E. obliqua.*

Methods

In order to assess the within- and between-leaf intrinsic variation in stomatal frequency from specimens of *A. melanoxylon*, *A. smithii* and *E. obliqua*, a total number of 20 leaves were collected per species from the outside of the crown behind the branch tip from single specimens in Victoria, Australia (Figure 1). This paper is part of a larger study to examine the potential of stomatal frequency in these species to track increasing subambient [CO_2]; via the use of herbaria. Herbarium-sheets typically only consist of one branch from a

	Acacia melanoxylon		*Acmena smithii*		*Eucalyptus obliqua*	
Test Variable	Within leaf stomatal density (mm2)	Within leaf fragment stomatal density (mm2)	Within leaf stomatal density (mm2)	Within leaf fragment stomatal density (mm2)	Within leaf stomatal density (mm2)	Within leaf fragment stomatal density (mm2)
Leaf	+ (P=0.047)	+ (P=0.011)	– (P=0.148)	+ (P=0.037)	+ (P=0.046)	– (P=0.060)
Location (tip, middle & base)	+ (P=0.019)	– (P=0.285)	– (P=0.191)	– (P=0.896)	– (P=0.331)	– (P=0.617)
Surface	– (P=0.507)	– (P=0.963)	n/a	n/a	+ (P=0.001)	+ (P=0.005)
Leaf*Location	– (P=0.169)	– (P=0.150)	– (P=0.097)	– (P=0.363)	– (P=0.374)	– (P=0.346)
Leaf*Surface	– (P=0.601)	– (P=0.380)	n/a	n/a	+ (P=0.318)	– (P=0.079)
Leaf*Location*Surface	– (P=0.327)	– (P=0.415)	n/a	n/a	– (P=0.242)	– (P=0.313)
	Acacia melanoxylon		*Acmena smithii*		*Eucalyptus obliqua*	
Test Variable	Within leaf stomatal index	Within leaf fragment stomatal index	Within leaf stomatal index	Within leaf fragment stomatal index	Within leaf stomatal index	Within leaf fragment stomatal index
Leaf	– (P=0.417)	– (P=0.098)	– (P=0.220)	+ (P=0.016)	+ (P=0.029)	– (P=0.290)
Location (inner, middle & outer)	– (P=0.067)	– (P=0.424)	– (P=0.174)	– (P=0.205)	– (P=0.973)	– (P=0.418)
Surface	– (P=0.647)	– (P=0.863)	n/a	n/a	+ (P<0.001)	+ (P=0.005)
Leaf*Location	– (P=0.079)	– (P=0.290)	– (P=0.112)	– (P=0.702)	– (P=0.441)	– (P=0.265)
Leaf*Surface	– (P=0.672)	– (P=0.466)	n/a	n/a	– (P=0.517)	– (P=0.223)
Leaf*Location*Surface	– (P=0.613)	– (P=0.734)	n/a	n/a	– (P=0.230)	– (P=0.300)

Table 2: Assessment of intrinsic variation in stomatal density (mm^2) and index among leaves (n = 5) from different locations within a leaf (tip, middle and base), within a leaf fragment (inner, middle and outer) and between leaf surfaces from each of these locations in *Acacia melanoxylon, Acmena smithii* and *Eucalyptus obliqua* using General Linear Model Analysis ('–' - no significant difference; '+' - significant difference, $P \leq 0.05$).

single tree, so the experimental design of this study is to replicate herbaria and assess the intrinsic variation associated with this resource.

Sampled leaves were dried using a plant press and light box over a two-week period. Once dried, 5 leaves were selected randomly from each sample for stomatal frequency analysis. A leaf square approximately 4 x 4 mm was removed from the tip, middle and base of each leaf from each of the three species (Figure 2). Chemical digestion dissolved leaf biological material, leaving the waxy cuticle which was mounted on a microscope slide, ready for stomatal analysis, as per Christophel and Rowett (1996).

Three replicate stomatal / epidermal cell counts were taken using a light microscope fitted with a graded eyepiece on a known viewing field; these counts were obtained from the adaxial and abaxial surface of leaf squares sampled from the tip, middle and base of the 5 leaves of each specimen. Within the leaf fragment i.e. the leaf square removed mid-leaf, 3 replicate stomatal / epidermal cell counts were taken from the inner, middle and outer fragment, on both adaxial and abaxial surfaces. As *A. smithii* is hypostomatous (i.e. stomata restricted to the abaxial surface), no stomatal analysis was conducted between leaf surfaces.

Stomatal density was then expressed as number of stomata per mm^2, while stomatal index was calculated by equation 1, as per Salisbury (1927).

$$\text{Stomatal Index (S.I.)} = \frac{\text{no. of stomata X 100}}{\text{no. stomata + no. epidermal cells}}$$

(**Equation 1**)

Statistical analysis involved the conduction of a full-factorial repeated-measures general linear model (GLM) analysis (SPSS Version 12.0) to determine significant variation in stomatal frequency, among leaves of the same species, within different positions on the leaf surface, between adaxial and abaxial leaf surfaces, and within a cuticle (i.e. leaf fragment).

Results

Assessment of intrinsic variation in stomatal density from leaves of A. melanoxylon

Significant differences were found in stomatal density amongst different leaves within a single specimen of *A. melanoxylon* and amongst various locations within a single leaf (Table 2). No significant difference was found between adaxial and abaxial leaf surfaces for stomatal density, nor was there any significant interaction between any of the specimens assessed (Table 2).

Variation in stomatal density within a cuticle, a 4 x 4mm leaf square, sampled from the middle of leaves from *A. melanoxylon* were found to be significantly different (Table 2). There was no significant difference in stomatal density sampled from various locations within a leaf fragment, nor was there any difference between leaf surfaces or interactions between specimens assessed (Table 2).

Assessment of intrinsic variation in stomatal index from leaves of A. melanoxylon

Stomatal index of *A. melanoxylon* was found not to vary significantly among different leaves, among locations within the same leaf or between leaf surfaces (Table 2). Variation in stomatal index within a leaf fragment (inner, middle and outer positions), among leaves from the same position and between adaxial and abaxial leaf surfaces were also not significant (Table 2).

Assessment of intrinsic variation in stomatal density from leaves of A. smithii

Stomatal density in *A. smithii* was not significantly different when compared from various locations among leaves (Table 2). Nor was a significant difference noted for stomatal density from different locations within a single leaf, and no interaction between the test subjects was found to be significant (Table 2).

Significant variation was demonstrated in stomatal density within a leaf fragment sampled from the mid point among leaves of *A. smithii* (Table 2). No significant difference was found at various locations within the leaf fragment, nor was there any significant interactions between specimens tested (Table 2).

Assessment of intrinsic variation in stomatal index from leaves of A. smithii

No significant difference was found among leaves when stomatal index was examined from various locations within *A. smithii* leaves (Table 2). Sample position within an individual leaf and interaction between these factors, also did not significantly influence stomatal index (Table 2). When stomatal index was sampled from the mid point among leaves, a significant difference was found (Table 2). Sampling stomatal index from various locations within the leaf fragment revealed no significant variation, nor was there any significant interaction between factors (Table 2).

Assessment of intrinsic variation in stomatal density from leaves of E. obliqua

Stomatal density demonstrated significant variation among leaves and between leaf surfaces from leaves of *E. obliqua*, a significant interaction between leaf * surface test subjects, was also found (Table 2). As the leaves of *E. obliqua* hang vertically, leaf surfaces were designated 1 and 2, as opposed to adaxial (upper) and abaxial (lower) leaf surfaces. No significant difference was noted in stomatal density from different locations within leaves (Table 2). However, stomatal density did vary significantly between leaf surfaces, but there were no significant interactions between any test factors (Table 2).

Assessment of intrinsic variation in stomatal index from leaves of E. obliqua

Intrinsic variation in stomatal index from *E. obliqua* was significant among leaves and between leaf surfaces, no significant interaction was observed between these test factors (Table 2). There was no significant variability in stomatal index in relation to location on the leaf (Table 2). Stomatal index did not vary significantly among leaves when sampled from the same leaf location or among different positions within a leaf fragment, however, a significant difference was found between leaf surfaces (Table 2). Also, interactions between test factors were not significant (Table 2).

Discussion

Intrinsic variation in stomatal density and index was assessed among leaves, within leaves, within leaf fragments and between leaf surfaces from individual specimens of *A. melanoxylon*, *A. smithii* and *E. obliqua*. As hypothesised, stomatal index produced a less variable measure of stomatal frequency than stomatal density (Tables 2), thus being less prone to intrinsic variation, a finding consistent with many studies (Salisbury, 1927; Sharma and Dunn, 1968; James

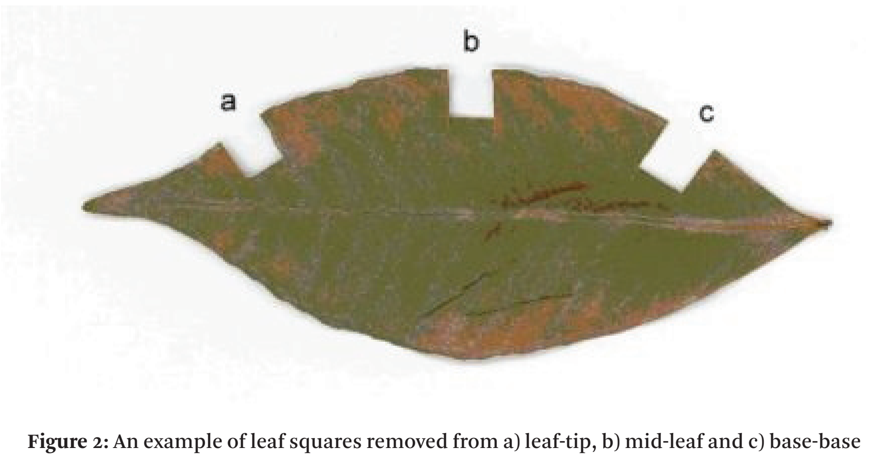

Figure 2: An example of leaf squares removed from a) leaf-tip, b) mid-leaf and c) base-base from a leaf of *Acmena smithii,* which was used for the assessment of within leaf stomatal frequency variation.

and Bell, 1995; Ferris et al., 1996; Smith et al., 1989; Zacchini et al., 1997; Stancato et al., 1999; Royer, 2001). This consistency in stomatal index is due to stomata being expressed as a ratio to epidermal cells, which accounts for epidermal cell expansion that may be influenced by a number environmental variables and hence, alter stomatal density (Salisbury, 1927; Beerling and Chaloner, 1992). Therefore, stomatal index is the preferred measure of stomatal frequency when attempting to apply this character as a biological-proxy (Beerling and Chaloner, 1992; Van Der Burgh et al., 1993).

Intrinsic variation among leaves of Acacia melanoxylon, Acmena smithii and Eucalyptus obliqua

Stomatal density in *A. melanoxylon*, and stomatal density and index in *A. smithii* and *E. obliqua* exhibited significant intrinsic variability among leaves (Tables 2). Interestingly, stomatal density and index in *A. smithii* was not significantly different among leaves when sampled from multiple locations, although was significantly different among leaves when sampled from a consistent location (mid-point). Conversely, in *E. obliqua* stomatal density and index did vary significantly among leaves when sampled from multiple positions, but did not significantly vary when sampled from a static location (Table 2). Either of these scenarios is less than ideal because fossil material may contain complete leaves and / or leaf fragments, so significant variation within any stomatal character has the potential to obscure any possible climatic signal.

Intrinsic variation in stomatal density could be assumed to be attributed to, in part, by leaf-age which would affect epidermal cell expansion and, hence stomatal density (McElwain and Chaloner, 1995). However, this is unlikely as a) all leaves were collected progressively down the branch starting behind any obvious juvenile leaves, and b) stomatal frequency is fixed early in leaf development typically, when the leaf is 10 – 60% of its final size (Tichá, 1982). The most likely cause of intrinsic variation among leaves is shading or genotypic variation.

Shading by self or nearest neighbours would result in a heterogeneous microclimate across the leaf surface, with resultant variations in irradiance, leaf temperature and relative humidity (Givnish and Vermeij, 1976). These variables may potentially influence epidermal cell expansion and stomatal initiation; thus affecting both stomatal density and index (Körner et al., 1983; Ferris et al., 1996; Tichá, 1982; Furukawa, 1997). Interestingly, stomatal index in *A. melanoxylon* did not exhibit any significant intrinsic variation (Table 2), thus whatever factor(s) that influenced stomatal density in *A. melanoxylon*, and both stomatal density and index in *A. smithii* and *E. obliqua* was not influencing stomatal initiation in *A. melanoxylon*.

Intrinsic variation over the leaf surface in Acacia melanoxylon, Acmena smithii and Eucalyptus obliqua

Significant intrinsic variation was observed in stomatal density when sampled from the tip, middle and base of leaves of *A. melanoxylon* (Table 2). Variation in this stomatal character is likely due to microsite variation across the leaf surface, which is driven by boundary layer thickness (Givnish, 1978) and decreased water potential that is, increased evaporative demand and poor water supply (Royer, 2001). The product of increased evaporative demand is smaller epidermal cell size, and increased stomatal density per unit area (Royer, 2001).

No significant variation was found in stomatal index of *A. melanoxylon* among different leaf positions as stomatal index is insensitive to factors that influence epidermal cell size, such as, evaporative demand. Nor was any significant variation observed in stomatal density or index within leaves of *A. smithii* and *E. obliqua* (Tables 2). This lack of intrinsic variation across the leaf suggests that microsite variability over the leaf surface is not large enough to elicit significant change in stomatal initiation or epidermal cell expansion in *A. smithii* and *E. obliqua*, which is in contrast to previous studies (Salisbury, 1927; Sharma and Dunn, 1968; Ferris *et al.*, 1996; Smith *et al.*, 1989; Zacchini *et al.*, 1997; Stancato *et al.*, 1999; Royer, 2001).

Species specific sensitivity to microsite variability over the leaf surface may result from different plant life strategies. For example, *A. melanoxylon* uses phyllodes (modified petioles) as photosynthetic organs due to their high water use efficiency (Brodribb and Hill, 1993) and therefore may potentially be very sensitive to evaporative demand across the leaf surface, in comparison to *A. smithii* and *E. obliqua*.

Intrinsic variation over a leaf fragment in Acacia melanoxylon, Acmena smithii and Eucalyptus obliqua

Examination of the inner, middle and outer regions of a mounted cuticle (i.e. leaf fragment) revealed no significant variation of stomatal frequency in *A. melanoxylon*, *A. smithii* and *E. obliqua* (Table 2). As the inner leaf fragment represents mid lamina and the outer leaf fragment representing the leaf margin, the hypotheses stating that intrinsic variation is expected to be observed across this region of the leaf can be rejected. This finding is in contrast with previous research using other tree species (Salisbury, 1927; Sharma and Dunn, 1969; Smith *et al.*, 1989). Also, this suggests uniform stomatal distribution over leaf fragments in these species and explains the notable lack of intrinsic variation across the leaf surface.

Intrinsic variation between leaf surfaces in Acacia melanoxylon, Acmena smithii and Eucalyptus obliqua

Stomatal frequency did not vary significantly between the adaxial and abaxial leaf surfaces in *A. melanoxylon* (Table 2), suggesting that intrinsic or environmental factor(s) are exerting the same influence upon stomatal initiation and epidermal cell expansion, irrespective of leaf surface; resulting in consistent stomatal distribution between leaf surfaces. This finding is in contrast to past studies that have found the abaxial surface to be the most stable, in terms of stomatal frequency, differences in these results may be attributed to species-specific variation (Rowson, 1946; Sharma and Dunn, 1968 & 1969; Royer, 2001; Greenwood *et al.*, 2003).

Acmena smithii is hypostomatous, that is, stomata are restricted to the lower leaf surface, so no analysis was conducted for this variable. Significant intrinsic variation was found in stomatal density and index between leaf surfaces of *E. obliqua* (Tables 2), suggesting varying microclimatic conditions between leaf surfaces are eliciting different stomatal frequency responses. The environmental variable that is most likely to be attributed to this response in *E. obliqua* is irradiance. As leaves hang vertically they will receive morning and dusk light directly, one may assume that stomatal frequency would be greater on the leaf surface receiving morning light, as this would be the time when internal leaf [CO_2] is most reduced and thus demand would be at its greatest.

If stomatal frequency is to be employed as a palaeoclimatological tool, it would be highly desirable to select species that 1) have an existing fossil record, and 2) exhibit low degrees of intrinsic variability in their stomatal frequency, thus reducing the error associated with any past climate estimate. Significant intrinsic variation among leaves will result in a larger sample size being required in order to reduce this potential error, which may not always be possible in a limited fossil sample. Also, many fossil leaf samples are fragmented, so using a selected species that does not exhibit intrinsic variation across the leaf surface would be of great use. Stomatal index in *A. melanoxylon* meets all the requirements to be applied in the palaeobotanical realm to provide palaeoclimate estimates, due to the lack of intrinsic variation associated with this stomatal character and an established fossil record. Palaeoclimatological estimates based on leaf morphological characteristics also have the potential to provide valuable information on how future climate change may affect modern-day ecosystems at a regional level. Therefore, the ability to identify the appropriate candidates for palaeoclimatological analysis is fundamental in the interpretation of regional climate change; this research paper identifies an appropriate technique that can be applied for other plant taxa. Future research can extend to other species in the *Acacia*, *Acmena* and *Eucalyptus* genus' to determine if other related species exhibit the same intrinsic variation.

Conclusions

It was found that stomatal index in *A. melanoxylon* was not influenced by any intrinsic factor tested in this study, making stomatal index of *A. melanoxylon* an ideal candidate for application within the palaeobotancial realm.

Stomatal density of *A. melanoxylon* demonstrated significant intrinsic variability among leaves and among different leaf positions. Stomatal density and index in *A. smithii* was only found to vary significantly among leaves, while *E. obliqua* exhibited significant variation in stomatal density and index among leaves, and between leaf surfaces within those leaves.

It can be concluded that stomatal frequency in these three Australian tree species were relatively stable, in that, of the 4 measures of intrinsic variation (1 Among leaves, 2 Over the leaf surface- tip to base, 3 Across the leaf surfaces- mid lamina to margin and 4 Between leaf surfaces) no species exhibited significant variability in more than 2 test variables.

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The 2008 Australasian INTIMATE Meeting and Friends of the Quaternary Field Trip

Onekaka, Golden Bay, 12-15 June 2008

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On the 12th and 13th of June 2008, the Australasian Quaternary Association Inc. (AQUA) held the annual Australasian INTIMATE (INTegration of Ice-core, Marine And TerrEstrial records) meeting at Onekaka, Northwest Nelson. The meeting brought together 22 Quaternary scientists to present research and share ideas in the rustic charm of Victoria University's historic field station (Figure 1), and with the small dining room at capacity and an open fire warming our backs, intimate was an accurate description of the proceedings.

The list of attendees at the meeting included distinguished academics, industry research scientists and a handful of postgraduate students, who spent most evenings engaged in conversation, stimulated by

Figure 1. The Friends of the Quaternary Attendees (left top right). Back row: Les Cwynar, David Barrell, 3rd Row: Sam Dean, Fiona Shanhun, Helen Bostok, John Carter, Carol Smith, Andrew Mackintosh, Jeremy Pugh, 2rd Row: Phillip Tonkin, Rob Rose, Tim Barrows, Jamie Shulmeister, Giuseppe (Pepy) Cortese, David Hood, Martin Brook, Travis Horton, Front row: Marcus Vandergoes, Olivia Hyatt, Peter Almond, Sam Taylor, Andrew Lorrey. Absent: Iain Campbell.

Figure 2. A profile of the pit excavated into the terrace surface at Puramahoi (left) compared to Kaituna Formation deposits seen in East Takaka (right)

a selection of locally produced beers at the nearby inn. Besides providing a forum for lively debate and sharing ideas in a relaxed atmosphere, the two-day meeting was an opportunity for many to contribute to the growing Quaternary knowledge base with presentations and posters detailing their research. The event also provided an opportunity to review progress on an integrated climate event stratigraphy (CES), stemming from the successful launch of CESs for Australia and New Zealand at the 2007 XVII INQUA Congress in Cairns.

James Shulmeister (University of Canterbury) began the oral presentations by detailing preliminary LGIT (Last Glacial–Interglacial Transition) climate signals from an Auckland maar. Les Cwynar (University of New Brunswick) added an Australian flavour with his reconstructions of the palaeoclimate of Tasmania. Travis Horton (University of Canterbury) detailed the potential of stable isotopes as paleoenvironmental proxies. The first day concluded with a discussion led by Peter Almond (Lincoln University) about the progress to date of the INTIMATE initiative, and how the second phase of NZ-INTIMATE should proceed alongside the OZ-INTIMATE project.

The rain continued to fall on Day 2, so hot coffee and a seemingly endless supply of muffins were on hand as the next round of presentations got underway. Martin Brook (Massey University) began by presenting a glacial chronology from Park Valley, Tararua Range. Andrew Mackintosh (Victoria University of Wellington) gave a reconstruction of glacial activity in New Zealand during the LGM, while David Hood (University of Canterbury) maintained the glacial theme with a history of the Darwin-Hatherton glacial system in Antarctica. Giuseppe Cortese (GNS Science) detailed the work GNS was undertaking to develop a modern oceanic dataset using marine sediment samples for paleoclimate reconstructions in the SW Pacific. The only Australian attendee, Tim Barrows (Australian National University) followed the talks with a rundown of the initiatives of OZ-INTIMATE in the context of developing and integrating the NZ-INTIMATE project.

In the afternoon, Sam Dean (NIWA) outlined more recent changes to the New Zealand climate, and the use of climate model simulations to attribute temperature increases to natural or anthropogenic forcing. Carol Smith (Lincoln University) and Andrew Lorrey (NIWA) rounded out the oral presentations with climate reconstructions from vegetation proxies, examining LGM interstadial vegetation from phytoliths and OIS3 climate from Kauri tree ring chronologies respectively.

A selection of posters at the meeting provided interesting conversation topics during the coffee breaks, which included work from Jeremy Pugh (University of Canterbury) on the glacial history of the Lake Heron basin and John Carter (Victoria University) who presented a reconstruction of ancient atmospheric $^{13}CO_2$ from phytolith-occluded carbon. Marcus Vandergoes (GNS Science) detailed work toward an expanded chironomid temperature inference model for New Zealand. There was also a copy of the NZ-CES produced in 2007 courtesy of David Barrel's team at GNS, on display throughout the event.

After listening to a host of presentations over two days, detailing event stratigraphy from glacial features, climate simulation models, marine microfossils, stable isotopes, phytoliths, tree rings and invertebrate subfossil proxies, it was time to leave the comfort of the fireside and embark on the Friends of the Quaternary (FoQ) Field Trip, held over the 14th and 15th of June.

Figure 3. The Canterbury pit crew hard at work.

Figure 4. Lunch stop on Day 1 of the FoQ field trip; Looking toward the head of the Cobb Reservoir.

The focus for the field trip was the late Pleistocene geomorphology and stratigraphy of northwest Nelson. After a short drive, we met with local expert and our guide for the first day - Iain Campbell. The first stop was near Puramahoi where we viewed the Rockville Formation Terrace gravels and soil weathering. The terrace surface we were standing on was estimated by Iain Campbell to have formed during MIS 8, 3 glacial cycles ago. We walked across this terrace to view an excavation pit (Figure 2). The deposit was iron panned and a pond had formed in the bottom. A cemented siliceous-layered podsol soil was present. The estimated annual rainfall at this location was up to 3000 mm, which accounts for the significant weathering and leaching.

Although the site was located on farmland, low nutrient soils resulted in reduced vegetation productivity. A surface of low quality organic matter was underlain by an iron-coloured quartz rich E-Horizon, with an iron- and aluminium-rich alluvial B-horizon. The E-horizon had a degree of cementation, indicating some antiquity. There were 2 phases to the soil profile, reflected in a boulder conglomerate, which may be a beach deposit from the Pariwhakaoho River, overlain by a lag sand of accumulated silicate, associated with the removal of soluble minerals.

Next stop en route to the Cobb Valley was a location south of Takaka, where a road cutting exposed dioritic gravels of the Kaituna Formation, presumed to have formed in glacial age alluvial fans (Figure 2). Here we saw an accumulation of organic compounds with incipient silica cement, which was estimated to be approximately 100 ka by Iain Campbell. We observed grusification of diorites and granites, and spotted rocks, which may be schists.

After a brief delay due to a punctured tyre courtesy of a narrow bridge (Figure 3), we made our lunch stop for Day 1 on the ridge overlooking the Cobb Dam and reservoir in the Cobb Valley (Figure 4). The dam was built to produce hydroelectric power from the Cobb River, but was inactive when we viewed it due to presently low lake levels.

The Cobb Valley exhibits a rapid transition from a glacial u-shape to a v-shaped profile below the level of the dam. However, we saw a cut platform at a high altitude down-valley of the dam, indicating ice at higher elevations extending further down the valley. Possible explanations for this transition to the v-shaped gorge were that it was protected by gravel, ice, or a combination of both (dead ice). As recession of the ice occurred, fluvial processes eroded gravel and sediment. Similar examples were described by members of the group from the Otira Gorge in Arthurs Pass (Figure 7).

It was also evident from exposed rock above the gorge (and the presence of a historical mine site in the area) there was a large component of erosion-resistant magnesite, making it unlikely the gorge could have been eroded post-LGM.

Discussion ensued about the relative extent of ice flowing from the Cobb Valley, and it was noted that ice from a valley to the west would have also extended far enough to join with glacial ice flowing from the Cobb. A glacial bench below the dam was dated at 18 ka by Shulmeister et al. (2005) using ^{10}Be and ^{26}Al cosmogenic exposure ages, and is in phase with ice occupying the gorge during the LGM.

At the road cutting above the dam there was evidence of the ice extent in ice-deformed regolith. Large boulders overlying the sediments in this bench also displayed striations from contact with other rock surfaces during ice transport down-valley (Figure 5).

Several roche moutonees were evident at the head of the lake where the road ends, and a short walk up the valley took us over a forested moraine wall to view montane bogs by the river (Figure 6). Moraines in the area are heavily forested. However, the intervening areas on the Cobb Valley floor have no forest cover, only extensive tussock grassland vegetation. This pattern of vegetation was attributed to cold air drainage into the depressions at the base of the valley. This resulted in stratified vegetation cover, with cold tolerant grasses and sedge species occupying the swampy areas with low relief, while a canopy of *Nothofagus* sp. and *Halocarpus* sp. occupied the moraine ridges at slightly higher elevation, above the cold air depressions. The *Nothofagus* forest also extended up the valley walls to the natural bush-line.

One of the kettle-hole bogs we observed was approximately 1 hectare in area. When sampled by Shulmeister *et al.* (2003), it was found to contain close to 4.5 m of peat with blue grey glacial silts in the base. A radiocarbon date from just above the blue grey silts yielded an uncalibrated age of 17,100 $\pm$ 100 yr B.P (Shulmeister *et al.*, 2003). A section of the CV1 core taken from the same bog was tightly dated to Younger Dryas times (Shulmeister *et al.*, 2003). The vegetation on the moraine confining the bog consisted of *Nothofagus* sp. with *Halocarpus* cover bordering the bog tussock grassland. The arrival of silver beech on the slope above and around the kettle-hole moraine was radiocarbon dated to 3511 $\pm$ 72 yr B.P (uncalibrated) by Shulmeister et al. (2003). This coincides with an increase in delta ^{13}C values in the South Island speleothem record which forms the basis of the NZ CES, implying dryer climatic conditions were present at this time (Alloway *et al.*, 2007).

Saturday evening consisted of beer and an All Blacks test at a lively local Takaka Tavern. This was followed by a less than lively Sunday morning clean up of the field station before embarking on the final day of the FoQ field trip.

The trip began with a stop at Harewood's Lookout over the beautiful panorama of the Takaka Valley. This valley is different to most valleys as it has very little fluvial drainage. The main tributary enters to the side of the

Figure 5. Tim Barrows representing the Australian FoQ here looking closely for striations in the outcrop...find any Tim?

Figure 6. FoQ participants deep in discussion at the Kettle-hole Bog

Takaka Valley from the northwest and may explain the absence of glacial features in the head of the Takaka Valley.

It was hypothesized that ice exiting the Cobb Valley flowed northeast into the Takaka Valley. A lively debate ensued as to the likely process (glacial vs. fluvial) responsible for the formation of steeply dipping (5-7°) terraces observed on the western side of the valley. According to James Shulmeister's interpretation based on their height and orientation, these were most likely kame terraces, which formed as glacial ice exited the Cobb Valley. These kames extend all the way to Uruwhenua where there is the possibility of a terminal moraine ridge close to Sam's Creek. However, kettle-hole like structures in the terrace surface were not conclusive.

The trip then moved out of the bay and headed south. Led again by Iain Campbell, we went on a tour through the Moutere Depression/Nelson Lakes region to examine the glacial and periglacial environments and the occurrences of the Kawakawa Tephra with in these environments.

The Moutere depression is composed of gravels over 1000m thick. It is constrained by the Alpine Fault and Waimea/Flaxmore fault, to the west, and extends 25 km north-west to the foot of the Arthur Range. The gravels are Late-Pliocene in age and overlain by the Porika Formation, the oldest recognized quaternary glacial deposit (Suggate, 1965).

The first stop of the day was an exposed bank along the roadside close to Kerr's Hill. A team of Niwashi-wielding soil scientists, led by Philip Tonkin (University of Canterbury) sent sediment flying as they unearthed a well-formed fossil gully deposit typical of periglacial activity in the Moutere Hills area. The channel was full of sub-angular material suggesting past exposure of boulders to freeze-thaw conditions causing down slope movement of scree. The next stop was on the southern side of Kerr's Hill to look at an exposure of the Kawakawa Tephra. This Tephra was bordered by sub angular clasts similar to fossil screes, and suggest deposition occurred during colder climatic conditions.

The last stop of the day was in the Howard Valley to have a look at an excellent exposure of the Kawakawa Tephra first recorded by Iain Campbell in 1986. Iain showed us 2 sites where the Tephra layer is visible. The Tephra exposure by the stream was overlain and underlain by an organic material; however, at the second occurrence the organic material was not present. No pollen was present in the Tephra layer however the peat above and below the Tephra contained numerous grassland pollen spectra which were dated at approximately 20 ka (Campbell, 1986).

The sedimentary sequence consisted of grey silty sands overlain by organic material, which was topped by gravels. There was a good discussion about the paleo-environment during the deposition of the Tephra. This may have been deposited during colder periods, followed by aggradation of finer sediments and organic material which was then overlain by coarse material as the supply of sediment increased.

This concluded the INTIMATE Meeting and FoQ field trip for 2008. After 4 days of thought-provoking debates, discussions and blueberry muffins, we made our farewells to the non-Cantabrian contingent and headed home.
The 2008 INTIMATE meeting helped bring together a broad spectrum of Quaternary scientists to build a more detailed knowledge of the timing of climatic and environmental changes in the Quaternary, focussing on event stratigraphies associated with the end of the Last Glaciation.

By supporting the 2008 INTIMATE meeting and associated FoQ fieldtrip, AQUA continues its commitment to Quaternary science by promoting scientific communication and collaboration, providing an important forum linking quaternary research to the present with implications for the future.

Acknowledgements

People present over the 4 days were Peter Almond, David Barrell, Tim Barrows, Helen Bostok, Martin Brook, Iain Campbell, John Carter, Giuseppe Cortese, Les Cwynar, Sam Dean, David Hood, Travis Horton, Olivia Hyatt, Andrew Lorrey, Andrew Mackintosh, Jermeny Pugh, Rob Rose, Fiona Shanhun, James Shulmeister, Carol Smith, Sam Taylor, Phillip Tonkin and Marcus Vandergoes.

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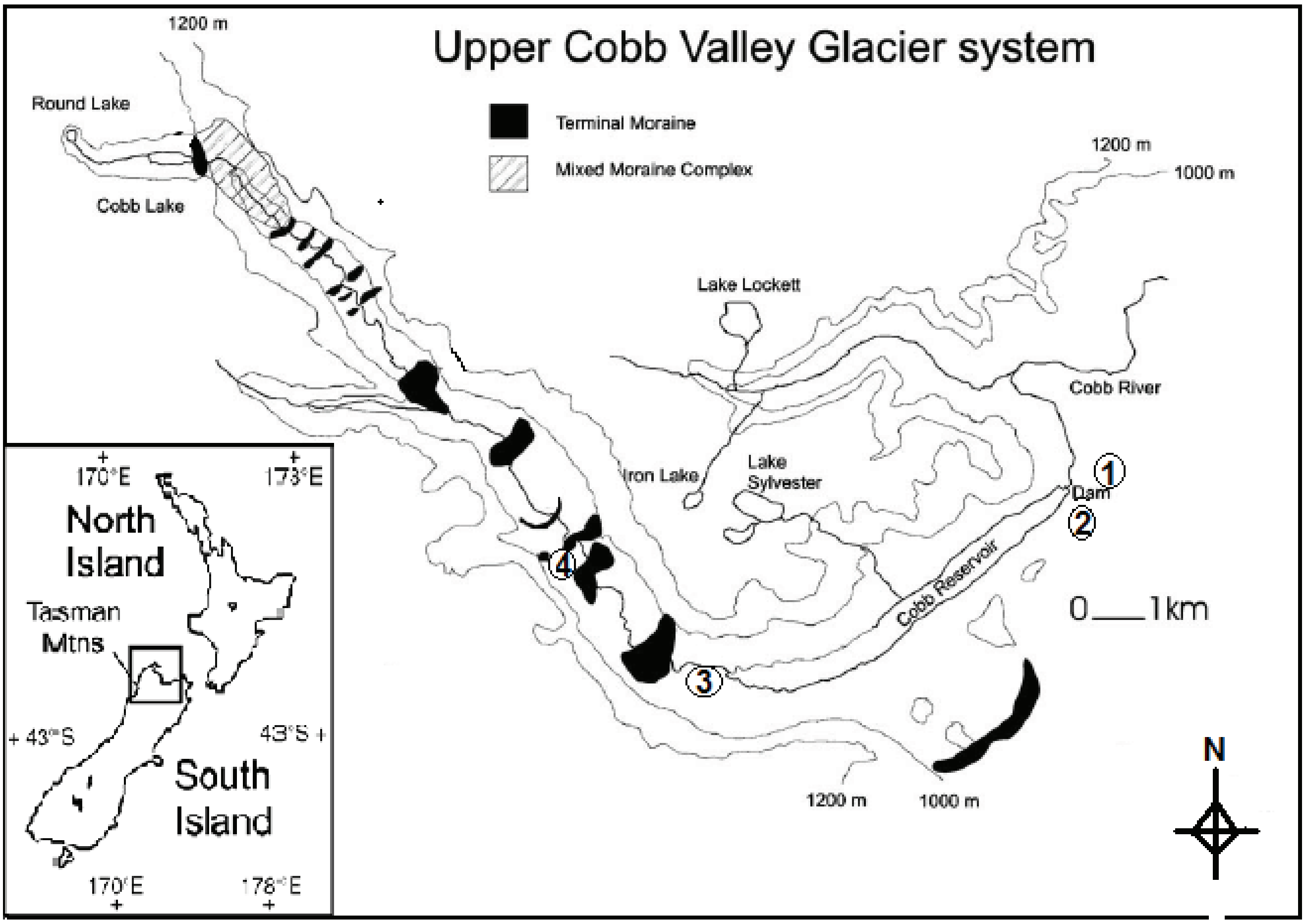

Figure 7. Site map of FoQ fieldtrip to Cobb Valley (map adapted from Shulmeister et al., 2005) Sites visited included: 1- Cobb Lookout, 2- Ice deformed regolith, 3- Roche moutonees and 4- Kettlehole Bog.

The Flinders University "Indigenous Archaeology in Australia" Field School, northwest Queensland

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From 24th June until July 22nd 2008 a group of graduate students from around Australia participated in a field school hosted collaboratively by staff from the Department of Archaeology, Flinders University and members of the Woolgar Valley Aboriginal Corporation (WVAC). The field school was based at an Indigenous rock shelter site known as Gledswood Shelter 1, located on a remote pastoral property, Middle Park Station, north of Richmond in northwest Queensland.

This area has been the subject of archaeological investigations by the coordinator Dr Lynley Wallis (Flinders University) who, since 2001, has coordinated a variety of projects with the WVAC. These have included:

- Surveying and recording of archaeological sites on Middle Park Station (Wallis et al., 2004)
- Geophysical surveying and excavation of hearths around Richmond and Bora Station (Moffat et al., 2008, Wallis et al., 2004)
- Investigation of the alleged Woolgar Massacre of Aboriginal people in the late nineteenth century (Wallis et al., 2005, Moffat and Wallis, 2005, Moffat et al., 2006)
- Archaeology of the Woolgar goldfield (Beale, 2006)
- Documenting Aboriginal art on Middle Park Station (Wallis et al., 2004)
- Trialing geophysical techniques for rock shelter investigations.

Wallis commenced an excavation of the Gledswood Shelter 1 from mid-2006, in association with a Flinders Research Grant. The shelter deposits were unexpectedly deep and due to time constraints, the initial test-pit had to be lined and backfilled. Additional funding was subsequently awarded from the Australian Institute of Aboriginal and Torres Strait Islanders Studies Unit (AIATSIS) in June 2007; this grant is being used to continue excavations at the site until either bedrock or culturally sterile units were reached. This background provided a context for the 2008 field school.

The field school was designed to extend students' knowledge of a range of field-based archaeological techniques, with a particular focus on vocational skills. The research conducted at these field schools is also aimed at building collaborative partnership with members of the WVAC with respect to research, teaching and learning, focused around community archaeological and heritage-based projects.

Students participated in various archaeological tasks centred around the recording of indigenous sites, places and landscapes. Work included aspects of site surveying, mapping, undertaking significance assessment, understanding conservation and management issues and photography, as well as the rock shelter excavation. These skills were developed in areas such as the Lower Woolgar township on the Woolgar Goldfield and the Rocks Crossing Axe Grinding Groove site, located on a tributary flowing into the nearby Woolgar River.

Students also worked with Flinders University research fellow and ANU PhD candidate Ian Moffat. Moffat instructed the students in the applications of archaeological geophysics to indigenous archaeological sites, with opportunities to trial equipment relating to this discipline, including a magnetometer and ground penetrating radar, in the field. Moffat also demonstrated to students the importance of sedimentology in identifying, understanding and recording not only indigenous sites, but also in understanding their environmental contexts and site formation processes.

Students learnt vital skills in interacting with Indigenous communities and local landowners. Communicating and negotiating with these stakeholders is vital in any archaeological research, and students experienced this first-hand from WVAC representative, Helen Smith. Smith's extensive knowledge of the landscape, esteem for Dr Wallis and interest in the queries of the students certainly highlighted to me the importance for the archaeologist to establish a close and trusting relationship with the communities they work with. Students also received a visit from Ken Isaacson, a local community member from the Mt Isa region and former Executive Council Member for the World Archaeological Congress, and Tanya Willis, a Cultural Heritage Officer with Southern Gulf Catchments. Both visitors spent a day working with the students and gave presentations on aspects of heritage management from a natural resource management and community perspective.

Every student who participated in the field school not only learnt about the archaeological discipline, but broader life skills. Flinders University post-graduate student, Kylie Lower, felt that one of the most interesting aspects from her field school experience was learning about perceptions of archaeological practice

Figure 1. Students Sarah Finch and Claire Von Maltzahn excavating the Gledswood Shelter I site.

Figure 2. Ian Moffat preparing to collect orientated sediment samples from the Gledswood Shelter I site.

from the Traditional Owners of the area: 'This field trip enabled me to participate in activities that I could not have done through straight university lectures and text books.' Sarah Finch, a recent graduate from the University of Queensland, echoed this sentiment, adding that 'the intensive nature of the field school really opened my eyes to the nature of working in the real environment of archaeological consultancy'.

Mick McKenzie, a Kuyani man from the Flinders Ranges and surrounding region in South Australia, participated in the field school as part of his work for BHP Billiton at the Olympic Dam expansion. 'I learnt a lot about basic archaeological techniques that I can now adopt in my own work in South Australia', Mr. McKenzie noted. 'I am now extremely interested in continuing further studies in this area, and have built strong bonds between the team members I worked with on this field school.'

Personally, I have learnt a wide range of skills that I will most certainly use in my own career. Apart from the practical aspects of this field school, such as learning field archaeological methods, I also enjoyed the company of the diverse range of people we met and the experiences that they shared with us.

I would like to thank everyone who contributed to the organisation of this field school. Firstly, to the members of the WVAC, especially Helen Smith, for allowing us to work and stay on their beautiful Country. Thank you to Lynley Wallis, for her tireless organisation of this field school and to Ian Moffat, Morgan Disspain and Victoria Wade for their teaching and patience. Also, I would like to thank Dick Cribb for his generous hospitality and Scott Hinze for granting access to the Gledswood site and for his assistance with logistics (particularly when we got the 4WD bogged in the river crossing!).

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ABOVE: Flinders University graduate students undertaking the Indigenous Archaeology Field School on Middle Park Station in North west Queensland take a break from undertaking field surveys of the Woolgar River.

BELOW: Anna Leditschke, a Flinders University masters student in Cultural Heritage Management, takes readings using the dumpy level. (Photos: Ian Moffat)

Speleothem research unlocking rainfall archives

Filling a critical knowledge void with speleothem-based research

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Australia is recognised as having a highly variable climate. However, the recent drought that has affected southern Australia has initiated extensive community debate about management of the nation's water resources. Declining rainfall and surface runoff has caused water storage reservoirs fall to unprecedentedly low levels. This has led to the planning and construction of desalinisation plants in Western Australia and the eastern states. Simultaneously, increasing population and a major increase in irrigated agriculture over the last 30 years, particularly within the Murray-Darling Basin, have contributed to greater water demand. Thus, the need to appropriately manage Australia's water resources is undisputed.

The current extended drought is impacting heavily on virtually all sectors of our community. Drought subsidies and water allocation have and continue to affect economic growth. Reduced domestic water availability, recycling and quality are highly charged issues. Extended, more intense and costly bushfire seasons are forecast due to climate change. Possible adverse health effects from warmer temperatures and dust, for example, are not yet known while land degradation and the threat to our endangered ecological species are not quantifiable. These far reaching impacts have prompted the wide interest into the nature of this drought and the desire to place it into a historical context.

Thus there is an immediate need for the best possible information for planning future water management strategies that are flexible and resilient enough to cope with strong inherent climate variability and future climate change. The inadequacy of the existing 100-year instrumental rainfall record as a basis for planning water resource allocation and storage requirements has been highlighted by the extended drought. A key question that cannot be answered using the existing relatively short instrumental record is whether the recent dry phase reflects an extreme event within the spectrum of natural climate variability or whether our climatic baseline has shifted. Much longer-duration records of natural rainfall variability are needed to resolve this. Robust, high-resolution palaeoclimate records from key water resource regions can provide this information.

Collaborative research by ANSTO, the Australian National University, the University of Newcastle and the University of Melbourne is being undertaken to construct multi-centennial to multi-millennial records of past rainfall from speleothems (cave stalagmites, stalactites) for key water resource regions in Australia (southwest Western Australia, the Murray-Darling Basin and the Sydney basin). Targeted karst areas are located in the Leeuwin-Naturalist, Yanchep and Kosciuszko National Parks, and Wombeyan Karst Conservation Reserve. Such information will provide critical baseline climatic data to better quantify and provide new insights into Australia's historic climate variability. This research is supported by a number of agencies involved in water resources and land management such as Land & Water Australia, Sydney Catchment Authority, the Indian Ocean Climate Initiative, the Water Corporation (WA), Department of Environment and Conservation (WA) and the Department of Environment and Climate Change (NSW).

Speleothems represent excellent terrestrial archives of high-resolution palaeoclimate information for southern Australia via the oxygen isotope and trace element variations they record. Speleothems have the capacity to preserve rainfall variability, dated with precise chronologies, extending from modern times back tens of thousands of years. Rainfall isotopes (linked to rainfall characteristics including amount) are preserved in the speleothem calcite, as are trace elements reflecting water residence times, the amount of soil and rock weathering and vegetation activity, all of which have a direct hydrologic connection. Variation in geochemical signals between wet and dry years has been proven (Treble et al., 2003; 2005; McDonald et al., 2004; 2007; Treble and Fischer, 2008; see Figure 1 for an example). Rainfall variability records are currently being reconstructed at decadal to sub-decadal, or better, resolution extending from the 20th and 21st C back in time for at least several centuries.

This research will make four major contributions towards understanding rainfall variability and the management of Australia's water resources:

- Firstly, by providing detailed, high-resolution rainfall records that extend well beyond the instrumental rainfall record, the research will provide critical baseline hydrologic information that reveals the intensity, frequency and duration of past droughts in southwest and southeast Australia. By capturing a larger sample of climatic "events", the data will enable evaluation of the robustness and resilience of contemporary water management policies adopted by state agencies, such as the rules determining irrigation allocations.

- Secondly, long-duration palaeoclimate records can be used to test, calibrate and improve the reliability of the current suite of global circulation and regional climate models. Increasingly, climate modellers are being asked to produce long-range hydrologic forecasts at the regional level to assist in developing future water management plans, particularly for future climate change scenarios. The performance and reliability of these models will be greatly enhanced by incorporating records produced by this study into the calibration and validation phases of model development.
- Thirdly, the records from this study will also be of value to climatologists examining how large atmospheric and ocean circulation patterns have changed historically and what such changes mean for regional rainfall patterns. As many of the current medium-term (seasonal to annual timescale) rainfall forecasting models are reliant on sea surface temperature observations, better resolution of long-term rainfall trends and global ocean and atmospheric circulation patterns will enable more accurate medium-term rainfall forecasting.
- Finally, the research will also fill the major southern hemisphere deficit in global high-resolution palaeoclimate records particularly for the last 1000 years and eventually, critical periods of past climate change in the Holocene and Pleistocene.

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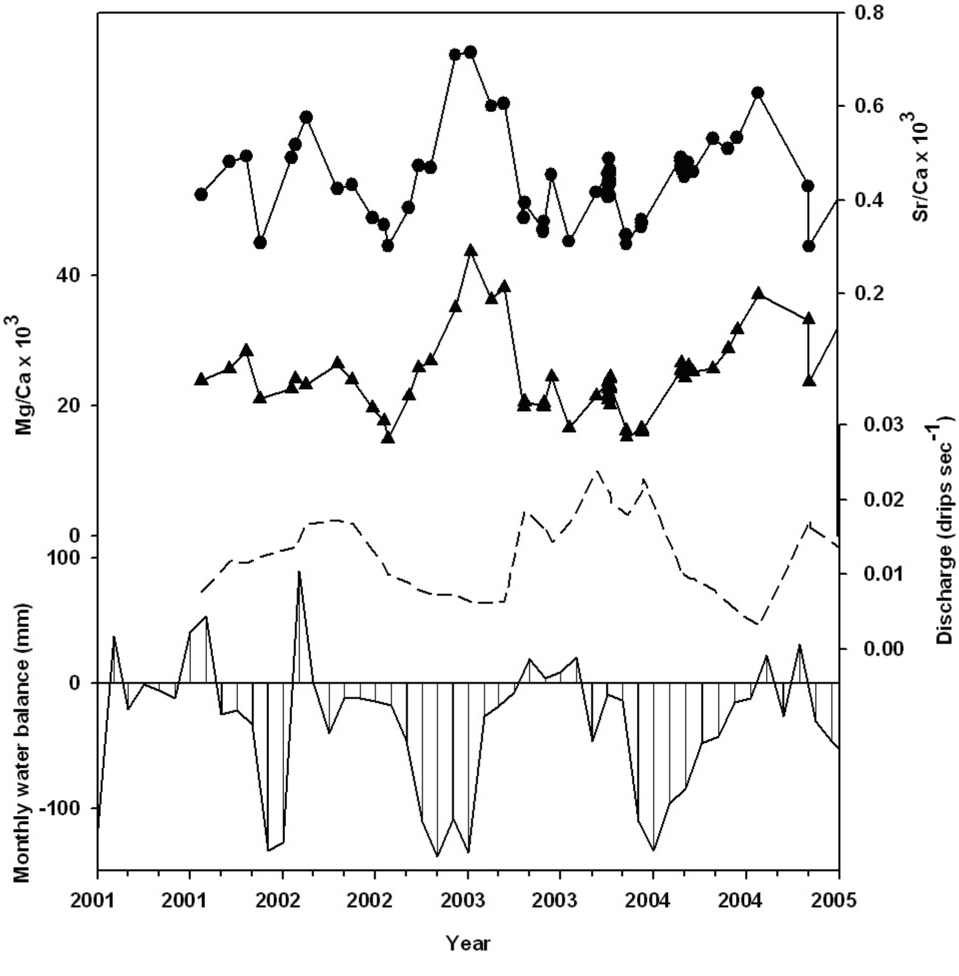
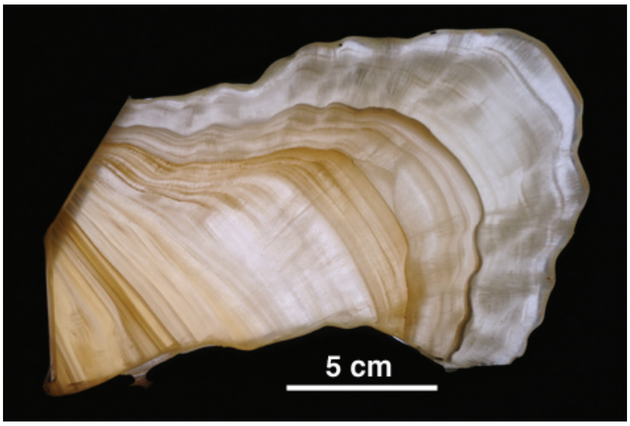


Figure 1: The hydrochemical response of cave drip waters from Kooringa Cave, Wombeyan to surface water balance (adapted from McDonald et al., 2004; 2007). Research at Wombeyan Caves has revealed that the chemistry of percolation waters passing through shallow caves systematically shifts according to the local moisture balance, which is strongly linked to regional rainfall. Specifically, the Mg/Ca and Sr/Ca of drip waters increase sharply during periods of water deficit due to calcite precipitation occurring in dewatered fissures above the cave. This geochemical signature is transferred to the speleothem via known partitioning coefficients.

TOP TO BOTTOM: Cave monitoring, Golgotha Cave, southwest Western Australia. Doline entrance, Golgotha Cave, southwest Western Australia. Cross-section of stalagmite in transmitted light. (Photos: Pauline Treble)



Channel breakdown and floodplain wetland morphodynamics in the Macquarie Marshes, south-eastern Australia

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The Macquarie Marshes occupy the distal reaches of the Macquarie River in south-eastern Australia and typify the distinctive style of channel breakdown of many allogenic, lowland-dryland rivers in the Murray-Darling Basin. A nested hierarchy of avulsion and channel breakdown exists in the system, ranging from the rivers and palaeochannels of the alluvial plain (> 10,000 km^2) to individual creeks, marshes and floodouts (< 100 km^2). This study examines the causes of channel breakdown in the Macquarie River and the geomorphic character and behaviour of the channels and floodplain wetlands in the breakdown zone.

The Macquarie River experiences downstream reductions in discharge, stream power, channel cross-sectional area and sediment calibre in its mid-lower reaches, before breaking down into a mosaic of smaller anastomosing and distributary channels and marshes where channel form is often lost completely. In-channel and floodplain sedimentation, serial avulsion and non-equilibrium fluvial conditions leading to marsh floodouts dominate this part of the system. Historical evidence (circa the last 150 years) shows that the frequency of avulsion in the Southern Macquarie Marshes is quite high, with an inter-avulsion period of around 70 years based on two recent, nested suites of channel changes. Avulsion and channel breakdown shift the foci of flooding and sedimentation on the low-gradient floodplain and wetlands respond by relocating, expanding and contracting. The forms and processes of avulsion and channel breakdown were investigated in detail in Monkeygar Creek, Monkeygar Marsh and Willancorah Swamp within the Southern Macquarie Marshes. Low discontinuous levees and a broader alluvial ridge line the main channel of Monkeygar Creek and proximal cross-floodplain gradients (0.003 to 0.022 m m^{-1}) are up to an order of magnitude greater than the prevailing longitudinal bed gradients (< 0.0001 to 0.0007 m m^{-1}). The channel declines in depth (~ 2.5 to < 0.5 m), cross-sectional area (~ 30 to < 3 m^2) and changes shape (width to depth ratio ~ 4 to 30) downstream, until a fine-grained floodout surrounded by wetlands occurs at the terminus. In-channel vegetation (up to 100 % intrusion) and sediment plugs can lead to backflooding and flow diversion. A general upward fining textural sequence (70 – 90 % mud to > 90 % mud) was found in the floodplain deposits and a subtle decrease in sediment calibre occurs away from the levees. An increase in sand content (up to 40 % sand) also occurs in the floodout zone and lower reaches of the marsh, where distinct sandy layers reflect flood-pulse deposition.

Environmental radionuclides, caesium-137 (^{137}Cs) and unsupported lead-210 (^{210}Pb$_U$), in marsh sediments indicate significant low concentration catchment inputs over time (^{137}Cs ~ 1.3 Bq kg^{-1}; ^{210}Pb$_U$ ~ 21 Bq kg^{-1}), while very low concentrations occur in contemporary suspended sediments, rain and aeolian dust. ^{210}Pb$_U$ profiles indicate greater overbank sedimentation for the proximal floodplain and in-channel benches over the last 90 years or so, while the thickness of recent deposits follows the topography of the floodplain, being greatest on the levees (up to 30 cm) and lower on the distal floodplain (< 10 cm). Sediments in the floodout zone have the greatest radionuclide inventories (^{137}Cs ~ 14 to 148 mBq cm^{-2}; ^{210}Pb$_U$ ~ 37 to 1000 mBq cm^{-2}) and depths (up to 40 cm), indicating a focal point of recent and fairly rapid sedimentation (0.04 to 1.1 cm yr^{-1}). Relatively high accretion rates (0.39 to 0.53 cm yr^{-1}) also occur further upstream on the levees in Monkeygar Marsh, while the distal floodplain has lower accretion rates (0.08 to 0.36 cm yr^{-1}), as does Willancorah Swamp downstream (0.03 to 0.55 cm yr^{-1}). Low to moderate sedimentation rates (0.14 to 0.2 cm yr^{-1}) on bank-benches reflect in-channel deposition and channel contraction. The mean contemporary sedimentation rates near the main channel in the Southern Macquarie Marshes, and especially those in the floodout zone, are around an order of magnitude greater than longer-term floodplain accretion rates (~ 0.018 to 0.292 cm yr^{-1}) previously found in the system.

The mechanism of avulsion in the Macquarie Marshes involves a combination of overbank and in-channel sedimentation processes which bring the system closer to an intrinsic stability threshold before a flood event and/or a channel blockage acts as a trigger for channel displacement. Alluvial ridge development via vegetation-enhanced, fine-grained overbank sedimentation around the main channel provides the slope for a potential avulsion course, which is a precondition for avulsion in this system. In-channel sedimentation and reeds cause marked declines in cross-sectional area and depth, leading to further reductions in fluvial efficiency, blockages, backflooding and decreases in existing channel slopes. Sedimentation within and around the failing channel and erosional scour of flow paths on the floodplain then lead to development and incision of a new channel, which can lead to the partial or total abandonment of the parent stream. Channel breakdown in the Macquarie Marshes is a threshold-driven response to fluvial inefficiency. Distributary outflows, enhanced by avulsion, lead to downstream reductions in discharge and channel capacity until channel breakdown occurs in the lower reaches where sediment can no longer be transported and is dispersed on the floodplain in unchannelised floodouts and marshes. Since the style of deposition and marsh morphodynamics appear to be characteristic of other floodplain wetlands in the Murray-Darling Basin, this research provides a conceptual and practical framework for understanding other lowland-dryland fluvial systems in the context of their Late Quaternary evolution.

Amendments to the Australasian Quaternary Association (AQUA) Constitutions

Approved at the AQUA Extraordinary Meeting, December 9th, 2008, Victor Harbor, South Australia

Item 1: "10 PROCEEDINGS AT MEETINGS
10.5 Except in the matters of amendments to this Constitution, which must be passed by a three quarters (3/4) majority of members present, issues at meetings shall be decided by a simple majority of those present and voting in favour of the proposition – each member present being entitled to one vote only. Voting at meetings shall be on the voices, or by show of hands or ballot at the discretion of the president unless two or more members demand a ballot, whence voting shall be by ballot."

Rationale for amendment:
*Procedure for the election of officers and committee members is not an exception to the voting procedures outlined in Section 10.5.
* No requirement for a postal vote for amendments to the constitution is provided in Section 17, which details procedures for altering the constitution. Section 17 (Alteration of constitution) states that "The resolution presented must be passed by a three quarters (3/4) majority of members present."

Item 2: "11 COMMITTEE OF MANAGEMENT
11.1 The affairs of The Association shall be managed by an Honorary Committee, which shall consist of Ordinary, Student, Concession and Life members holding the offices of: President; Vice-President; Immediate Past President (ex-officio); Secretary; Treasurer; Public Officer; Conference Secretary; Editor of Publications; Information Technology Editor; and, up to 4 other committee members who may be co-opted by the committee, and may include the Chairperson of the Committee for Quaternary Research and an INQUA representative. If the position of President is filled by a member who primarily resides in Australia, the position of Vice-President shall only be filled by a member who primarily resides outside Australia (within Australasia)."

Rationale for suggested amendment:
* Section 11.1 currently contains no reference to a Vice-President, although the position is referred to in Section 12.
* The requirement for at least 4 other committee members is an unnecessarily complex administrative structure.
* The requirement for the Vice-President to be a resident of New Zealand unless the position of President is occupied by a resident of New Zealand reflects current practice.

Item 3: "11 COMMITTEE OF MANAGEMENT
11.4 Nominations for the positions of members of the Committee may be received by the Secretary until the date of the proposed general meeting:
(i) where more nominations than positions available are received, the position will be allocated to the nominee who receives a simple majority of votes cast by those members present;
(ii) if no nominee receives a simple majority of votes cast, a runoff ballot shall be held whereby members present vote for the two nominees with the greatest number of votes in the initial ballot;
(iii) if insufficient nominations are received to fill the number of vacancies on the Committee, the President shall arrange to fill any such position by negotiation;
(iv) if the nominations received equal the vacancies on the Committee those nominations shall be declared forthwith."

Rationale for suggested amendment:
* Election procedure conforms to voting procedures outlined in Section 10.5.
* Clarifies procedure for situation where no nominee receives simple majority of votes cast.

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ABOVE: Rainwater pooling between dunes in the Simpson Desert after a storm in early February 2008. Photo: Carmen Krapf

Quaternary AUSTRALASIA

Quaternary Australasia publishes news, commentary, notices of upcoming events, travel, conference and research reports, post-graduate thesis abstracts and peer-reviewed research papers of interest to the Australasian Quaternary research community. Cartoons, sardonic memoirs and images of mystery fossils also welcome.

The Australasian Quaternary Association (AQUA) is an informal group of people interested in the manifold phenomena of the Quaternary Period. It seeks to encourage research by younger workers in particular, to promote scientific communication between Australia, New Zealand and Oceania, and to inform members of current research and publications. It holds biennial meetings and publishes the journal Quaternary Australasia twice a year.

The annual subscription is AUD35, or AUD25 for students, unemployed or retired persons. To apply for membership, please contact the Treasurer (address below). Members joining after September gain membership for the following year. Existing members will be sent a reminder in December.