

VOLUME 42 | NUMBER 2 | DECEMBER 2025

# *Quaternary* AUSTRALASIA



The Rhyme of the Ancient Stratigrapher

The Belgica Expedition 1897-1899

Challenges and Limitations of  
Cave Surveying for Archaeology



## AQUA LIFE MEMBERS

Current life members are Jim Bowler, Eric Colhoun, John Chappell (dec), Peter Kershaw, John Magee, Matt McGlone, Geoff Hope (dec) and Jeannette Hope.



Jim Bowler  
(Photo credit: socialpolicyconnections.com.au)



Eric Colhoun  
(Photo credit: Tim Barrows)



John Chappell (dec)  
(Photo credit: Helen Chappell)



Peter Kershaw  
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John Magee  
(Photo credit: Giff Miller)



Matt McGlone  
(Photo credit: Manaaki Whenua  
Landcare Research)



Geoff Hope (dec)  
(Photo credit: <https://iced.s.anu.edu.au>)



Jeannette Hope  
(Photo credit: Stephen Berry,  
Australian National University Archive)

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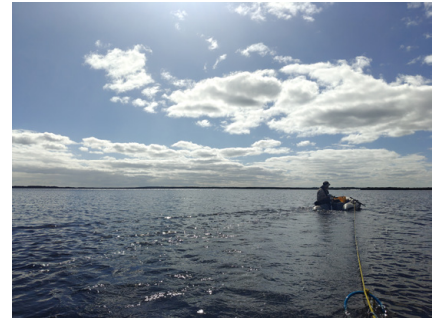
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#### Front cover photo:

John Tibby in a boat on Lake Jasper, towing Teye Aukes in a kayak, see [Field trip report south-western Western Australia](#) (Photo credit: Teke Aukes).

#### Below:

Partially excavated Diprotodon skeleton spreadeagled on floor of Lake Callabonna at site SIAM 3, 1970 with T. Maddock in background smoking a pipe.

See [A Diprotodon's last supper](#) (Photo credit: Rod Wells).





## EDITORIAL

Dear Quaternarists,

As we come to the tail end of 2025, this issue of *Quaternary Australasia* stands as both a reflection and a remembrance. A number of valued Australasian Quaternarists passed away recently and we use this issue to honour the lives and legacies of Richard “Dizzy” Gillespie, David Price, and Ian Sobbe — colleagues whose contributions to Quaternary science, mentorship, and friendship have deeply shaped our community. Their passion for understanding the ancient world continues to inspire new generations of researchers.

This year also brought moments of great joy and renewal. My (Lauren) family and I were delighted to welcome our son, August Matthew Alliston-Linnenlucke, born on 6 January 2025 — a beautiful reminder of life’s continuity and the new beginnings that mirror the rhythms we study in the Quaternary record.

Of course, this issue also highlights the diversity and depth of active Quaternary research across Australasia. From cave surveying challenges in Wallacea to new insights into the field landscapes of Noongar boodja/south-western Western Australia landscapes, our contributors remind us of the dynamic environments we study and the dedication required to document them. The featured research on Diprotodon guts and lake sediments from Lutruwita/Tasmania exemplifies the power of interdisciplinary approaches to examine longstanding questions.

We playfully celebrate creativity in science through *The Rhyme of the Ancient Stratigrapher* and spotlight emerging scholarship in our thesis abstract section. Tim Barrows’ review of Patrick De Deckker’s *The Belgica Expedition* rounds out the issue, bridging polar history and Quaternary inquiry.

Thank you to our authors, reviewers, and readers for another year of collaboration and discovery!

Wishing you a safe and restorative break, and moments of inspiration in these pages.

**Lauren Linnenlucke**  
Editor

**Kathryn Fitzsimmons**  
Shadow Editor



We encourage authors to use dual place names where possible (e.g., Kati Thanda-Lake Eyre), to acknowledge Country where the work was undertaken, and to acknowledge any Traditional Owner groups involved in the work.

AQUA acknowledges the Traditional Owners of the lands and seas of Australasia on which we live, work and conduct research, and we pay our respects to Elders past and present.



**Left:** Augies first snow experience at Perisher  
**Right:** Trying on mum’s Akubra



## PRESIDENT'S PEN

Dear AQUA colleagues,

I mentioned in an earlier Pen that I intended AQUA to become a Deductible Gift Recipient (DGR). This will mean AQUA will be eligible to issue tax-deductible invoices for donations. We sought some external advice and were quoted \$6000 by a consultant to do this. We thought that this was too steep for a small organisation, so Alex Francke (Treasurer) and I decided to tag team and do this ourselves. Given how long it has taken, we've occasionally wondered at the wisdom of this decision.

But the good news is that the end is in sight. Back in 1999, our Treasurer Christine Kenyon had the foresight to incorporate AQUA and register AQUA for an Australian Business Number (ABN). This is important to provide legal protection for members and office bearers, so they are protected against personal liability for legal problems or the organisation's debts. We can also accept donations and have bank accounts in the organisation's name. However, there are some compliance costs and reporting.

We recently discovered that our ABN was no longer compliant, so I applied for a new ABN, which covers us as an "Other Incorporated Entity". We have updated our records in Consumer Affairs Victoria and the Australian Business Register. I obtained our Incorporation Certificate from Victoria, where we originally were incorporated for historical reasons. However, we have been operating nationally (and internationally, if you count our New Zealand meetings) since 1999, so Alex has registered us as an Australian Body with the Australian Securities and Investments Commission. We now have a NSW "branch" which is my office at UNSW.

Alex spearheaded our application with the Australian Charities and Not-for-profits Commission (ACNC), and we are now registered with them as a charity that operates nationally. We fall under the categories "Advancing the natural environment" and "Advancing education". The final step is DGR status with the Australian Tax Office (ATO). The ATO have assessed us, and we fit the bill. However, we need to make some changes to our governing document (our constitution) to be fully compliant. These changes are necessary to demonstrate that we have a Gift Fund, winding up revocation requirements for the contents of the Fund, and to show that the organisation is not acting as a conduit (i.e. not laundering money). This will also ensure we remain recognised as a not-for-profit organisation and not charge GST. Alex put a great deal of effort into reading and learning the issues around our legal structure, regulation and policies, and I thank him on behalf of the organisation.



AQUA currently administers the Leanne Armand Award on behalf of the original donors. Unfortunately, DGR status will be too late for the donations in that Fund, but we'd encourage the original donors to maintain the award. We will also make a second award that will support *"the provision of information or education, or the carrying on of research, about the natural environment or a significant aspect of the natural environment"*. The disbursement will be matched to the fund size to ensure it continues into the future.

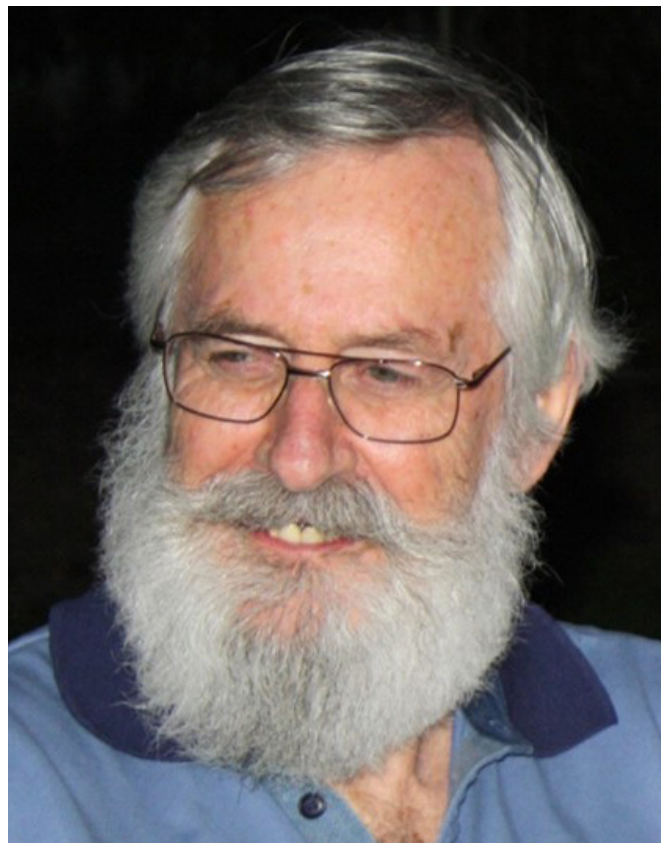
All of this is a long way to say that hopefully, this will encourage philanthropy to support students of AQUA into the future, supporting our role as an organisation to study the environment and its changes through time!

**Professor Tim Barrows**

*AQUA President*

## VALE RICHARD “DIZZY” GILLESPIE: COLLEAGUES BID FAREWELL

A giant in radiocarbon dating, Richard “Dizzy” Gillespie, recently passed away. Here, a number of his colleagues pay tribute to his life and work.



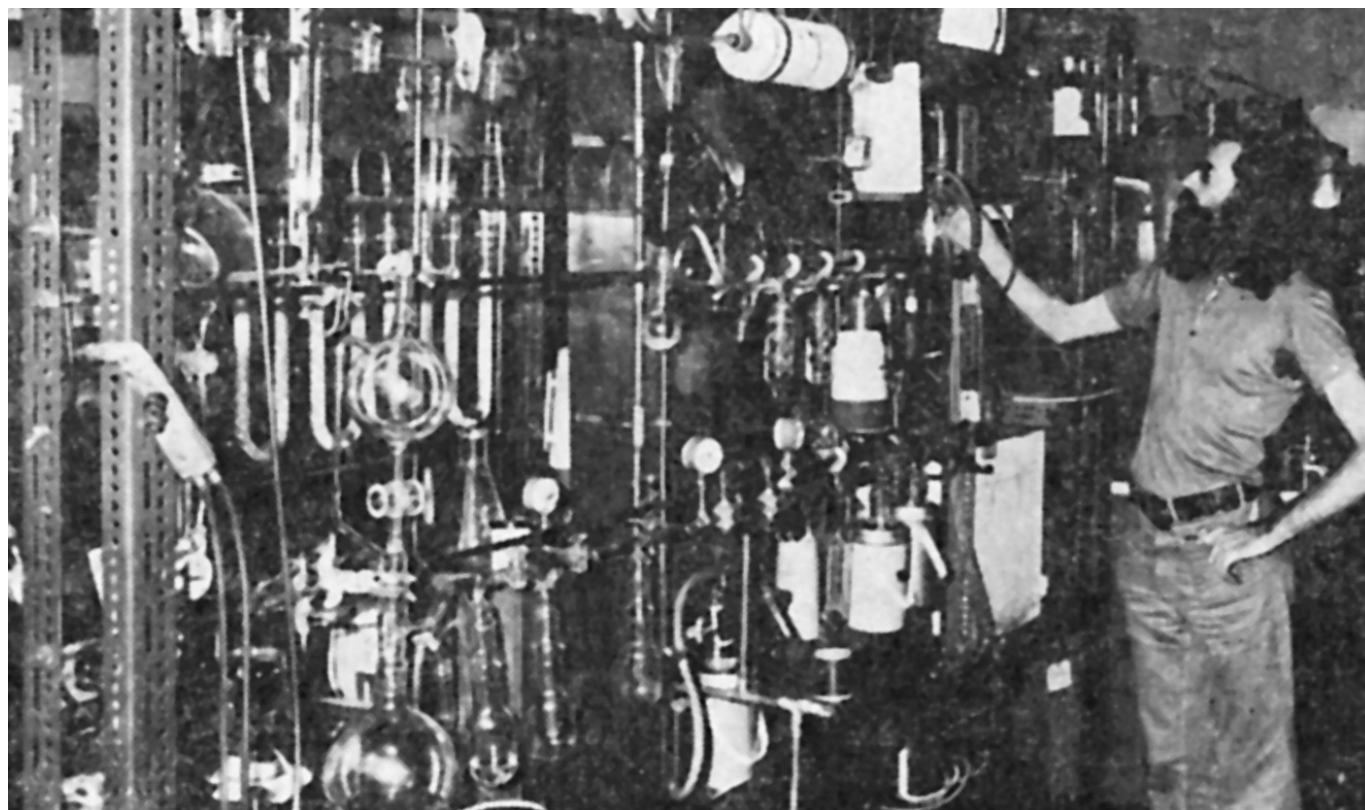
### TRIBUTE FROM TIMOTHY BARROWS

*Chronos Radiocarbon Facility, University of New South Wales*

Richard completed a BSc (Hons IIA) in 1969 and then completed a PhD in Physical Chemistry, both at the University of Sydney. He worked as a laboratory technician in industry prior to and during his research training. His first role after his PhD was as a Professional Officer at the Sydney University Radiocarbon Laboratory (1974–1979), before moving on to becoming the Senior Chemist at the Oxford Radiocarbon Accelerator Unit (1980–1984) in the United Kingdom (Gillespie, 2023). Following a brief stint as Research Associate in the Department of Geosciences at the University of Arizona he returned to Australia to take up positions as Researcher then Senior Research Fellow (1987–1992) at the influential Department of Biogeography & Geomorphology at the Australian National University. After his time at ANU he freelanced as a radiocarbon dating consultant but continued to research and publish.

Left – Photo 1: Profile Richard Gillespie

Below – Photo 2: Sydney University Radiocarbon Laboratory in 1973.





Richard was crucial to establishing one of the first radiocarbon laboratories in Australia. Richard Temple, in the Department of Physical Chemistry, Sydney University, had been tasked with establishing a radiocarbon laboratory in 1964, but it was not until 1970 with the help of Richard Gillespie that this vision was realised. Richard Gillespie had received training from Henry Polach, the former Director of the Radiocarbon Laboratory at ANU, and was responsible for commissioning a system to convert carbon to benzene for liquid scintillation counting to measure radiocarbon. During this time, Richard was awarded his PhD for work on radiocarbon dating of marine shells. The laboratory mostly reported dates from archaeological sites and assisted substantially in studies of coastal environmental changes. These early radiocarbon measurements were important for new chronologies from all over Australia, in Africa and beyond (Sydney University Natural Radiocarbon Measurements (lists I-V)). Upon Richard's resignation in 1979, he was replaced by Mike Barbetti (Ratinac, 2008).

Richard wrote a total of 87 journal articles, book chapters and other papers (H-index of 27). His first paper was in *Nature* in 1966 on the liquid ion-exchange extraction of some physiologically active amines – before he completed his undergraduate degree! He co-authored another five papers in the *Nature* portfolio and two in *Science*.

Richard was particularly passionate about improving radiocarbon dating to tackle the ongoing questions of when people arrived in Australia and when did the megafauna go extinct. He is particularly well known for the following papers:

- *Lancefield swamp and the extinction of the Australian megafauna* (Gillespie et al., 1978)
- *Radiocarbon dating of bone by accelerator mass spectrometry* (Gillespie et al. 1984a)
- *On the reliability of age estimates for human remains at Lake Mungo* (Gillespie & Roberts, 2000)
- *Dating the first Australians* (Gillespie 2002)
- *Short overlap of humans and megafauna in Pleistocene Australia* (Gillespie et al., 2006)

I enjoyed correspondence with Dizzy over the last 15 years. He was always generous with his ideas and data. We exchanged samples and talked about radiocarbon dating at Lake Mungo. After I took over as Director at the Chronos Radiocarbon Laboratory, we talked about sample preparation techniques, especially oxidation methods, and about reviewing his Radiocarbon User's Handbook, which is still useful, though a bit out of date and hard to

find. He passed on the Sydney Radiocarbon Laboratory database and archives (except for those of Mike Barbetti, which are lost), an amazing legacy produced over three decades.

## TRIBUTE FROM COLIN MURRAY-WALLACE

*Formerly of School of Science, University of Wollongong*

I first met Richard Gillespie in about 1988 when I was involved in radiocarbon and amino acid racemisation dating in The N. W. G. Macintosh Centre for Quaternary Dating at Sydney University. The Centre was established in 1984 through a bequest by Anne Macintosh and had relocated from the Chemistry Building to next door in the Madsen Building. The Centre was located on the ground floor because of the excessive weight of the Quantalus Liquid Scintillation Counter (Ratinac, 2008). Richard came into the Centre to catch up with people and to see how it was developing. That meeting would lead to many subsequent discussions over the years, where we explored approaches for extracting endogenous amino acids from shells and other organic materials to establish the integrity of finite radiocarbon ages close to the practical limits of the method. In the early 2000s, as Head of School, I appointed Richard as an Honorary Research Fellow in the former School of Earth and Environmental Sciences, University of Wollongong. Here, he had the opportunity to examine aspects of protein chemistry and relate amino acid racemisation measurements to radiocarbon ages. A recurring theme during this period was Richard's steadfast commitment to good science, and his abiding interest in the continued development and refinement of radiocarbon dating.

Richard's expertise in radiocarbon dating enabled him to participate in a wide range of research projects, ranging from geochronological contributions to archaeological investigations of early human presence at Lake Mungo and the Willandra Lakes region (Gillespie, 1998), examining patterns of Quaternary megafaunal extinctions, dating cellulose from the stomach contents of Diprotodons (Gillespie et al., 2008; this issue), to refining techniques in sample preparation for radiocarbon dating by accelerator mass spectrometry, and quantifying marine reservoir effects in the turnover of radiocarbon in ocean surface waters (Gillespie, 1975). Richard was also a co-author of the thought-provoking book, *The Bone Readers – Atoms, genes, and the politics of Australia's deep past* (Tuniz et al., 2009).

## TRIBUTE BY RACHEL WOOD

*School of Archaeology, University of Oxford*

Dizzy moved to Oxford to work with Robert Hedges and John Gowlett to help establish the Oxford Radiocarbon Accelerator Unit (ORAU) (Gillespie, 2023). He had a flair for imaginative chemistry preparations and laid the foundations for many of the techniques currently used in the ORAU. In particular, he was an early proponent of the compound-specific methods that stand at the cutting edge of research within the radiocarbon field even today (Gillespie et al., 1984). He published the first two radiocarbon date lists from the ORAU (Gillespie et al., 1984a, 1985), which included samples from the iconic sites of Goughs Cave (UK), Monte Verde (Chile), and the West Kennet long barrow (UK), as well as significant objects such as the Mappa Mundi. The chronology of these sites paved the way for studies that would continue for decades within the ORAU and other facilities around the world.

On his return to Australia, Dizzy continued with radiocarbon research – often from what he termed his ‘shed lab’. In this lab, he worked on methods to better date cellulose, including material found in the gut contents from megafauna (Gillespie 2019; this issue), achieving blanks that are typically only found within the controlled environments of university facilities. His research continues to contribute to our understanding of the early peopling of Sahul and the extinction of the megafauna. He continued to work on a manuscript on the age and diet of a remarkable collection of *Diprotodon* fossils from Lake Callabonna while in hospital.

**Photo 3:** Richard Gillespie enjoying wine and a smoke with Mark Pollard at the Oxford Radiocarbon Laboratory, probably Friday drinks.



## TRIBUTE BY TIM JULL

*Professor Emeritus, University of Arizona*

Dizzy arrived in Arizona in the late summer of 1985 as a postdoctoral fellow to work on bone chemistry with the Arizona AMS group. At that time, there were only a handful of operating AMS machines running carbon-14. Arizona and Oxford had very similar machines based on the original design of Ken Purser at General Ionex. He set up a lab dedicated to extracting collagen from small bone samples, following the existing protocols from Austin Long’s counter laboratory in the Geosciences department. The laboratory then still had gas counting (soon to be phased out), liquid-scintillation counting and AMS.

As a natural rebel, Dizzy was not totally comfortable with Reagan-era politics (one cannot imagine what he would think today). He soon found a number of soulmates and other colourful scientists with similar interests at the Desert Laboratory on Tumamoc Hill. This lab had been founded by the Carnegie Institution in 1903 and had a long history of studying the development of the environment in the Sonoran Desert. The director at the time, Paul Martin, was a well-known scholar in Quaternary extinctions. This led to a number of adventurous field trips to Mexico and less adventurous ones within Arizona to study mammoth-kill sites and other archaeological traces. Dizzy travelled extensively during his time at Arizona. After a year or so, he moved on (back to Australia).

## TRIBUTE BY MARTIN WILLIAMS

*Formerly University of Adelaide*

During the sixteen years (1969-1984) I was in the School of Earth Sciences at Macquarie University, Richard and I worked closely together, dating late Quaternary shells from the lower Blue and White valleys in Sudan, and from lakes and springs in the Ethiopian Rift.

On one occasion, we were up a cliff in the Ethiopian Rift collecting samples for dating when a war party of local nomads came waving their rifles and yelling to us to come down. Richard was nonplussed. “What should we do?” “Finish sampling” was my stern advice. We did and then climbed down to distribute water to the thirsty warriors, one of whom I knew well.

Richard Gillespie was also a gifted musician and played in his local band. During his time in America, he visited the legendary Louis Armstrong, and rumour has it that they played an extempore gig together.

After Richard moved from NSW to Adelaide, he often came to visit us, talk science, and share a contemplative drop of Coopers ale. We miss him greatly and salute his many scientific achievements.



**TRIBUTE BY ROBERT WASSON**

*Emeritus Australian National University, Adjunct James Cook University and National University of Malaysia/Universiti Kebangsaan Malaysia (UKM)*

In 1972, when I began fieldwork for my PhD on the Mundi Mundi Alluvial Fans west of Broken Hill, I had a conversation with Richard, who was then at the University of Sydney, about sampling for charcoal dating. TL and OSL were not on the radar.

He then undertook a flight to Broken Hill, at his own expense, to help with my sampling. I met him at the airport, and we travelled to the vast plain, which was to become a major location for the Mad Max 2 film and later the Mundi Mundi Bash. He was great company with many stories of his own sampling exploits, and he helped me enormously because at that stage I had little experience, having only taken a few samples at my Honours field site somewhat further east.

From that time onward, Richard was always ready to provide advice, the most recent being when I was sampling cheniers on an island offshore from Darwin. If he didn't know the answer to a question, he would put me in touch with another expert. He was also prepared to indulge me in what in retrospect, was an audacious proposal, to obtain reliable ages from soil carbonate using radiocarbon.

Richard was a friend and colleague who was always willing to help with good advice and practical assistance. He will be sorely missed.

**TRIBUTE BY JOHN MAGEE**

*Formerly of the Australian National University and “Dizzy Heights”*

I first connected in person with Dizzy when he joined the ANU Dept of Biogeography and Geomorphology as a Research Fellow from 1987 to 1992. Dizzy's appointment probably arose because Dizzy was keen to return to Australia and both he and John Chappell believed it would be timely to invest resources into AMS radiocarbon applications to Australian Quaternary sites and chronologies. Dizzy occupied an upper floor departmental office that was equipped with a fume hood and built an AMS target production line, while also establishing collaborative connections with internal and external researchers and establishing links with accelerator facilities to date samples. Dizzy's office “lab” extended onto benches adjacent to the fume hood – probably untenable in modern OH&S regimes. I personally benefitted from collaboration with Dizzy at this time, having recently embarked on my part-time PhD research at Lake Eyre. SLEADS Project cores from 1982-3 drilling in Madigan Gulf contained about a metre

of finely laminated gypsum and clay perennial-lake sediments lying between the modern surface salt crust, and a putative LGM thicker, denser buried salt layer. The intercalated wet phase was believed to be Holocene but was then undatable, although the clay laminae in those evaporites contained pollen and micro charcoal. Dizzy successfully AMS dated new micro-organic extractions, establishing a firm Holocene chronology for the sequence. This outcome probably typifies Dizzy's wide collaborative activities during his fellowship, as his work enabled many other researchers and projects to access the AMS small sample capability, allowing novel dating materials and innovative new techniques of sample pretreatment and decontamination.

There were also some troubled times at ANU, when Dizzy's interactions with and expectations of access to research support staff were perceived as somewhat high-handed and abrasive by the latter. These communication issues were probably exacerbated by Dizzy's speech dysfluency. However, those ructions did not result in any long-term animosity or grudges, and Dizzy was always a regular and enthusiastic participant in departmental social activities, notably the informal inter-departmental cricket competition. Although Dizzy did not excel at either batting, bowling or fielding, his love of the game and his keenness to participate more than compensated for any skill shortcomings, and the times that he contributed an important catch, wicket, or some valuable runs were important to him. Near the end of Dizzy's fellowship, Henry Polach, the foundational and long-term director of the ANU conventional radiocarbon laboratory, retired. With his fellowship ending and now well established in ANU and Canberra, Dizzy was an applicant for the position, probably with reasonable expectations to be a favoured inside candidate. However, a decision was made to widen the facility's scope to embrace additional dating techniques and a non-radiocarbon practitioner from outside ANU was appointed. Not surprisingly, Dizzy was bitterly disappointed at this outcome, though from other perspectives, Dizzy's penchant for working alone, his tight radiocarbon research focus and his history of difficulties managing support staff all suggest that he was not well suited to leading a laboratory facility in a bold new direction with radiocarbon reduced to a mere component. However, I suspect that Dizzy might well disagree with and contest that assessment.

During Dizzy's ANU fellowship, he had arranged the completion of a one-room cabin-style dwelling built on a pole-supported deck platform on land he owned in the “hippy-country” rainforest hills just outside Stokers Siding in the NSW Northern Rivers region. This somewhat eccentric retreat was built at the edge of a hilltop overlooking a modest overgrown farm dam. At the bottom

of the steep driveway, a rustic hand-painted sign on the side of the rural access road announced the entrance to “Dizzy Heights”. At the end of his time at ANU, Dizzy packed up his life in Canberra and headed to Dizzy Heights. But he had not come home to drift into early forced retirement and discontent about what might have been; rather, he also brought all the portable remnants of his research laboratory equipment and materials and set up his own chemistry lab in a Dizzy Heights back shed. In this facility, he continued to research radiocarbon sample pretreatment, using journal access via internet connection to tertiary institution libraries and continued collaboration with colleagues via email. He also travelled regularly, visiting colleagues and research sites as well as conferences and meetings. This achievement was certainly facilitated by the arrival of email communication and the internet, but given the formidable logistical and financial issues, his achievements and productivity over some 20 years is astounding. After departing ANU, I worked on Quaternary geology aspects of a large groundwater investigation project in the surficial aquifers of the Darling Valley near Menindee. A sonic core in the modern Darling meander scrolls encountered a large wood fragment, providing an opportunity to radiocarbon date the sequence. The heavy humic staining of the sample cautioned against routine submission to a commercial radiocarbon facility, and I advised contracting Dizzy to extract a more reliable dating sample component free of contamination. Dizzy managed to extract a very pure cellulose sample, which produced a reliable early mid-Holocene age. Dizzy not only got some valuable income but also the leftover sample remnants provided him with ongoing research material of known age. I suspect similar contract arrangements with other researchers were an important component of Dizzy’s ongoing research support.

As a testament to his chemistry skills, his backyard lab never succumbed to explosion, fire or a hazmat emergency – at least none that he ever admitted to me. Nor was he ever raided by the heavily armed, body-armoured enforcement arm of the war on drugs, who tended towards deep suspicion of any rumours of a backyard lab. In addition to his research, life at Dizzy Heights also included occasional village cricket matches and opportunities to play drums with a local geriatric blues band. I remember Dizzy, then approaching 70, telling me that he was the youngster in the band who stood in for the regular drummer in his 80s, giving Dizzy hopes of more regular future gigs. This return to active music participation brought Dizzy great pleasure, but eventually age and infirmity took their toll, key band

members dropped out, and the gigs ceased. Meanwhile, Dizzy expanded Dizzy Heights by adding an adjacent separate structure containing a bedroom, bathroom and laundry on an expanded deck with a single roof extending over the combination. This created a comfortable, small, all-facilities dwelling well suited to the warm, humid climate. Because I have two sisters living nearby, I regularly incorporated visits to Dizzy Heights into family visits to the region. Our discussions ranged widely from research, colleagues and Quaternary chronology to current affairs and events in the wider world. We also often watched live test cricket on TV, and probably agreed more about the cricket than many other topics, but discussions were always lively and good-humoured. Over its initial years, the one-room version of Dizzy Heights somewhat notoriously lacked an entrance door; instead, the door hole had a two-piece hanging builders’ paper curtain nailed to the architrave. Dizzy’s explanation was that he had “run out of money at the critical time, the builders had departed, and, anyway, doors were overrated in that climate”. Imagine my surprise when one year I arrived to find the building paper gone and an impressive door filling the hole. Dizzy explained that his father had gifted him a door for Christmas. Dizzy is possibly the only person in the known universe ever to receive a front door as a Christmas present.

Eventually, age, health and infirmity issues rendered continued living at Dizzy Heights untenable. He could no longer venture down to the dam to pump essential non-potable water to his supply tank or keep up a myriad of other essential maintenance activities. So Dizzy sold Dizzy Heights and many of his possessions and relocated to a rented unit in Tweed Heads, where, in a phone call, he described estuarine water views and hopes that he could continue aspects of his research life and see out his days on his meagre budget. Unfortunately, times changed, rents skyrocketed, and Dizzy realised that he needed to move, not just out of that rental but out of that whole region where living costs now greatly exceeded his means. Therefore, he again packed his life into his car and set out to find somewhere affordable. He ended up in Adelaide. I had some phone conversations with him during these relocations and afterwards in Adelaide, but the last time I saw Dizzy face to face was at Dizzy Heights.



## IN RICHARD’S OWN WORDS

“On dropping out of Dandenong High School mid-final year, I found a job with SA Rubber Mills as a lab tech working on rubber and plastic components for the nearby GMH Holden plant, and on the development of polyurethane foam padded arm-rests, etc, for Holdens, and for household bedding. Four years of that was enough, so I hitch-hiked to Sydney via Mackay and Brisbane.

There I was offered a job at ICI in the industrial smoglands of Auburn. I had just accepted that when another job was offered, in the Pharmacology Department at Sydney University. This sounded more appealing than industrial Auburn, so I applied and was given the job. My boss Dr Diana Temple became my mentor, taught me many chemistry tricks, and told me I should do a degree. First, I had to matriculate, which I did by getting old exam papers from the library. I finished up getting 5B scores, which got me into Engineering but not Science. But I did well enough in first year and was able to transfer to Science.

Cleaning out my room, I noticed on Prof. Richard Temple’s (Diana’s husband) door was a hand-written note looking for a student to build a benzene synthesis line for radiocarbon dating. Never heard of that, but thought I would give it a go, and after applying, I was offered a PhD scholarship to build the system. I became possibly the first PhD student to build and operate a commercial radiocarbon dating laboratory.

After 10 years of liquid scintillation counting, that was enough, so I quit and went on the dole. Then when that money ran out, I went to the library looking up recent issues of *Nature* and *New Scientist*, and up came a job at Oxford, closing in 3 days, to work with new radiocarbon accelerator technology. I sent a telegram saying that a full application would follow, which Prof. Temple assured me I would not get. After an interview in Melbourne with Prof ET Hall, he rang me the same evening to offer me the job and thus began the best four years of my career.

Since the early Sydney days, I have been involved with the chemistry of samples collected by archaeologists and geologists destined for radiocarbon and stable isotope analysis. Fieldwork in Africa, Europe and North America, as well as many regions of Australia, has afforded diverse multi-disciplinary research opportunities.”

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## VALE: DAVID PRICE – IN MEMORIAM

Gerald Nanson and Tim Cohen

*School of Science, University of Wollongong*

It is with great sadness we write that David Price died on 2 September 2025 at Wollongong Hospital, while surrounded by his loving family. His funeral was on 12 September in Wollongong. He had been in good health for nearly all of his 86 years, even attending lectures and regular coffee mornings with friends during his final few months.

David was born on the 25 September 1938 in West Sussex, England. He remembered, as a child during the World War II years, the sound of ‘doodlebugs’ flying over the family house on their way to strike London, and of enterprisingly collecting from trees the parachutes left behind by those aviators lucky enough to escape from downed aircraft so that his mother could use the silk to make articles of clothing. Food was rationed, and sweets so loved by children were nonexistent. As a teenager after the war, he attended Bognor Regis Technical School, seven miles from home, before completing a Higher National Certificate in Applied Physics as a tertiary qualification, then working at the Armament Research Unit in Langhurst. At age 26, he and a friend emigrated to Australia. After several years he got a job as a technical officer at the Australian National University. David was part of a research team in the School of Fundamental and Theoretical Physics, developing thermoluminescence (TL) dating for the authentication of ancient artifacts and for dating geomorphological and archaeological sediments.

David moved to the University of Wollongong (UoW) in 1986 to take up an appointment as a professional officer in the Department of Geography. There, he established a TL dating laboratory for geomorphological and archaeological research. This move was both serendipitous and auspicious. His collaborative investigations with colleagues over subsequent decades drove UoW to become a premier institution globally in Quaternary research. David dated over 4000 samples while at the UoW, never saying no to an interesting dating problem, and is named on hundreds of peer-reviewed research papers as a consequence. He often worked evenings and weekends to complete an ever-increasing number of research projects. His authenticity work on ceramics tested over 1500 items and became the benchmark for the verification of artifacts by museums, private collectors, and antiquity dealers. It also became essential for helping to fund investigations into less well funded scientific research projects. His TL results,



and the promise of more, were profoundly important in the acquisition of ARC and other research funding for UoW staff, and for instigating new Quaternary research across Australia. Thanks to the breadth and depth of his contribution to the research work of postgraduate students and academic staff at UoW, David has left an enormously positive legacy and impact on the lives of his colleagues. Many have said *thank you* to him personally for a level of service over many years that went well beyond his job description! There would not be one amongst his collaborators who would not wish to acknowledge their particular gratitude to David. Pun intended, it would be no exaggeration to say that his luminescence dating *shone a light* hundreds of thousands of years into Australia’s Quaternary past!

In 1992, he received one of the inaugural UoW Vice-Chancellor’s Awards for Outstanding Service. In 2013, after his retirement, he was made an Emeritus Fellow of UoW, a distinction very few non-academic staff receive. With his wife Jacqui, David was a supporter of numerous university and local charities and organisations, including annually raising money for cancer research. At his passing, one UoW colleague who knew him well wrote: *David will be remembered as a true gentleman and, just as importantly, a gentle man. His kindness and compassion shone through in everything he did, touching countless lives with warmth and generosity. He gave of himself so freely, always with a quiet grace and an unfailing sense of care for others. Those who had the privilege of knowing him will carry with them the memory of his genuine spirit and his unwavering commitment to making a difference.* Importantly, during his decades of tenure at UoW, David, with his finely tuned taste for instant coffee, ran the departmental coffee club!

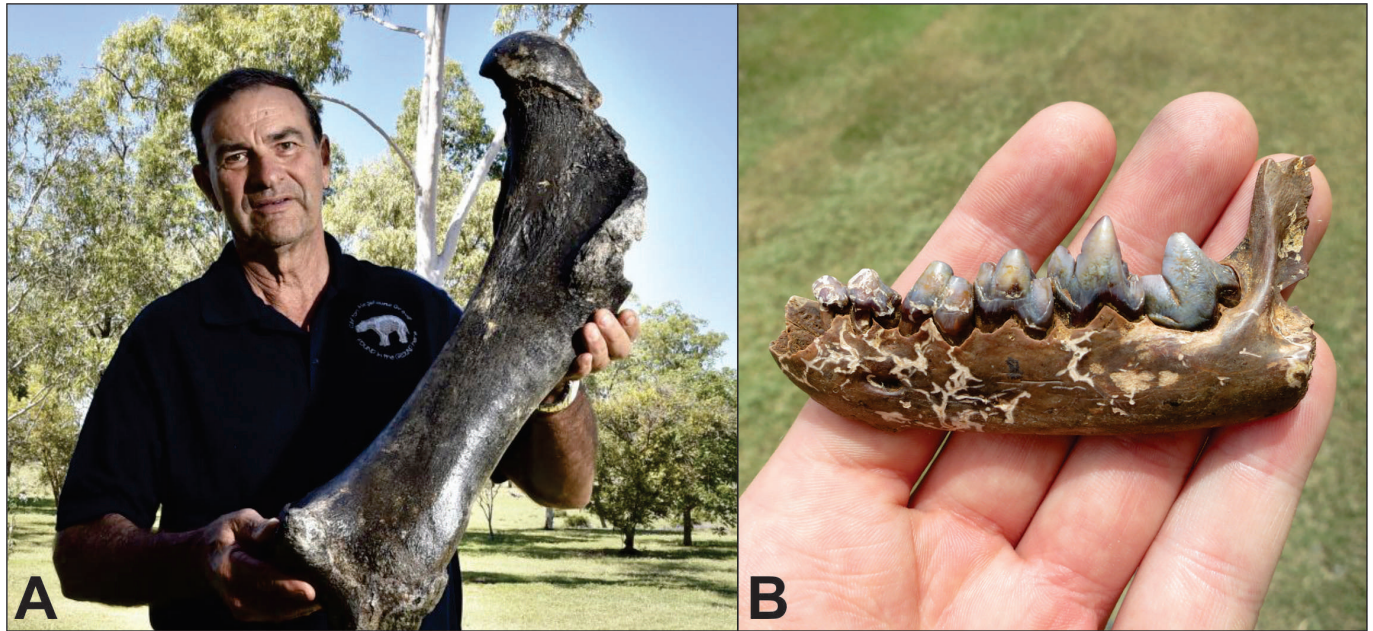
David was a remarkable scholar and a thoroughly decent human being with a remarkable sense of duty and family, someone who will be greatly missed.



## VALE: IAN SOBBE (1952–2025)

Gilbert J. Price

*School of the Environment, The University of Queensland, Brisbane, Australia*



**Figure 1:** A. Ian Sobbe holding one of his prized *Diprotodon* fossils (photo: Bev Lacey); B. Lower jaw of a Giant Tasmanian Devil from Ian's collection.

Although Ian Sobbe (Figure 1A) had spent a lifetime immersed in the landscapes and fossils of the Quaternary, it was only in 2024 that he was introduced to the AQUA community in a significant way. During the AQUA Minjerribah / North Stradbroke Island meeting that year, participants joined a pre-conference field trip to the Gondwanan Rainforests of southeast Queensland and the late Quaternary megafauna fossil sites of the Darling Downs (Price 2024). One of the highlights of that trip was a visit to Ian's private fossil collection, and fossicking with him along the megafauna-rich creeks near Clifton. For many of the participants, this was their first encounter with Ian. As always, he made an immediate impression with his quiet enthusiasm and encyclopaedic knowledge of the fossils beneath their feet (Stringer 2024).

Ian grew up on the Darling Downs. As a descendant of farmers, he was always destined for life on the land. After studying at Queensland Agricultural College in Gatton (now a campus of The University of Queensland), he returned to farming, but his fascination with the ancient fossils exposed along the creeks of the Downs began in childhood.

In the early 1960s, his family was visited by Professor Edmund Gill, a Melbourne-based researcher with varied interests in Quaternary geomorphology, palaeontology and archaeology. Gill was on the Downs to investigate the region's fossil deposits and was so impressed by young Ian's curiosity that he later offered to fund his study of palaeontology in Melbourne under his supervision. Although Ian's parents politely declined the offer, their son's passion never waned.

As an adult, Ian explored fossil deposits across Australia, but it was the ancient palaeo-channels of the Darling Downs that held his heart. He would often pause farm work to check what the latest floods had revealed. He had the uncanny ability to spot the faintest glimmer of bone from metres away.

Ian was far more than a collector: he was a self-taught researcher. In the late 1980s, he conducted predatory feeding trials with live Tasmanian Devils housed at Brisbane's Lone Pine Zoo to interpret tooth-mark patterns on bones. He was later able to show that Devils (various mainland species of *Sarcophilus*; Figure 1B) had gnawed his fossil bones tens of millennia before he found them (Sobbe 1990). Around the same time, Ian





**Figure 2:** A. Ian (right) about to reveal his incredible Marsupial Lion skeleton to AQUA field trip participants; B. Ian (left) showing off his fossil preparation facility to the AQUA group; C. Front page of local newspaper (10 July 2024) reporting Ian's Marsupial Lion discovery and AQUA field trip.

excavated and donated upper skull elements of the giant carnivorous goanna, *Megalania* (*Varanus priscus*), to the Queensland Museum; decades on, these are still the only known specimens of those particular cranial elements for the species (Molnar 1990). Among his later findings, Ian reported the first Late Pleistocene record of the carnivorous Spotted-tail Quoll (*Dasyurus maculatus*) in the region (Sobbe & Price, 2016) and also documented teeth from powerful, land-based predatory crocodiles there (Sobbe et al. 2013).

Ian saved his biggest biting discovery for the AQUA field trip itself. About a year earlier, while filming for the ABC *Catalyst* documentary *Megafauna: What Killed Australia's Giants* (released 2024), he spotted the top-end of a femur eroding from a creek bank and quietly bagged it. Days later, he rang me. After cleaning the specimen and removing the carbonate crust, he said, “You know what, Gilbert, I think that bone might be a *Thylacoleo*.”

The so-called ‘Marsupial Lion’ (*Thylacoleo carnifex*), a 150 kg apex predator, already featured in Ian’s collection, but this find prompted a return visit to the site. He soon uncovered not only the rest of the femur but a near-complete skeleton. As it turns out, this is one of the most complete *Thylacoleo carnifex* specimens ever found in an open deposit across the entire continent. Ian excavated the skeleton with minimal of support and prepared it in his home-made fossil lab. He delighted in showing it off, for the first time, to the AQUA field-trip group. The discovery even made the local newspaper, with several AQUA participants pictured alongside the fossil (Figure 2).

I could go on about Ian and his remarkable discoveries and contributions, but I want to share one final anecdote about that AQUA field trip. During the journey, and more than once, some of the younger members came up to me to ask questions about Ian’s collection or about other things we were finding along the creek. It amused me to



see their faces when I replied, “I don’t know, you’ll need to ask Ian about that.” Their expressions were a little perplexed that the academic was throwing the question back to the bloke they thought was just a farmer.

But Ian was never ‘just’ a farmer. He was a genuine peer in the field, a leader in fact. He showed that you don’t need a formal degree in Science to make a genuine impact. A curious mind, a willingness to discover, and a desire to learn more about the world are all that you need.

Ian died on 7 September 2025 after a brief illness. He is survived by his wife, Dianne, and their daughter, Amy.

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**Photo 3:** A young Ian Sobbe, his father Frances Sobbe and pioneering scientist Edmund Gill.

## QUATERNARY ARTS

### Tribute to Colin Murray-Wallace: The Rhyme of the Ancient Stratigrapher

Colin Woodroffe

#### The Rhyme of the Ancient Stratigrapher

It's an academic problem, and we really do not know  
How the coast developed, and why it looks 'just so'  
Ask Colin Murray-Wallace, the hero of this rhyme  
He has a special talent: he can read the sands of time

The sands you've known, may turn to stone, fair is foul and foul is fair  
The present key unlocks the past, but is the future written there?

There are no ways, that in 6 days, with another just for sleep,  
The world was made, as the good book sayd, Nay time is far too deep  
Archbishop Ussher, What a rusher! found six thousand years.  
Add a million, make that a billion, and still no 'vestige' appears!

Relative dating is over; it's too late to date your aunt!  
You just want to put things in order. But you absolutely can't!  
And 'count from the top' just has to stop. What if you have a hiatus?  
Could it be, the things we can't see, were simply done to frustrate us?

Unspill the spell, Time will TL — for an age is never a guess.  
With heat or with light, you're bound to be right, when you luminesce!  
And what can you tell from a fragment of shell, so small it's hardly in sight?  
Despite its size, it'll racemise, and what's left will soon be right.  
Not all that's been, has C 14, and it isn't overstating  
To say there's a lot that is simply not - amenable to dating.

Let Colin regale yer, in South Australia, with stories of his capers.  
Take a quick look - inside of his book, or read some of his very fine papers.  
The mighty Murray's in no hurry, to carry its waters south;  
Picture a river, reduced to a sliver; it can't even open its mouth.

Pray tell of the day, at Guichen Bay, and where the sands are from.  
So Colin re-told, of the sands that are old, with help from Thom and Tom.  
Off to the Woakwine where the wines are fine, in their terra rosa soils.  
A sample from here, another one near, enjoy the spoils of your toils.

His peregrination, to that part of the nation, enabled Colin to surmise  
The land is uplifting, the sea has been shifting, and the timing of some of its highs.  
You've not heard the last, of stratigraphies past, tales of the Naracoorte Range  
But focus instead, on what lies ahead, the next might be even more strange.

When the work of the geologist is finished, when the period becomes a full stop  
The most important chapter, will be that that sits on top.  
So Gilbert said, though he's long dead, and Colin in all his emails  
It's what's happening now, and why and just how, the here and now that prevails  
Now we are here, but it still isn't clear, how now can be related.  
The Chronologist's bind, I think you will find, is that yesterday's now is now dated.

Beware the ruthless, avoid the truthless, false facts and fake news,  
ChatGPT, won't help you see, what Darwin called false views.  
At the age when the sage turns the very last page, and closes the chapter on strife  
It's never too late, to rejuvenate, with the buoyancy of life!

Is there a moral, hidden in coral, or inscribed on Katelysia?  
It could be worse, buried in loess, written in dust would be easier.  
Time's left it traces, in the strangest of places; not in watches or clocks  
It's refrain's written plain, across the terrain, in sands and remarkable rocks.

In the fullness of time, at the end of the rhyme, when everything's signed and sealed  
In the Book of All, like a crystal ball, ALL will be revealed.  
And at that stage, the ink's dried on the page, will the geologist put down his pen?  
Or will he insist, there are bits that he's missed, and edit the whole thing again?

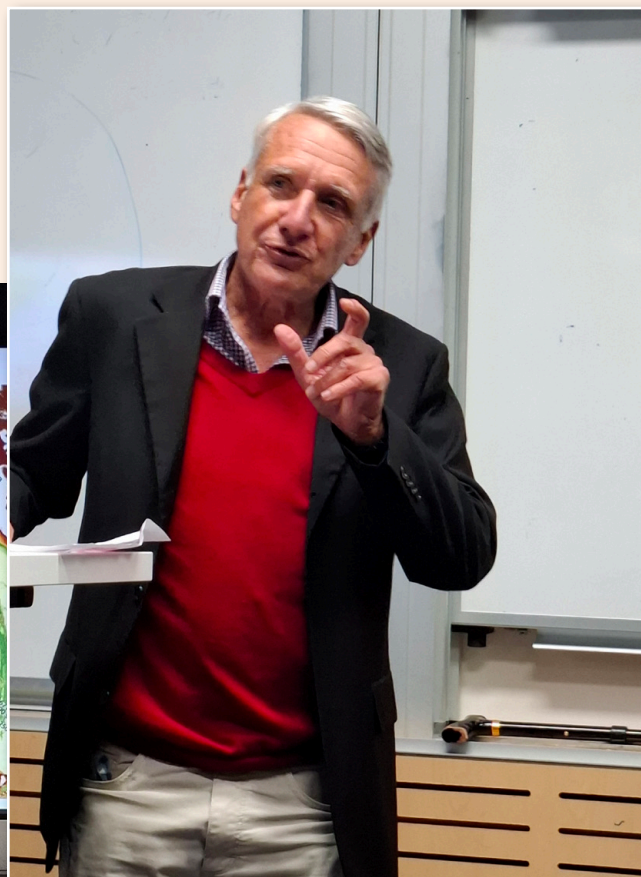
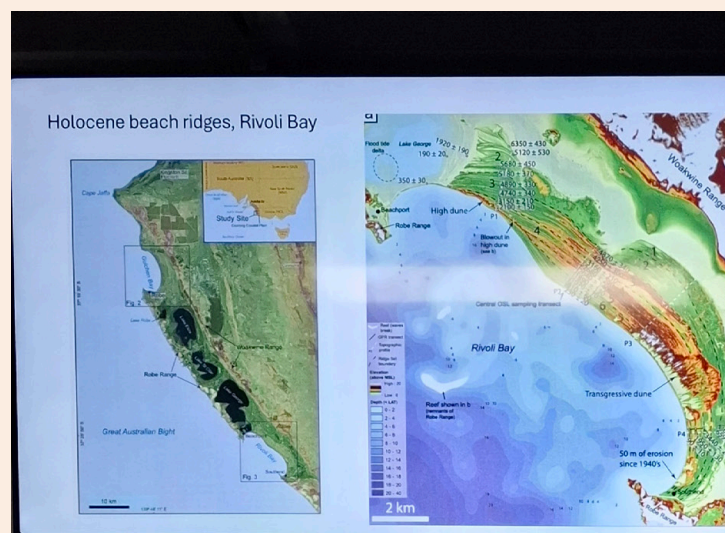
Photograph by Michael Gray





**Right – Figure 1:** Colin Woodroffe reading the Rhyme of the Ancient Stratigrapher at the Allan Sefton Memorial Lecture in August 2025.

**Below Figure 2:** Colin Woodroffe (left), Kerrylee Rogers (centre) and Colin Murray-Wallace (right).





## BOOK REVIEW

## THE BELGICA EXPEDITION 1897-1899

Patrick De Deckker

De Deckker, P. (2025). *The Belgica expedition 1897-1899*. Published by the author: Australia. ISBN 978-1-7640255-1-5. 295 pp.

Review by Timothy Barrows

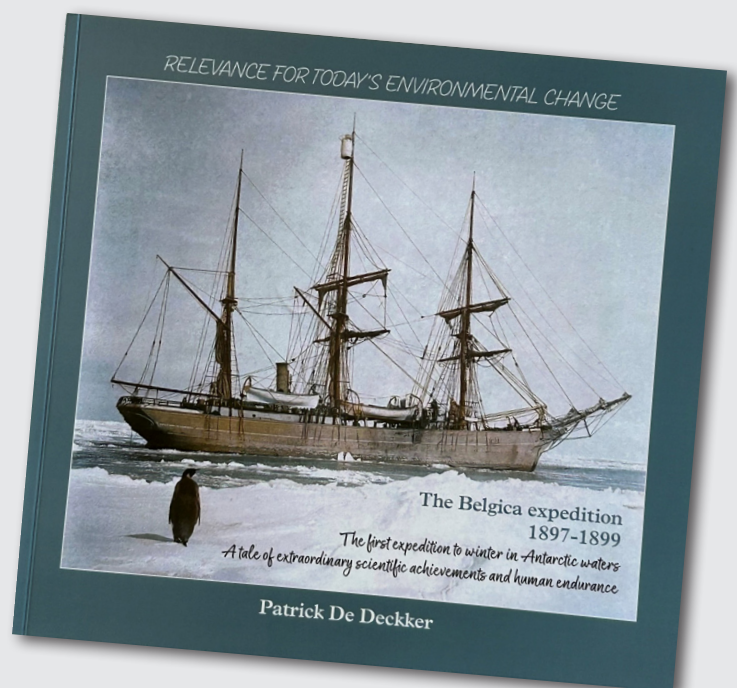
*Chronos Radiocarbon Laboratory, UNSW Sydney*

Have you heard of an expedition to Antarctica on a voyage of discovery and human endurance, but it got stuck in the ice? No, I don't mean Shackleton's voyage, which ended in disaster, but an earlier one that ended in success. The voyage of the S.Y. *Belgica*, funded by Belgium, took place 17 years earlier and didn't get as much press in the English-speaking world, but it was the first ever successful winter expedition to Antarctica.

Antarctica was a mystery at the time (the 1890s), and it wasn't even clear whether it was a continent or completely surrounded by ice. There was considerable scientific interest in exploring it and charting its coastline. The ship departed from Antwerp in August 1897, and the expedition intended to spend a year at Victoria Land, including a journey to the magnetic South Pole. After some success, things didn't go as planned. After failing to find a way into the Weddell Sea, the ship became trapped in the ice of the Bellingshausen Sea. Conditions were grim during that winter, with scurvy and poor morale. The crew ate penguin and seal meat, and the men slowly recovered (raw meat contains small amounts of vitamin C). The ship was freed from the ice after drifting for more than a year when the crew used explosives to help clear a channel. They returned to Belgium after 2.5 years.

The expedition gathered a vast amount of oceanographic data from the Bellingshausen Sea as well as biological, geological and glaciological data from around the Antarctic Peninsula. They even spent time in the Beagle Channel, where they also gathered data, including anthropological observations. They collected a full year of meteorological data, which, together with the other data, is a valuable baseline for climate change today from a previously inaccessible area vulnerable to warming.

Unfortunately, the scientific reports (92 publications), mostly in French, didn't make a big impact in the English-speaking world, and Patrick has sought to remedy this. He has painstakingly made the findings accessible in this large volume (De Deckker, 2025), following up on a previous article in *Polar Research* in 2018. The collection of the information took Patrick around the world through numerous archives in Belgium, Romania, Norway, Poland and the US. The colourised photos (by Patrick) add life to the original images, and the penguin cartoons by Dace De Deckker are delightful.





# CHALLENGES AND LIMITATIONS OF CAVE SURVEYING FOR ARCHAEOLOGY — A FIELD STORY FROM TANIMBAR AT THE EDGE OF WALLACEA

Hendri A. F. Kaharudin<sup>1,2</sup>

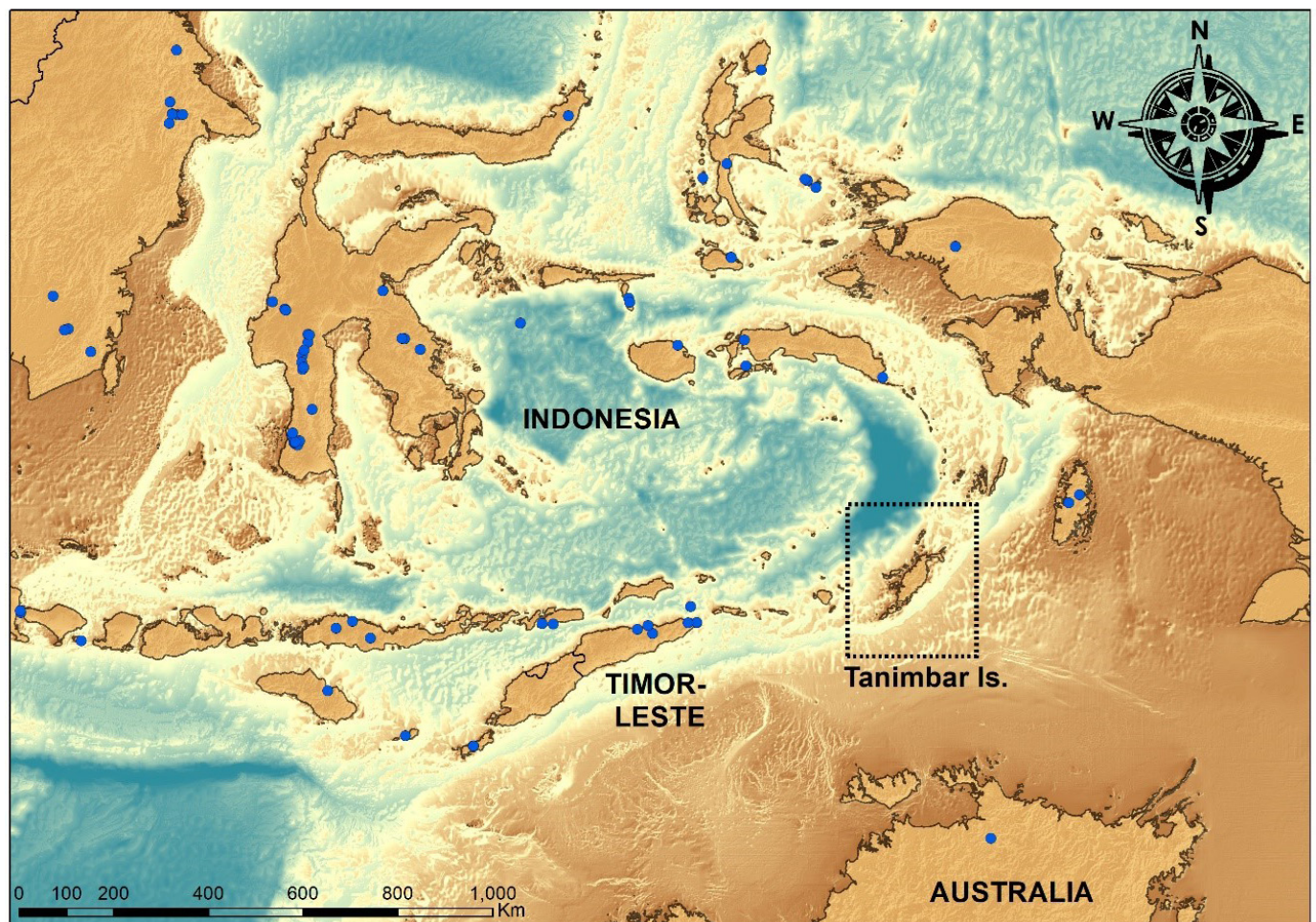
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## WHY TANIMBAR?

Wallacea has long been a fascinating region for paleo research. This biogeographical zone, located between Asia and Australia, includes numerous islands such as Sulawesi, the Moluccas, and the Lesser Sunda Islands. Its position at the intersection of two major continental plates has created a natural laboratory for evolutionary studies (Ali & Heaney, 2021). The Wallace Line, first described by Alfred Russel Wallace in the 19th century, marks one

of the most significant biogeographical boundaries on Earth, separating Asian and Australian fauna (Wallace, 1869). As a result, Wallacea is especially valuable for investigating evolutionary processes, species dispersal, and biodiversity patterns across deep time. The deep oceanic trenches that have long isolated these islands made the migration of terrestrial species challenging, contributing to the region's remarkable endemism and distinctive biodiversity (Hall, 2013).



**Figure 1:** Dated archaeological excavations of cave and rockshelter sites in Eastern Indonesia (blue dots), highlighting the lack of research to date on the Tanimbar Islands. Data source from Kaharudin et al. (2020).

The Tanimbar Islands occupy a unique geographical position at the easternmost edge of the southern Wallacean archipelago (Figure 1). Despite their significance, archaeological investigations in Tanimbar have so far been limited to surveys across a few of the islands, which have confirmed substantial archaeological potential. Evidence ranges from prehistoric sites — such as caves and rockshelters — to remnants of colonial occupation, including ceramics, cannons, and other artefacts (Ririmasse, 2016a; 2016b). Systematic excavation and analysis of cultural assemblages from Tanimbar would not only provide the first direct insights into the region's prehistoric past but could also yield crucial information about early human migration through southeastern Wallacea. Such work has the potential to clarify patterns of inter-island connectivity, the arrival and settlement of Austronesian populations, and possible westward movements from New Guinea (and greater Sahul) back into Wallacea.

### SURVEY METHODS AND CHALLENGES

Prehistoric humans likely explored and inhabited a wide range of environments across Island Southeast Asia. Archaeological evidence — including fossils and artifacts — has been recovered from diverse ecological settings such as coastal zones, river valleys, highland plateaus, and deep cave systems (Bellwood, 2017). Among these, caves and rockshelters are particularly valued in prehistoric archaeological research. Frequently used for habitation or burial, these sites often function as natural archives, preserving traces of human activity over extended periods (Anderson, 1997; Barker et al. 2005; Kaharudin et al. 2020).

The taphonomic conditions within caves further enhance their archaeological significance. Compared to open-air sites, many caves maintain more stable microclimates, characterised by relatively constant temperatures and humidity levels. They are also buffered from destructive external forces such as rain erosion, solar radiation, and intensive biological activity. These protective conditions limit vegetation intrusion and surface weathering, contributing to the preservation of stratigraphic integrity (Goldberg & Sherwood, 2006; Straus, 1990). Moreover, the sheltered environment of caves often supports the exceptional preservation of organic materials that would typically degrade in open contexts — such as bone tools, shell ornaments, plant fibres, and charcoal from ancient hearths (Kealy et al. 2020; O'Connor et al. 2019). Some caves may also preserve fragile cultural features like rock art, which can survive in relatively pristine condition for tens of thousands of years (Ilmi et al. 2021).

Such preservation enables high-resolution archaeological reconstructions. Stratified deposits in caves allow

researchers to construct detailed chronological sequences, making it possible to trace shifts in material culture, subsistence strategies, and social practices over time — insights that are often more difficult to obtain from open-air sites due to their greater exposure to environmental disturbance. However, caves and rockshelters are not immune to post-depositional processes (Huntley et al. 2021; Louys et al. 2017; O'Connor et al. 2010). Internal factors such as water percolation, sediment slumping, ceiling collapse, and bioturbation can significantly alter site formation and preservation conditions.

These complexities make the search for an ideal prehistoric site particularly challenging. Survey seasons are typically limited from one week to a month, depending on environmental conditions, site accessibility, and research funding (Kealy et al. 2018; Louys et al. 2017). Within such a short window, identifying even a single site with strong archaeological potential is often considered a significant success. Survey strategies usually begin with the consultation of geological maps to locate areas of steep topography, which are more likely to host caves or rockshelters. This method, however, often restricts investigations to karst or limestone landscapes (Cuthbertson et al. 2021; Horrocks et al. 2002). On volcanic islands, where caves are more likely to form from overhangs or lava tubes — as seen at Makpan on Alor Island (Kealy et al. 2020) — potential sites are far less visible through remote or map-based analysis alone. In such cases, systematic ground surveys become essential, though they are often time-consuming and physically demanding.

These methodological constraints are further compounded by the dynamic tropical landscapes of Island Southeast Asia. Dense vegetation, particularly in lowland rainforests, often obscures cave entrances and rockshelters that would be more easily visible in arid regions. Seasonal changes in vegetation density and ground cover mean that surveys conducted at different times of the year can produce dramatically different results. Sites that are accessible and visible during the dry season may become completely inaccessible once the wet season begins.

The monsoon season presents another major challenge. Many locations, whether on different islands or in remote areas within the same island, can only be reached by boat due to the lack of road infrastructure. During certain months, sea conditions become too dangerous for travel, creating narrow seasonal windows for archaeological fieldwork that require careful planning. In much of Island Southeast Asia, the peak monsoon typically occurs between November and March (Aldrian & Susanto, 2003). During this time, sea conditions can be treacherous, even





**Figure 2:** (a) The survey process begins with obtaining permission from local landowners, (b) followed by systematic exploration of the area using multiple transportation methods: vehicles, motorcycles, foot trekking, and (c) boat travel. Upon discovery, (d) potential artefacts and (e) archaeological sites are meticulously documented and recorded for subsequent detailed investigation.



for experienced local boatmen. Wave heights can increase suddenly, storm surges can damage coastal landing sites, and visibility is often reduced by heavy rainfall. These hazards not only prevent safe access to research areas but also pose serious risks to transporting equipment, particularly delicate scientific instruments that are vulnerable to rough crossings and sudden downpours.

Logistical challenges in accessing remote islands further constrain survey efforts. Transportation infrastructure varies greatly across the region. Many islands in Wallacea are reachable only by infrequent boat services or costly charter flights. Field teams must carefully balance the need for comprehensive survey equipment with the practicalities of portability, particularly when trekking through difficult terrain with limited vehicle access. These constraints often require difficult decisions about which areas to prioritise and which must be deferred for future investigation.

In these circumstances, local knowledge is invaluable. Indigenous communities, with generational familiarity with the landscape, often guide researchers to promising locations that might otherwise remain undiscovered. Oral histories frequently include references to caves used by ancestors or associated with cultural practices, providing important leads for archaeological research. However, building the trust and relationships needed to access this knowledge requires significant time and commitment, often beyond the scope of typical survey periods. This presents an additional challenge for research teams operating under tight timeframes and funding limitations.

After narrowing down the survey area using geological maps, the next essential step is to visit the nearest village and meet with the village chief. We introduce ourselves, explain the purpose of our research, and inquire about any caves, rockshelters, cultural sites, or historical artefacts within their territory. The chief typically assigns a guide with extensive local knowledge, often an elder, hunter, or farmer whose fields lie far from the village, to assist with the survey. It is customary to bring small ceremonial offerings as a sign of respect. These typically include betel nut, local tobacco, and *sopi* (traditional distilled liquor), though the specific items may vary depending on local customs (Kaharudin et al. 2024a). The survey often continues by asking permission from the landowner (Figure 2a), followed by exploring the area using cars, motorbikes, trekking on foot (Figure 2b), or traveling by boat (Figure 2c). Potential artefacts (Figure 2d) and sites (Figure 2e) are then recorded for further study.

## IDENTIFYING POTENTIAL SITES FOR EXCAVATION

During our two-week field survey in June 2022, we focused on the southern and eastern regions of Yamdena Island and parts of Larat Island. These areas were selected primarily due to accessibility and budget constraints. On Yamdena, most villages and road infrastructure are concentrated along the east coast. The main airport and harbour are located in Saumlaki, a small town on the island's southeastern tip. From Saumlaki, we travelled south to survey the Olilit area before continuing northward along the coastline. In contrast, the western part of Yamdena and the surrounding islands in the Tanimbar group are only accessible by small boat. Larat, situated north of Yamdena, is currently the only nearby island connected by bridge. Our work on Larat concentrated on sections of the northern coastline.

In total, we documented fourteen caves and rockshelters across Yamdena and Larat, each showing varying archaeological potential (see Figure 3). Bwae Pnuan 1, 2, and 3 are rockshelters in the rocky hills surrounding Olilit. These sites feature thin sediment layers and exposed rocky floors, limiting their excavation potential due to insufficient cultural deposits. Bang Tutudar 1 is a semi-vertical cave with a steep but accessible descent, while Bang Tutudar 2 is a vertical shaft approximately two meters deep with a narrow entrance measuring about 2x1 m. Shell remains found at both sites suggest temporary habitation, and pottery fragments were identified within Bang Tutudar 1. However, the cave's vulnerability to erosion from heavy rainfall likely means most cultural deposits have been significantly disturbed or displaced. Three additional rockshelters near Olilit — Safa Swean, Bwae Mpusuk 1, and Bwae Mpusuk 2 — serve as resting places for local villagers tending their fields. Unfortunately, these sites lack sufficient sediment layers for meaningful excavation.

North of Olilit lies Ilngey village, which contains two substantial caves: Bang Das and Bang Ruti. Bang Das features a small creek and pond inside, serving as a valuable freshwater source for local residents. Bang Ruti is a large vertical cave requiring a two-meter descent to access its expansive chamber below. Both caves show extensive water erosion patterns, making archaeological excavation challenging. The prospect of obtaining pristine stratified deposits necessary for establishing chronological occupation sequences is limited at these sites due to their hydrological conditions. Near Ilngey is Sifnana village, home to Gua Lordes Maria. This small cave sits below the current ground level and has been developed into a Christian prayer site by local villagers. The cave is unsuitable for archaeological investigation due to its insufficient sediment layers and its sacred status among the local community.



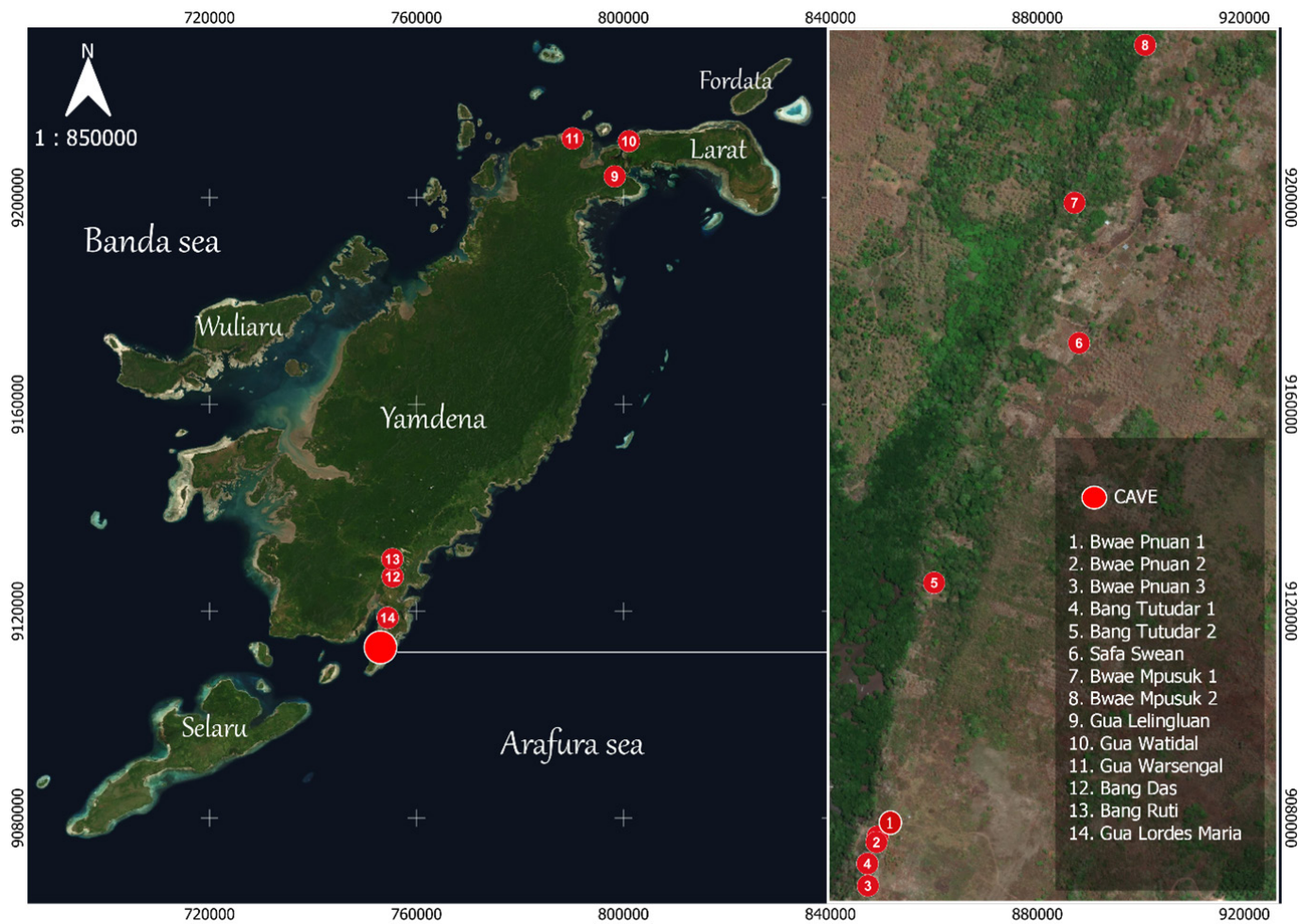


Figure 3: Cave and rockshelter recorded in Yamdena and Larat Islands during the 2022 survey.

Figure 4: Excavation at Elivavan Rockshelter revealing a 42,000-year-old record of human occupation in Tanimbar.





On Yamdena's north coast, we documented Gua Lelingluan in Lelingluan village and Gua Warsengal in Kainara village. Gua Lelingluan, situated in a resident's backyard, currently serves as a household disposal area and shows no indication of archaeological potential. Gua Warsengal, accessible only by small boat due to its remote location from nearby villages, contains surface pottery and shellfish remains, suggesting past human occupation. Unfortunately, its proximity to water sources from both downstream areas and the beach, combined with substantial ceiling rockfall, has severely disturbed the site, compromising its excavation potential. A similar situation exists at Gua Watidal on Larat Island's north coast, where pottery and shellfish remains are present but heavily disturbed due to the cave's proximity to the beach, where high tides regularly wash away sediment deposits.

Our assessment of caves and rockshelters across Yamdena and Larat Islands revealed numerous constraints that limit their potential for archaeological excavation. Many sites lack sufficient sediment accumulation to support meaningful stratigraphic analysis, while others are inaccessible due to their sacred status within local communities or have been repurposed for practical use. Natural processes present additional challenges, including water erosion, tidal action that removes coastal deposits, and ceiling collapse resulting in substantial rockfall. High humidity and fluctuating temperatures further complicate preservation conditions, while poor lighting and restricted visibility hinder effective documentation and *in situ* analysis.

Fieldwork is also complicated by logistical barriers such as limited access to remote areas, the absence of established infrastructure, and dense vegetation overgrowth that can obscure or physically block cave entrances. Although surface artefacts and faunal remains are occasionally present — often displaced by internal water movement — securing intact, stratified deposits essential for constructing reliable chronological sequences remains exceptionally difficult throughout the surveyed area. This taphonomic complexity fundamentally limits the applicability of conventional archaeological excavation methods in the Tanimbar Islands.

Comparable surveys in other regions encounter different challenges. These include the repurposing of caves into restaurants (e.g., The Cave Restaurant, southern Bali), places of worship (e.g., Gua Maria Tritis; Kaharudin et al. 2023), and tourist attractions (e.g., Gua Gong and Gua Selarong, Java), where surface modifications such as concrete paths and staircases are common. Even Liang Bua in Flores — known as the discovery site of *Homo floresiensis* — was once used as a school in the 1940s, although this did not significantly disturb

its cultural layers. Additional disturbances, such as guano mining, looting, and animal burrowing, further compromise site integrity and stratigraphic resolution.

## ELIVAVAN EXCAVATION AND FUTURE RESEARCH POTENTIAL

To the north of Yamdena and Larat Islands lies Fordata Island. Archaeological surveys for potential cave sites on parts of this island were previously conducted by Balai Arkeologi Ambon (Ambon Archaeological Center) (Ririmasse, 2016b). With permission from Balai Arkeologi Ambon, we reassessed several of these caves and identified Elivavan as the most promising and suitable site for excavation. Elivavan is a limestone rockshelter located on the southwest coast of Fordata Island, approximately 500 meters equidistant from the villages of Awear and Romean. Its proximity to these villages presents a logistical advantage, allowing us to base operations in the village and commute daily to the site, eliminating the need for a temporary campsite (Kaharudin et al. 2024b). The limestone wall, draped in lush vegetation, rises over 8 m high and forms a shelter with a dripline spanning approximately 2–4 m (Figure 4). This provides a dry and protected area suitable for excavation, with the extent of the dripline suggesting significant portions of the shelter are unaffected by water erosion during rainfall (Kaharudin et al. 2024b).

Situated at an elevation of 50 m above present sea level and approximately 280 m inland from the current coastline, Elivavan would have offered past occupants' convenient access to marine resources, while remaining protected from coastal disturbances such as high tides or tsunamis. This elevation and distance from the shoreline also help preserve sediment integrity. During excavation, the site's coastal proximity is advantageous, enabling wet sieving to be conducted on the nearby beach and finds to be dried in an open area just beyond the vegetation line and above the tidal zone (Kaharudin et al. 2024b).

Excavations at the Elivavan Rockshelter have yielded a diverse assemblage of cultural and faunal materials, highlighting its significance as an early human occupation site in southeastern Wallacea. Cultural remains include ceramic fragments in the upper stratigraphic layers and a variety of lithic artefacts found throughout the sequence. The faunal assemblage is particularly notable for its diversity, comprising both terrestrial and marine taxa. These include macropods — suggesting connections with Sahul — as well as microfauna such as snakes, rodents, and lizards. Marine resources are well represented by fish bones, shellfish, crabs, and sea urchins, reflecting a broad-spectrum subsistence strategy that capitalised on both inland and coastal environments. The lowest



cultural layer, dated to approximately 42,000 years ago, marks one of the earliest known instances of human presence in this region of Wallacea. This early date contributes to a growing body of evidence demonstrating the rapid eastward dispersal of modern humans through the archipelago during the Late Pleistocene (Kaharudin et al. 2024b).

The archaeological potential of Fordata Island is further emphasised by these findings. Although the initial 1x1 m test pit at Elivavan has reached bedrock, the site's stratified cultural deposits warrant further horizontal and vertical expansion to investigate activity areas, site formation processes, and diachronic changes in material culture and subsistence practices (Kaharudin et al. 2024b). Moreover, large portions of Fordata remain archaeologically unexplored, representing significant opportunities for future survey and excavation. In addition to Fordata, the nearby islands of Molu and Maru, located to the north, also hold potential for contributing to a broader understanding of regional prehistory. These islands may offer comparative data that help contextualise the Elivavan findings within wider patterns of early island colonisation, resource use, and inter-island connectivity in Wallacea. Systematic survey and test excavation on these islands could help clarify the extent, timing, and nature of human dispersals through the southeastern corridor of Wallacea, a region that remains underrepresented in archaeological narratives of early human migration.

Conducting archaeological surveys in remote regions such as eastern Indonesia has become increasingly feasible over the past decade. This shift is largely due to ongoing infrastructure development led by local governments, which has improved access to previously isolated areas. At the same time, advancements in digital tools have transformed the ways researchers plan and execute preliminary surveys. High-resolution satellite imagery, now more widely available through platforms like Google Earth, has enhanced the capacity for remote desktop-based reconnaissance, allowing archaeologists to identify promising landscapes and potential site locations before entering the field.

In addition, improvements in mobile technology and internet connectivity have enabled broader participation in site identification efforts. The widespread use of smartphones equipped with cameras, coupled with the rise of citizen journalism and digital content creation, has resulted in the informal reporting and documentation of cultural and natural features — including caves and rockshelters — that might otherwise go unnoticed by formal research networks. This growing public visibility

of potential archaeological sites on social media platforms and video-sharing services has created new opportunities for collaboration between local communities and researchers, and underscores the value of community-based heritage engagement.

Remote sensing technologies have also revolutionised archaeological survey methodologies, though their applicability varies depending on environmental and financial constraints. LiDAR (Light Detection and Ranging), in particular, has proven invaluable in tropical forest environments for its ability to penetrate dense vegetation and reveal microtopographic features — such as depressions, escarpments, or shelter entrances—that may indicate the presence of cave systems or cultural activity (Moyes & Montgomery, 2019). However, the high cost of LiDAR acquisition and processing remains a significant barrier for many projects, especially those operating with limited budgets in under-resourced regions.

Satellite imagery analysis provides a more cost-effective alternative and can be highly useful in open or semi-open environments (Kempf, 2019). However, its utility is limited in areas with thick forest cover, where cave openings and other surface features are easily obscured by vegetation. In such cases, integrating satellite imagery with ground-truthing and local knowledge remains essential. Ultimately, a combination of traditional survey techniques, remote sensing, and collaborative engagement with local communities offers the most promising strategy for identifying and assessing archaeological potential in the complex and varied landscapes of eastern Indonesia.

## ACKNOWLEDGEMENTS

This research was supported by funding from the ARC Centre of Excellence for Australian Biodiversity and Heritage (CE170100015) and Higher Degree Research funding from the School of Culture, History and Language at the Australian National University. We are deeply grateful to the team at Badan Riset dan Inovasi Nasional (BRIN) for their valuable support during our time in Ambon. Special thanks go to Devi Mustika Sari, Fairuz Azis, and Gilar Wicaksono for their indispensable contributions during the Tanimbar fieldwork. We also extend our sincere appreciation to Yongky Souisa for his assistance and local guidance during our transit in Saumlaki. Finally, we are especially thankful to the Tanimbar community for their warm hospitality and generous support throughout the survey.

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## FIELDWORK IN SOUTH-WESTERN WESTERN AUSTRALIA

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The south-western part of Western Australia (SWWA), on Noongar boodja, is one of 36 globally recognised biodiversity hotspots; regions that have an extraordinary level of endemism but are also heavily threatened by people. One of the threats in SWWA is climate change. In the last seventy years, winter rainfall, which is also when the region receives most precipitation, has been declining. My research aims to reconstruct how (hydro)climate in coastal SWWA has changed, and how aquatic ecosystems responded to these changes, over the last 2,000 years. From 31 August 2025 to 12 September 2025, John Tibby (primary supervisor), Gavan McGrath (collaborator from the Department of Biodiversity, Conservation and Attractions (DBCA)), Michael Venarsky (collaborator DBCA), Fabian Boesl (collaborator Edith Cowan University), and I went on a field trip to sample diatoms from 37 lakes and wetlands in coastal SWWA to use in a salinity/pH transfer function. Ironically, we planned this trip during one of the wettest winters in recent years, which proved both a blessing and a bit of a curse. On one hand, all of the lakes we wanted to visit were filled with water; on the other, the roads were as well. Initially, I planned for the group to split up in two teams to cover as much ground as possible, but after two days of going about it in a group, driving through puddles as deep as some of the lakes we visited and getting stuck in the mud at least once, it became clear that it would be safer to stick together the rest of the fieldtrip as well.

The weather during the first four days was nothing short of perfect: intermittently sunny, comfortable temperatures, and not too windy. On the first day, we managed to sample four sites. Quite good, but even more impressive considering that we were still very much figuring out the limit that one ute and one Land Cruiser with street tyres and a trailer could handle. On the second day, we kicked off with Lake Yeagarup (Figure 1), which became one of my favourite lakes of the trip. It is about 600m wide from end to end, and we recorded a depth of 9.2 m. It lies within the dunes and is surrounded by vegetation, although the picture does not do it any justice (I could have sworn it was sunny the entire time we were on it). The next one we went to was Lake Charley (Figure 2), the drive to which was a whole journey in itself. We had received suggestions on which roads to take from the local DBCA offices, which recommended using Charley Rd. to get to the lake; and so, we set out for Charley Rd. However, as it turned out, there were multiple Charley Roads going up to the lake. We had taken the one that became so narrow that the track changed from one suitable for cars to a motorcycle track. Trees were on either side, and left barely 2 cm of space. There was no way of turning back with the Ute and Land Cruiser carrying a trailer, and after every turn, we wondered whether we would be able to head on or whether we would be stopped by a pool of water or a

**Figure 1:** Image of Lake Yeagarup, Western Australia.



**Figure 2:** Image of Lake Charley, Western Australia.







**Top – Figure 3:** John Tibby in boat on Lake Jasper, Teye Aukes being towed in a kayak.

**Middle – Figure 4:** Teke Aukes kayaking on Lake Jasper, Western Australia

**Bottom – Figure 5:** Image of Lake Moates, Western Australia.

fallen tree. We pushed on until, at last, as the landscape changed from forest to dunes and opened slightly, there was finally enough space for a car again. After that, Lake Charley, surrounded by flowering wattle, was just a treat.

Honestly, I have something to say about all of the lakes we visited, but there is not enough space for that, so I will just give some highlights, which start, funnily enough, the next day: Day three! That day, we went to Lake Jasper (Figures 3 and 4): the largest lake in the area. Its size is very impressive and we had some of the best weather of our trip. I wish I could have stayed there, enjoying the sun in my kayak and listening to the birds and trees.

On Day five, the weather took a complete turn. It was rainy, cold, and there were winds of up to 80 km/h. This went on for four days. The highlight: Lake Owingup, where, after the Ute got completely stuck in the mud, John heroically walked out into the water to get a sample (paddling an inflatable was not an option - we tried, and failed), and, as I was pushing the boat back to shore, ended up in waist-high water where the rope of my life vest got stuck on something, which, to the delight of everyone around while I floated on the waves, inflated.

I'm nearing the end of my list of favourite lakes, but here are two more that I loved: Lake Moates and Lake Vancouver. There is not much to say about these other than how stunning they are. Lake Moates (Figure 5) is, in my opinion, one of the most beautiful lakes we visited. It is very big and it is adjacent to an incredibly tall dune whose light colour creates a stunning contrast between the dark of the water and the vegetation surrounding it. If you are ever in the area, give this lake a visit. Pictures do not capture its beauty well enough at all, but it is worth it. Lake Vancouver (Figure 6), on the other hand, is quite small, but as we were on the water taking samples, you could hear the ocean crash onto the beach just behind the trees. It is quite magical.

Finally (I promise), I cannot leave out one of the "hidden" gems: No Name 36 (I know, my lake names are incredible; Figure 7). We drove to this lake at the end of the day, around 17:30h, just before the sun started setting. To get to it, we had to hike through dense, waist-high thorny shrubs. It felt slightly endless, so somewhere midway through, I climbed a tree to make sure there even was a lake, and, spoilers, there was. Once we got there, though, it was a small patch straight out of paradise. The setting sun cast a soft glow over the water and onto the trees at the edge of the lake; swallows skimmed the water for tiny, floating insects; the only sound came from the birds, the wind, and us wading through the water. I have rarely ever seen something so calming and peaceful.





Above – Figure 6: Image of Lake Vancouver, Western Australia.

Below – Figure 7: Lake No Name 36, Western Australia.



To end this report, I would like to thank a few people. First, a big thank you to John Tibby whose trust and support during this fieldwork, and honestly throughout these last few months that I have been in Australia, has just been so amazing and encouraging. Sometimes I wonder if you even know how good you are, both in your work and as a person. Gavan and Mike, it was wonderful getting to know both of you a bit better in the field. Thank you for all you have done and continue to do. This field trip would, literally, not have been possible without you. Fabian, I don't think this trip would have been the same without you. Thank you for all the laughs and all the work that you did. I cannot wait to see what all of your effort brings.

# DIAPYRIC STRUCTURES IN ARCHAEOLOGY: A CASE STUDY FROM EASTERN AUSTRALIA

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## ABSTRACT

Differential vertical movements within an archaeological deposit can be triggered by variations in the density and plasticity of the archaeological layers. Acute stratigraphic disturbance can occur where archaeological deposits consist of swelling clays overlain by more massive, less clay-rich sediment mantles. Such movements can displace artefacts, bones and charcoal in such a way that depth is no guide to age and stratigraphic inversions can be the norm rather than the exception. In the case of a late Quaternary archaeological site in eastern Australia, the stratigraphic units were very distinctive in terms of colour, texture, structure, consistence, fabric and plasticity. As a result, the effects of internal mass movements and viscous soil flows were both striking and obvious. In many instances, however, the visible differences in colour and other physical attributes may be less evident and are often hard to discern in trial trenches of limited size. Archaeologists and geoarchaeologists need to be alert to these possible forms of disturbance, particularly when excavating fine-grained sediments. They may be more common than generally recognised.

## INTRODUCTION

Archaeologists are understandably concerned about locating, describing and sampling archaeological remains in primary context within stratified and well-dated sedimentary contexts. Given the time, effort and expense devoted to the excavation of stratified archaeological deposits, it is important to have reasonable confidence that the artefacts mapped and described from within such deposits are indeed in an undisturbed context (Wood & Johnson, 1978; Williams, 2019).

Less well appreciated is the possible impact of disturbance and differential displacement generated by physical processes which may be triggered by variations in the density of different archaeological layers. The aim of this short note is to describe one such instance from a late Quaternary archaeological site in eastern Australia, and to suggest that such forms of disturbance may be more common than is generally recognised.

## THE STUDY AREA

Trinke is a spring site overlying limestone bedrock and located west of the Great Dividing Range in Gamilaroi Country, east-central New South Wales, Australia (Figure 1). It lies within a circumscribed zone of uniform rainfall on the alluvial clay plains west of the town of Quirindi at latitude 31° 30'S and longitude 150° 41'E. Professor R.V.S. Wright chose the site in 1986 to test the hypothesis that the zone of uniform summer and winter rainfall in eastern Australia may have constituted a preferred refuge area for those elements of the megafauna that may have survived the climatic rigours of the Last Glacial Maximum, as well as the vicissitudes of human predation (Wright, 1986).

## SITE STRATIGRAPHY

Discharge from the spring outlet at Trinke has created swampy conditions around the discharge zone. Two archaeological trenches were dug: one (termed the southern trench) close to the spring outlet, which was quite wet and not always easy to excavate; the other (termed the northern trench) was further away and much drier and easier to excavate. The discussion that follows relates to the dry northern trench in which the stratigraphy was very clearly exposed. From the surface downwards the deposit consisted of an upper unit of grey silt (5Y 3/1-4/1) up to 80 cm thick with calcium carbonate concretions in the lower 20 cm; a middle unit of black clay (2.5Y 2/1) up to 40 cm thick; and a basal unit of gleyed and mottled yellow and grey clay (5Y 8/1, 7/1 and 8/3). Charcoal and burnt bone in the black clay unit yielded conventional radiocarbon ages ranging from about 15000 to 9000 years BP (Professor R.V.S. Wright; Dr M. Barbetti; both personal communication). The base of the grey silt was dated to about 6000 years BP.

A curious structure was evident in the west face of the northern trench (Figure 2). In the section it had the form of a flat-topped, roughly triangular area of black clay with curved sides. Inside this larger feature, there was a smaller feature in the form of a large question mark (appropriate, given the debate it sparked) composed of olive clay. This smaller feature intruded into and was encapsulated within the black clay. Both the black clay



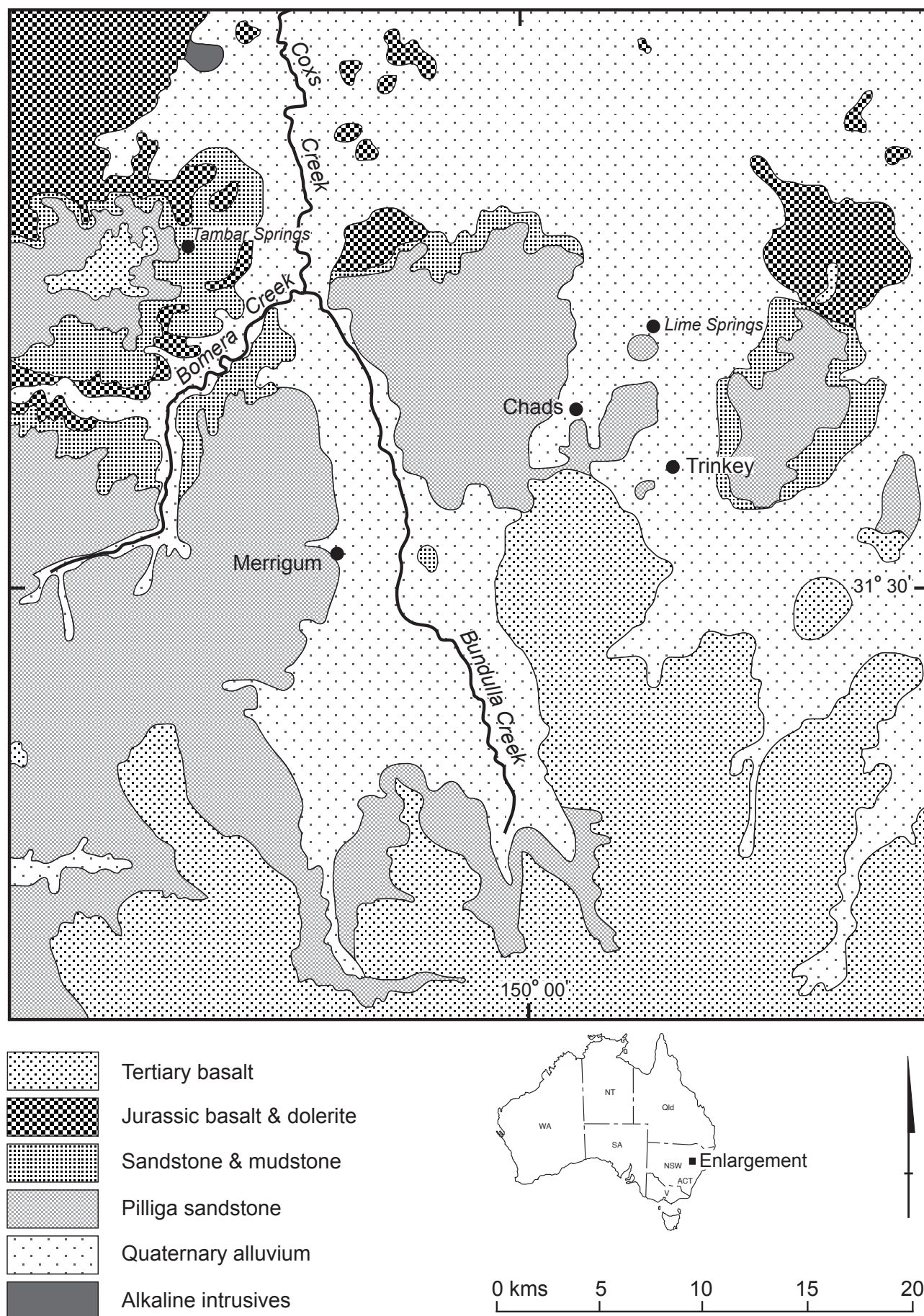


Figure 1: Trinkey spring site, New South Wales, Australia, with simplified geology.

and the olive clay were overlain by a grey silt mantle that ranged from 0 cm to 80 cm in thickness. The contact between the grey silt and the underlying black clay was undulating when seen in section, and mamillated when viewed in three dimensions.

This led to the question: what is the origin of this curiously uneven stratigraphy?

## INTREPRETATING THE DISRUPTED STRATIGRAPHY

Three possible models to account for the olive and black-clay structures exposed in the trench were vigorously debated during fieldwork:

1. One model was that the structures resulted from ancient spring-cleaning and the dumping of saturated clay away from the spring outlet.
2. A second model involved the rapid accumulation of wind-blown dust against a fallen tree.
3. The third model involved differential movement of the various sedimentary layers because of overloading. According to this model, the structure could be considered a simple diapiric structure, known to soil scientists familiar with the cracking clay soils in eastern Australia as a classic example of a *gilgai* structure (Paton, 1974), and more specifically as a *mukkara* form of *gilgai* (Paton, 1974, p.227, Figure 5).

*Gilgai* are a special form of diapiric structure formed by upward penetration of viscous subsurface sediment layers because of overloading from the overlying surface sediment mantles. Vertisols or dark cracking clays composed of montmorillonite or smectite clay minerals are especially prone to shrinking and swelling, and *gilgai* structures are common within such clays.

To test these three opposing models in the field, it was necessary to define as carefully as possible each of the physical attributes of the structure and to see whether or not each model could account for every observed attribute.

The field characteristics of the structure visible in the field and partially illustrated in Figure 2 may be summarised as follows:

1. The curved innermost structure consisted of olive clay (i.e., clay that was gleyed and permanently wet), 10-15 cm in diameter.
2. The basal shear plane ran diagonally and was slightly curved, with a dip ranging from 35° to 65°, averaging about 55°.
3. The structure was curved in the form of a question mark.
4. There were curved stringers of carbonate and one silt-filled crack, and a desiccation crack parallel to the convex side of the structure.
5. The structure was surrounded above and on both sides by black clay.
6. Grey silt covered the sloping upper surface of the black clay.
7. There was a sharp saw-toothed edge between the olive clay and the black clay on the south side of the feature.
8. There was a step-like lithological contact between the olive clay and the black clay on the north side of the feature.
9. There were clasts of hard calcareous clay within the olive clay.
10. The hard calcareous clay had a sloping surface and visible bedding planes.
11. There were several subsidiary slip-planes or shear-planes.
12. There was a hard calcrete bench to the south of the feature, and hard, more fragmented carbonate to the north of the feature.
13. There was a surface unit of grey silt across the top of the feature, but this was locally absent.
14. There was an absence of olive clay blebs within the black clay (as would be expected if the feature represented a tree fall and collapse of soil from the roots).

The above observations imply that the intrusion of the black clay and inner olive clay dyke came after the deposition of the grey silt mantle, suggesting a possible causal relationship between the deposition of the silt mantle and the upward displacement of the structure into the surface silt mantle. The only model that successfully accounted for every one of the physical attributes listed above and observed in the field was the *gilgai* or diapiric structure model. We may therefore conclude that this feature is not part of a humanly dug well or shallow depression, nor did it originate because of a tree fall.





Figure 2: Diapiric structure in the northern trench at Trinkey.

Whatever the origin of the grey silt mantle, its emplacement must have been a discrete and possibly rapid event. If the silt mantle was laid down relatively rapidly onto the moist and viscous black clays, the sudden increase in surface load would have triggered subsurface movement of the saturated and relatively plastic basal olive clays and local penetration of diapiric structures upwards through the overlying black clay unit and grey silt mantle.

### WIDER IMPLICATIONS FOR ARCHAEOLOGY

One result of differential vertical movements within an archaeological deposit is to displace artefacts, bones and charcoal in such a way that depth is no guide to age and stratigraphic inversions may be the norm rather than the exception. In the case of the late Quaternary archaeological site at Trinkey, NSW, Australia, the stratigraphic units were very distinctive in terms of colour,

texture, structure, consistency, fabric and plasticity. As a result, the effects of the internal mass movements and viscous soil flows were striking and obvious.

In many instances, however, the visible differences in colour and other physical attributes may be less evident and are often hard to discern in trial trenches of limited size. Archaeologists need to be alert to these possible forms of disturbance, particularly when excavating fine-grained sediments. Australia has the largest area (~880 000 km<sup>2</sup>) of cracking clays (vertisols/vertosols) of any country in the world (McKenzie et al., 2004), but other countries also contain very substantial areas, notably northern India, central and eastern Sudan, and the southern USA. Archaeological sites within such soils will be prone to the vertical displacements discussed above.

## CONCLUSION

The pronounced vertical displacement of stratigraphic layers visible in an archaeological trench at the late Quaternary archaeology site of Trinkey in east-central New South Wales is neither a result of anthropogenic spring cleaning nor of tree fall. Both models fail to explain the observed physical attributes of the feature. The most convincing explanation is that it is a *gilgai* structure. *Gilgai* are a special form of diapiric structure formed by upward penetration of viscous subsurface sediment layers because of overloading from the overlying surface sediment mantles. Vertisols or dark cracking clays composed of montmorillonite or smectite clay minerals are especially prone to shrinking and swelling and *gilgai* structures are common within such clays. In many instances, however, the visible differences in colour and other physical attributes may be less evident than at this site and may be hard to discern in trial trenches of limited size. Archaeologists need to be alert to these possible forms of disturbance, particularly when excavating fine-grained sediments. They may be far more common than is generally recognised.

## ACKNOWLEDGEMENTS

The fieldwork relating to this research note was undertaken on the traditional Country of the Gamilaroi People. This work is dedicated to the memory of my friend and colleague, Dr Don Johnson, whose pioneering work on bioturbation resonates to this day. I thank Professor Richard Wright for inviting me to take part in the excavations at this intriguing archaeological site. Dr David Horton and the late Dr Don Adamson provided the initial scepticism needed to encourage me to pursue the field investigation outlined above.

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# A DIPROTODON'S LAST SUPPER

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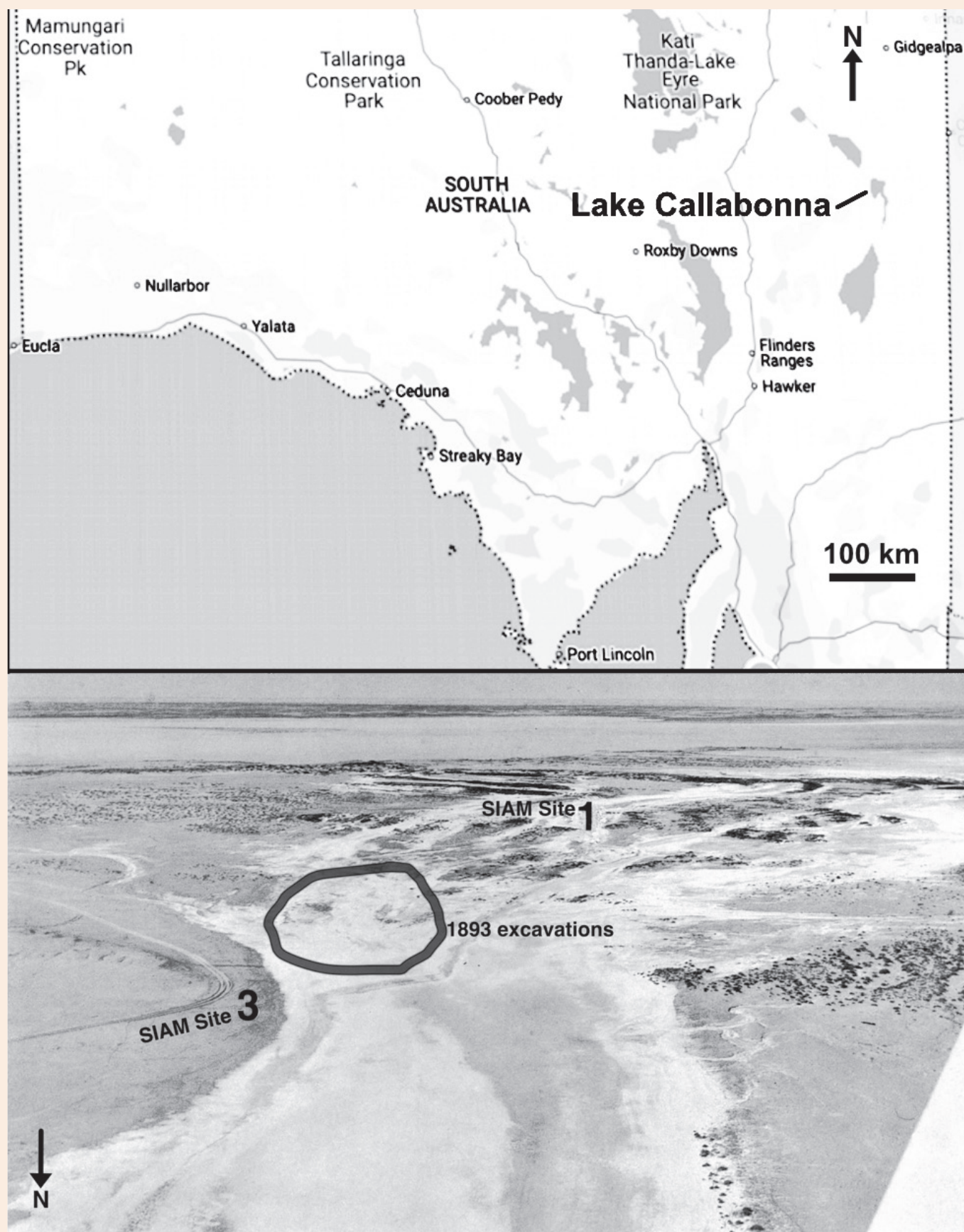
Key words: Callabonna; megafauna; food remains; stable isotopes; dating.

## ABSTRACT

Among the extinct marsupial megafauna bones recovered in 1893 from Lake Callabonna, Pilatapa Country, South Australia, were remnants of dried plant remains, which were deduced to be the gut contents of a *Diprotodon optatum*. These plant remains, now located in the South Australian Museum, have been used for both  $\beta$ -counting and AMS radiocarbon ( $^{14}\text{C}$ ) dating at four different laboratories, all of which yielded non-finite ages approaching the upper age limits of the  $^{14}\text{C}$  method. We used  $\delta^{13}\text{C}$  analysis on the gut contents for comparison with modern plants collected near the lake to assess the animal's diet. We also analysed an  $\text{M}_2$  molar tooth from the *Diprotodon* skeletal remains, which contained the gut contents for  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  ratios, and used combined U-series/Electron Spin Resonance dating to obtain a finite age for the tooth. Considering the uncertainties associated with environmental dose rate estimation, we argue that our US-ESR age of  $55 \pm 5/4$  ka (1 $\sigma$ ) is the most secure estimate for the true age of this *Diprotodon*, which overlaps with published ages on sediments containing extinct avian megafauna at the same lake. Our  $\delta^{13}\text{C}$  measurements show that the most likely fodder being consumed by this particular now-extinct *Diprotodon* just before it died on the lake floor was *Atriplex* spp. saltbushes, which are still present around the lake today and follow the  $\text{C}_4$  photosynthetic pathway.

## INTRODUCTION

Since the first report in Western scientific literature of fossil *Mammalia* in Australia, the skeletal remains of *Diprotodon* (the world's largest ever marsupial) have intrigued palaeontologists. At times likened to the elephant, hippopotamus, rhinoceros, and the giant ground sloth, there has been much speculation on its feeding behaviour (Owen 1877). An anterior right jaw fragment of a juvenile collected by Major Thomas Mitchell at Wellington Caves, NSW, in 1831 included the tusk-like first incisor. It was described by Owen (1838) as *Diprotodon* on account of the procumbent lower first incisor tooth. Over the next thirty years, Owen accumulated sufficient fossil remains of *Diprotodon* to reconstruct most of the skeleton, lacking only details of the manus and pes. Owen had noted the similarity in incisor dentition to that of wombats and beavers, but lacked details of the manus and pes. He was left to speculate that '*The marsupial monster brought down the tempting foliage by erosion of the trunk, not by the strong haul of a forcible grasp*' (Owen 1877, p 236). Owen (1871), writing to E.G. Waterhouse, then Director of the South Australian Museum, said: '*I forward you by this mail a copy of my paper on Diprotodon. You will see by it that the bones of the feet are still a desideratum.*'



**Figure 1:** A. Location map of Lake Callabonna in South Australia (modified from free to use map from bluegreenatlas/australia\_south\_australia), one of three smaller lakes between larger Lake Eyre and Lake Frome; B. area of 1893 excavations circled between location of SIAM Sites 1 and 3 (modified from oblique b/w aerial photo looking south taken by Dick Tedford in 1970), with extinct megafauna excavation sites mentioned in the text.



The discovery in 1893 of 'the veritable necropolis of gigantic extinct marsupials and birds' (Stirling 1894:185) at Lake Callabonna in South Australia (Figure 1) revealed hundreds of articulated individual Diprotodon skeletons scattered over much of the 50km<sup>2</sup> surface of the salina (Tedford 1973; Pledge, 1994; Wells & Tedford, 1995). Preserved were the remains of juveniles, adults and trackways, including foot pad and fur impressions. It was now possible for Professor Stirling, then director of the South Australian Museum, to realise Owen's *desideratum*. The Museum Board appointed a professional collector, Henry Hurst, to retrieve Diprotodon skeletons from Lake Mulligan (Callabonna). Early in this work, Hurst wrote to Stirling (February 16th, 1893, SAM archives), providing details of 11 individual Diprotodons that were either excavated or in the process of excavation. In subsequent handwritten correspondence, Hurst numbered these specimens using modern Hindu-Arabic numerals, viz., I–II.

Concerned by the lack of progress and the ongoing financial drain on the Museum's resources, Stirling (along with his deputy Zietz) visited the collecting site on 17–21 August 1893. When Stirling arrived, Hurst had already begun packing bones and partial skeletons for transport to Adelaide. Appalled by the state of the camp and the collection methods, Stirling gave Hurst the option to resign or be dismissed for, among other things, failing to keep *accurate records*. Hurst chose the former (Stirling 1893). Stirling then appointed Zietz to complete the task. To date, the only 'accurate' records we have been able to locate by Hurst, Zietz or indeed Stirling are to be found

in the correspondence files in the SAM Archives. These include lists of bones, some of which are accompanied by references to individual skeletons.

Housed in a box among the bones from the 1893 collections are plant remains (SAMA P59950) wrapped in newspaper and bearing labels with Roman numerals in the distinctive handwriting of A.H.C. Zietz (AZ), then Deputy Director of SAM.

The labels are as follows:

- (1) *No. VII, probably food of Diprotodon* (shown in Figure 2a)
- (2) *supposed to be the remains of food Diprotodon AZ*
- (3) *supposed to be food remains of Diprotodon.*

Also included is a small box with the label '*specimen of wood found in blue clay with Diprotodon about 2ft under surface*'.

The number seven or VII is of particular interest. Recently, one of us (RTW), while cleaning some of the bones from the SAM 1893 collections, discovered small paper squares glued to many of the fossil bones, bearing both pencilled Roman numerals and matching Arabic numerals. This discovery provided the cross-link between the putative food remains from Zietz VII and Hurst's specimen 7. Elements labelled both VII and 7 include right and left maxillary (P31859 M<sup>2,3,4</sup>, P31894 M<sup>2,3,4</sup> resp.), right jaw fragment with M<sup>1,2,3,4</sup> (SAMA P59950), left and right humeri, ribs, scaphoid and pes elements. In discussing this specimen Stirling (1894: 208) writes



**Figure 2:** Partially excavated Diprotodon skeleton spreadeagled on floor of Lake Callabonna at site SIAM 3, 1970 with T. Maddock in background smoking a pipe. See *A Diprotodon's last supper* (Photo credit: Rod Wells).

*“Associated with the skeleton of Diprotodon, in a relative position which corresponded with that of the abdominal cavity, were occasionally found loosely aggregated globular masses of what I judge to be the leaves, stalks and smaller twigs of some herbaceous or arboreal plants”, although later he comments “I could find no trace of leaves that might have indicated a diagnosis” and the woody samples submitted in 1894 to an expert in ‘xylography’, Professor Radlkofer at the Department of Botany, University of Munich, were identified as the remains of chenopods (Owen 1894).*

Over the next hundred years, these plant remains continued to attract attention (Gentili 1961; Tedford 1973, 1984; Pickard 1991). Dr Gurdip Singh (Dept. of Biogeography and Geomorphology, Australian National University), in a 1972 personal communication to R.H. Tedford, reported a pollen record extracted from the clays encapsulating a eucalypt branch, suggesting that a saltbush-dominated savanna surrounded the lake margins (Wells and Tedford, 1995). These findings are consistent with observations by SA Government geologist, H.Y.L. Brown (1894): *“There are no bushes or trees on the lake except samphires and plants of like nature, the surrounding sand hill country being, however, covered with saltbush of various kinds and stunted bluegums in the creeks and occasionally small trees on the sandhills.”*

In this paper, we apply a range of carbon isotope analyses to determine the composition and age of the gut contents (SAMA P59950) from this Diprotodon. We also apply combined U-series/Electron Spin Resonance dating to a mandible tooth from the skeletal remains of Hurst/Zietz specimen 7/VII (SAMA 59949), which contained the gut contents, to enable the determination of a finite age for these remains, which closely approaches the maximum age limit of the radiocarbon ( $^{14}\text{C}$ ) method.

## METHODS AND MATERIALS

### RADIOCARBON DATING

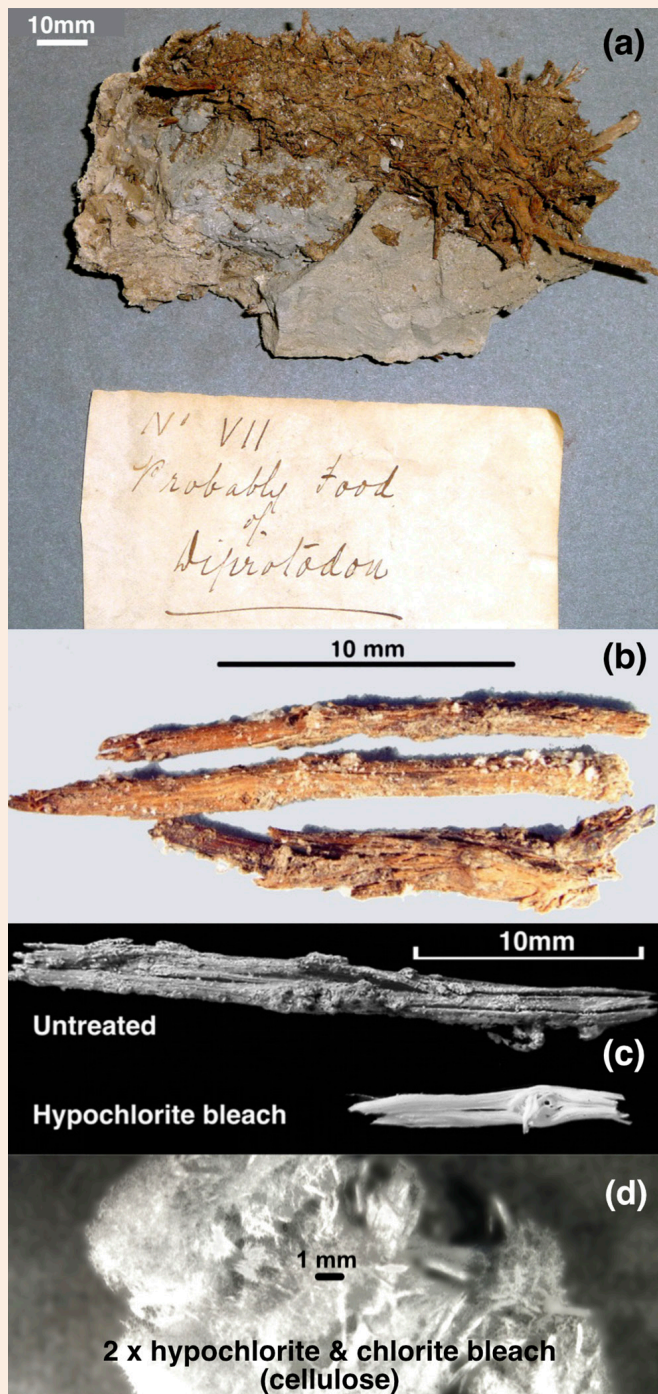
Woody match-stick-sized material from the presumed gut contents of the Diprotodon was first dated at the GNS laboratory in Lower Hutt, New Zealand, along with a tooth from the skeletal remains within which the gut contents were found and collected by Zietz in 1893. These were sent in 1957 to the NZ laboratory by Prof. Douglas Mawson, University of Adelaide. Results were reported back to Mawson in 1958 that the Diprotodon gut contents were >40,000 years old (NZ-205), beyond the range of  $^{14}\text{C}$  dating at that laboratory, while ‘dentine’ from the teeth yielded an age of  $6700 \pm 250$  years (NZ-206). These results were published by Fergusson and Rafter (1959).

In 1970, Dr R.H. Tedford recovered a piece of Eucalyptus wood at the base of the Diprotodon-bearing blue-green clay sediments at Lake Callabonna, which was sent to Teledyne Isotopes in Westwood NJ, USA, from where Buckley (1973) reported an age of >39,900 years (I-5479; SIAM [Smithsonian Institution American Museum] 86), beyond the dating range for that laboratory. Tedford (1973) commented that this result confirmed the NZ-205 Diprotodon gut contents age rather than the Diprotodon tooth ‘dentine’ result NZ-206. That tooth date was likely incorrect because the pretreatment methods used at the time were less efficient at removing contamination than more recent procedures (Wood et al., 2023). Probably, no intact dentine (the best material for  $^{14}\text{C}$  tooth dating) was left in those teeth from the hot, arid environment of Lake Callabonna, with a water table fluctuating repeatedly between zero and several metres, and with the precipitation of significant layers of a gypsum-rich crust, which would be recycled repeatedly during high-rainfall periods. We note that these results from NZ and the USA were processed before NBS Oxalic Acid became the universal Modern standard and the BP notation (Before Present, where ‘Present’ is defined as AD 1950) were laid out in resolutions of the 9th International Radiocarbon Conference in 1976, with the agreed upon details and much more published by Stuiver and Polach (1977).

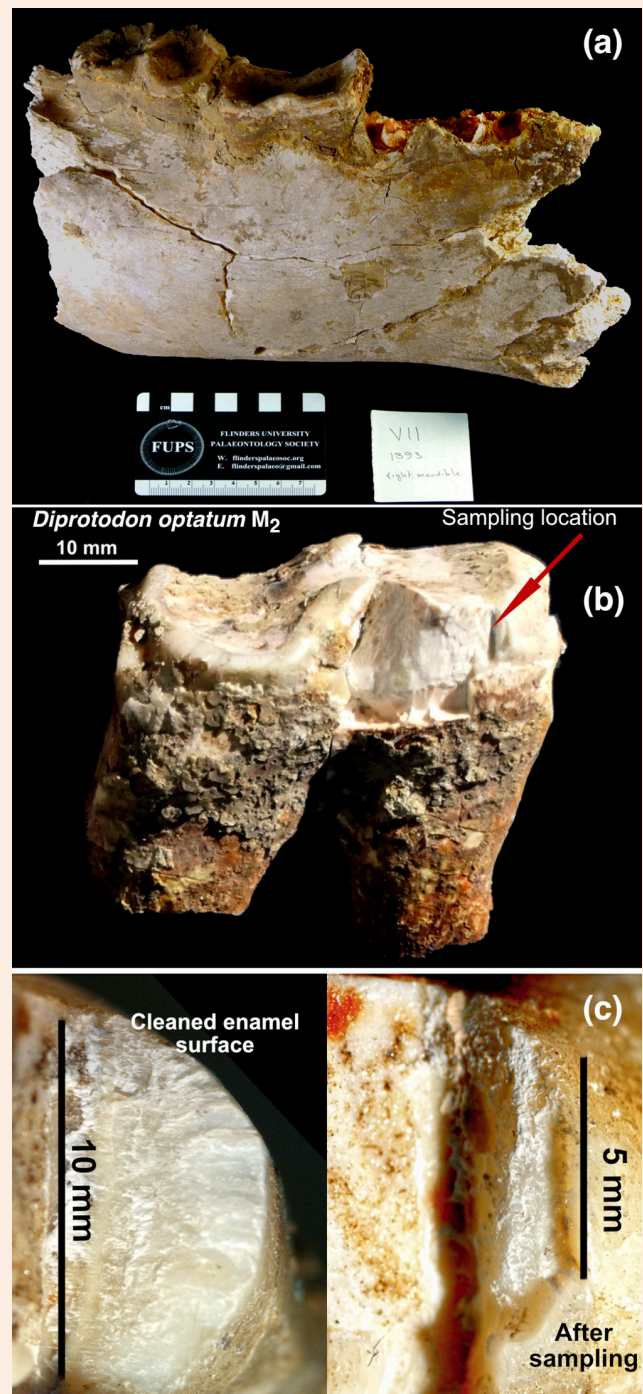
More recently, Gillespie et al. (2008) reported  $^{14}\text{C}$  dates on multiple fractions prepared from a new sample of the Zietz-collected Diprotodon gut contents (now referred to as GC-1) from the South Australian Museum, which was sampled in 2006 with permission from then-director Prof. Tim Flannery. Seven chemical and combustion-temperature fractions from oxidative pretreatments were reported, with a final result of >53,400 BP (ANUA-32710/11) deduced from the two oldest fractions. The chemistry used to produce those seven fractions was mainly a repeated sequence of acidic chlorite oxidation (bleaching) followed by alkaline extraction, with one experiment also using the dichromate oxidation method (Bird et al. 1999), which almost destroyed the sample; not an unusual result for the ABOX-SC method used on wood fractions rather than the charcoal for which it was designed.

The remaining three twigs from the gut contents GC-1 sampled for the 2008 paper were given a new pretreatment sequence by Richard Gillespie (RG), based on twice-repeated alkaline hypochlorite and acidic chlorite oxidations, the 2chlorOx method described in Gillespie (2019). Part of this sample was converted by Rachel Wood (RW) to graphite using standard methods (Wood et al. 2023), and SF measured the AMS  $^{14}\text{C}$  age (Fallon et al. 2010); the age reported here is for the first time.





**Figure 3:** *Diprotodon optatum* gut contents sample GC-1 collected by Zietz in 1893 from Lake Callabonna, South Australia; (a) sample as found in the South Australian Museum, with label hand-written by Zietz (Photo credit: Rod Wells); (b) water-washed fragments used in this work (photo credit: Richard Gillespie); (c) untreated twig and hypochlorite bleached twig (photo credit: Richard Gillespie); (d) cellulose from twice-repeated alkaline hypochlorite and acidic chlorite pretreatment (Photo credit: Richard Gillespie).



**Figure 4:** (a) Right mandible remnant with two molars from the Hurst/Zietz-collected *Diprotodon optatum* skeletal remains 7/VII, within which were found the gut contents sample GC-1; (b) M2 molar enamel sampled by RW at red pointer location for  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$ ; C. cleaned enamel surface (left panel), after sampling (right panel) (Photo credit: Rod Wells).

## STABLE C AND O ISOTOPE RATIOS

Stable C isotope ratios ( $\delta^{13}\text{C}$ ) were measured on the Zietz-collected 1893 gut contents GC-1 and on modern comparison plants collected by RTW from locations to the east and southeast of the Lake Callabonna margins. These samples were pretreated by soaking at room temperature for 1–3 days in alkaline hypochlorite (regular supermarket laundry bleach, containing 35 g/L NaClO in 4 g/L NaOH), a method previously shown to be effective for bleaching a wide variety of wood species in unpublished experiments by RG. This protocol removed bark and other coloured material from all samples. After washing with dilute HCl and distilled water, these samples were dried in a vacuum dessicator over silica gel. The resulting white twigs (photo in Figure 3c) were crushed in an agate mortar and pestle for  $\delta^{13}\text{C}$  analysis by DW on a VG Prism Isotope Ratio Mass Spectrometer (IRMS) in the SEALS Facility at the University of Wollongong, reported here for the first time.

New measurements were made by RW in the Radiocarbon Facility at ANU, using the fine white fibres of cellulose prepared from GC-1 twigs (SAMA P59950) by RG using the 2-chloroOx method in Gillespie (2019), as shown in Figure 3d.

A Diprotodon  $M_2$  molar from the right mandible of Hurst/Zietz 1893 7/VII (SAMA P59949) was also sampled and measured for  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  (Figure 4a,b,c) at the ANU Radiocarbon Facility by RW on a Europa ANKA-GSL elemental analyser connected to a Sercon 20-22 IRMS. Results for  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  ( $\pm 0.2\text{‰}$ ) relative to Vienna PDB on these plant and tooth materials are reported here for the first time.

## COMBINED U-SERIES/ESR DATING

One tooth ( $M_2$ ) from the right mandible (SAMA P59949) of the *Diprotodon optatum* specimen 7/VII, the skeletal remains containing the gut contents sample GC-1 (SAMA P59950), was sampled for combined U-series/Electron Spin Resonance dating. A fragment containing dentine and enamel was extracted from the tooth (Lab ID: #582; Figure 4). The enamel was cleaned on both sides to remove any contamination from the sediment and dentine, and to eliminate the external thickness irradiated by alpha particles. Both dentine and enamel tissues were powdered to  $<200\text{ }\mu\text{m}$  and analysed using the procedures outlined in Louys et al. (2022).

ESR analyses of the enamel sample and data reduction were carried out by Irene Romo-Díez (IRD) and Mathieu Duval (MD) at CENIEH, Spain, using a multiple aliquot additive dose (MAAD) method (Supplementary Data, Table S1). Solution U-series analyses of dental tissues were performed by Gilbert J. Price (GJP) with a Nu Plasma HR MC-ICPMS at The University of

Queensland, Australia (Supplementary Data, Table S2). The environmental dose rate from the host sedimentary deposits was assessed through a combination of *in situ* and laboratory measurements. Several bulk sediment samples were collected from remnant material attached to the various museum fossil specimens and analysed by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) following a four-acid digest preparation procedure (Supplementary Data, Table S3). Specifically, sediment samples SED-1 and SED-2 were collected from the same  $M_2$  tooth of specimen 7/VII, SED-4 to SED-7 were collected from the adjacent  $M_1$  tooth of specimen 7/VII, and SED-3 was taken from several related bone samples recovered during the 1893 excavation. *In situ* gamma dose rate measurements were performed independently by Lee J. Arnold (LJA) with a NaI probe connected to a Canberra Inspector-1000 multichannel analyser. Unfortunately, it was not possible to undertake these *in situ* measurements at the original fossil locality as the exact position of specimen 7/VII is not precisely documented within the 1893 excavation area. As such, gamma dose rate measurements were performed on similar lacustrine deposits that host *Diprotodon* fossil samples elsewhere at SIAM (Smithsonian Institution/American Museum) 1970 site 3 (in relative proximity to the inferred 1893 excavation site; Figure 1, (qv also McInerney et al 2021 Figure 1 F)), which are the subject of a separate, ongoing OSL dating study (Tables S4 & S5). The ‘energy windows’ approach described in Arnold et al. (2012) and Duval & Arnold (2013) was used to derive individual estimates of U, Th and K concentrations from the field gamma-ray spectra. The cosmic dose rate was estimated following the same approach as in McInerney et al. (2022) (see detailed explanations in [Supplementary Material](#)).

The combined U-series/ESR age calculations were undertaken using DATA (Grün, 2009), a DOS-based program that utilises the U-Series (US) model defined by Grün et al. (1988), thereby providing a US-ESR age result. A complete description of the dating procedure may be found in [Supplementary Material](#).

## RESULTS

### GUT CONTENTS (GC-1)

#### Radiocarbon Dating

Conventional Radiocarbon Ages (CRA) from *D. optatum* gut contents GC-1 collected in 1893 by Zietz, and *Eucalyptus* sp. wood\* from the extinct megafauna-bearing sediments collected by Tedford in 1970 are shown in Table 1. Note that NZ-205 and I-5479 were processed before the use of the NBS oxalic acid modern standard and BP notation was made mandatory in Stuiver and



**Table 1.** Uncalibrated radiocarbon ages reported previously, and in this work, for the 1893 Zietz-collected Diprotodon gut contents sample GC-1 (found within skeletal remains 7/VII), and the 1973 Tedford-collected Eucalypt wood\* from the blue-green clays containing the extinct megafauna. The NZ-205 measurements were reported before the BP notation, and the oxalic acid Modern standard was used. I-5479 measurements used the oxalic acid Modern standard, but not the BP suffix, both defined and specified for standard usage in Stuiver & Polach (1977).

| LAB. No.      | PRETREATMENT                    | <sup>14</sup> C AGE REPORTED | REFERENCE                   |
|---------------|---------------------------------|------------------------------|-----------------------------|
| NZ-205        | None                            | >40,000 years                | Fergusson and Rafter (1959) |
| I-5479*       | Hot acid and alkali             | >39,900 years                | Buckley (1973)              |
| ANUA-37210/11 | 2xNaClO <sub>2</sub> -NaOH-acid | >53,400 BP                   | Gillespie et al. (2008)     |
| SANU-61326    | 2xNaClO-acid-NaClO <sub>2</sub> | >53,800 BP                   | This work                   |

**Table 2.** Percentage C and  $\delta^{13}\text{C}$  measurements on 1893 Zietz-collected Diprotodon gut contents GC-1 from Lake Callabonna, South Australia, compared with modern plant samples collected by RTW from Frome Downs station and near Burra, east and southeast respectively of Lake Callabonna. We note that the only  $\delta^{13}\text{C}$  values comparable with GC-1 in the modern plants are the *Atriplex* spp. saltbushes.

| SAMPLE ID | PLANT SPECIES                                               | TREATMENT             | % C  | $\delta^{13}\text{C}$ |
|-----------|-------------------------------------------------------------|-----------------------|------|-----------------------|
| BS-1      | <i>Lycium australe</i>                                      |                       | 51.7 | -26.0                 |
| BS-2      | <i>Enchylaena tomentosa</i> (ruby saltbush)                 |                       | 40.1 | -23.7                 |
| BS-3      | <i>Atriplex vesicaria</i>                                   |                       | 41.5 | -12.2                 |
| BS-4      | <i>Rhagodia parabolica</i>                                  |                       | 45.0 | -24.3                 |
| BS-5      | <i>Maireana sedifolia</i> (Bluebush)                        |                       | 41.4 | -25.1                 |
| BS-6      | <i>Atriplex nummularia</i> (old man saltbush)               |                       | 42.4 | -12.6                 |
| FD-1      | <i>Acacia aneura</i> (mulga)                                |                       | 39.4 | -22.7                 |
| FD-2      | <i>Alechydon (Heterodendron) oleifolium</i> (bullocky bush) |                       | 38.5 | -22.9                 |
| FD-3      | <i>Casuarina cf. cristata</i> (black oak, variety A)        |                       | 43.4 | -22.9                 |
| FD-4      | <i>Casuarina cf. cristata</i> (black oak, variety B)        |                       | 41.8 | -21.3                 |
| GC-1      | 1893 Diprotodon gut contents                                | Water-washed          | 37.6 | -13.0                 |
| GC-1      | 1893 Diprotodon gut contents                                | hypochlorite bleached | 38.8 | -12.3                 |
| GC-1      | 1893 Diprotodon gut contents                                | cellulose             | 40.7 | -9.5                  |

Polach (1977). All of these uncalibrated radiocarbon ages are non-finite (beyond the maximum reliable  $^{14}\text{C}$  range), and therefore only provide minimum estimates for the true age of the fossil material. In particular, the last result obtained in the present work yields the minimum age constraint of 53,800 yrs BP (Table 1).

### STABLE C & O ISOTOPES AND % CARBON ANALYSES

The %C and  $\delta^{13}\text{C}$  results, obtained by DW at the University of Wollongong, for the Zietz-collected 1893 Diprotodon gut contents (both water-washed and holocellulose) and samples of modern plants (holocellulose) collected by RTW from locations east and south of Lake Callabonna (Frome Downs Station, and east of Burra near Redbanks megafauna site), South Australia, are shown in Table 2. Also included at the bottom of Table 2 are the new  $\delta^{13}\text{C}$  ratio and % carbon results from the same Zietz-collected gut contents sample GC-1, pretreated by RG using the 2-chloroOx method to prepare fine cellulose fibres (Gillespie, 2019), measured by RW at ANU (this work).

These measurements of  $\delta^{13}\text{C}$  ratios clearly show that the *Diprotodon optatum* gut contents GC-1 from within the Zietz collected skeletal remains 7/VII contain small twigs from *Atriplex* spp. saltbushes following the C<sub>4</sub> photosynthetic pathway.

Both  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  ratios from the Zietz-collected Diprotodon 7/VII right mandible M<sub>2</sub> molar tooth enamel, sampled and measured by RW at Australian National University (Figure 4), are shown here relative to the Vienna PDB standard ( $\pm 0.2\text{‰}$ ): Diprotodon M<sub>2</sub> molar tooth enamel  $\delta^{18}\text{O} = 6.4\text{‰}$ ,  $\delta^{13}\text{C} = -8.1\text{‰}$ .

The Diprotodon M<sub>2</sub> molar tooth enamel  $\delta^{13}\text{C}$  ratio of  $-8.1\text{‰}$  is consistent with results obtained for Diprotodon teeth from other areas of Australia, while the  $\delta^{18}\text{O} = 6.4\text{‰}$  value is more akin to the extinct giant kangaroos and wombats from arid or semi-arid zones (Price et al. 2017; De Santis et al. 2017; Prideaux et al. 2009).

### COMBINED U-SERIES/ESR DATING

The data inputs and outputs used to calculate the combined U-series/ESR age of the tooth sample are presented in Table 3, along with age uncertainties expressed at the 1 $\sigma$  confidence level. Two dose rate scenarios have been used to estimate the US-ESR age for the M<sub>2</sub> molar from skeletal remains 7/VII collected by Zietz in 1893, depending on whether the Site 3 gamma spectrometry evaluation (Scenario A) or the sediment attached to the dated tooth (Scenario B) is used for the gamma dose rate calculation (Table 3). We favour the age obtained using the sediment attached to the dated

1893 M<sub>2</sub> tooth rather than the Site 3 gamma spectrometry measurements, given uncertainties in the exact provenance of specimen 7/VII in the 1893 excavation area and its unknown stratigraphic relationship with the Site 3 fossil-bearing deposits targeted for *in situ* gamma spectrometry evaluations (see detailed discussion in [Supplementary Material](#)). Our preferred US-ESR age (regarded as the most reliable estimate) is therefore  $55 \pm 5/4$  ka (60–51 ka). However, we acknowledge that our favoured laboratory-derived dose rate estimates may not be entirely representative of the true gamma dose rate experienced by the tooth sample if spatial heterogeneities in the surrounding sediment matrix were not adequately captured by the small-sized (6–12 mg) sediment samples attached to the dated tooth (Table S3). Further discussion and Tables with the data used for the US-ESR age analysis are given in the [Supplementary Material](#).

We note that our US-ESR age for the Diprotodon specimen is significantly younger than an OSL age of  $75 \pm 9$  ka on sediment attached to skeletal remains from Lake Callabonna in the Museums Victoria collection (Roberts et al. 2001); however, it overlaps with OSL ages on sediments containing the giant extinct megafaunal birds, *Genyornis newtoni*, from Lake Callabonna of  $50.4 \pm 3.5$  ka and  $54.2 \pm 3.8$  ka (McInerney et al. 2022). As noted by Wells and Tedford (1995) and McInerney et al. (2022), multiple expeditions to Lake Callabonna have revealed that the megafauna fossils are eroding from a single stratigraphic layer of horizontal lacustrine sediments that extend in continuous, near-flat beds over several kilometres. The OSL ages obtained by McInerney et al. (2022), which are securely provenanced and directly associated with megafauna remains, can therefore be considered broadly contemporaneous with the miring event that trapped Diprotodon 7/VII. In contrast, the exact location of the OSL sample collected by Roberts et al. (2001) has not been properly documented, and the resulting OSL age of  $75 \pm 9$  ka was calculated using sediment recovered from a museum specimen that lacked *in situ* assessments of gamma dose rate, water content and overburden thickness. These non-trivial systematic uncertainties, as well as the poor precision of the original OSL age range presented by Roberts et al. (2001) (spanning 57–93 ka at 2 $\sigma$ ), make it difficult to draw meaningful comparisons with the US-ESR age obtained for Diprotodon 7/VII.

### DISCUSSION

The Lake Callabonna ‘necropolis’ is unprecedented among Australian megafauna sites. It has long been accepted that many animals in their attempts to cross the lake, perished by becoming mired in the finely laminated, ripple-marked (Pledge, 1994) and at times fluidised blue-



| SAMPLE                                                                      | #582            |
|-----------------------------------------------------------------------------|-----------------|
| <b>Enamel</b>                                                               |                 |
| Dose (Gy)                                                                   | $61.8 \pm 2.5$  |
| U (ppm), $^{234}\text{U}/^{238}\text{U}$ , $^{230}\text{Th}/^{234}\text{U}$ | See Table S2    |
| Alpha Efficiency <sup>(1)</sup>                                             | $0.13 \pm 0.02$ |
| Water content (%)                                                           | 0               |
| Initial enamel thickness ( $\mu\text{m}$ ) <sup>(2)</sup>                   | $1362 \pm 136$  |
| <b>Dentine</b>                                                              |                 |
| U (ppm), $^{234}\text{U}/^{238}\text{U}$ , $^{230}\text{Th}/^{234}\text{U}$ | See Table S2    |
| Water (%)                                                                   | $5 \pm 3$       |
| Removed enamel thickness ( $\mu\text{m}$ ) <sup>(2)</sup>                   | $93 \pm 9$      |
| <b>Sediment</b>                                                             |                 |
| U (ppm), Th (ppm), K (ppm)                                                  | See Table S3    |
| Water (% wet weight)                                                        | $27 \pm 5$ (3)  |
| Removed thickness ( $\mu\text{m}$ ) <sup>(2)</sup>                          | $60 \pm 6$      |
| <b>Combined U-series/ESR dating</b>                                         |                 |
| <b>Scenario A <sup>(4)</sup></b>                                            |                 |
| internal dose rate ( $\mu\text{Gy/a}$ )                                     | $21 \pm 3$      |
| beta dose rate, dentine ( $\mu\text{Gy/a}$ )                                | $3 \pm 0$       |
| beta dose rate, sediment ( $\mu\text{Gy/a}$ )                               | $85 \pm 11$     |
| Gamma + cosmic dose rate ( $\mu\text{Gy/a}$ )                               | $738 \pm 32$    |
| Total dose rate ( $\mu\text{Gy/a}$ )                                        | $847 \pm 33$    |
| p enamel                                                                    | 0.38            |
| p dentine                                                                   | 1.02            |
| US-ESR age (ka)                                                             | $72 \pm 4$      |
| <b>Scenario B <sup>(5)</sup></b>                                            |                 |
| internal dose rate ( $\mu\text{Gy/a}$ )                                     | $27 \pm 4$      |
| beta dose rate, dentine ( $\mu\text{Gy/a}$ )                                | $3 \pm 0$       |
| beta dose rate, sediment ( $\mu\text{Gy/a}$ )                               | $85 \pm 11$     |
| Gamma + cosmic dose rate ( $\mu\text{Gy/a}$ )                               | $1001 \pm 76$   |
| Total dose rate ( $\mu\text{Gy/a}$ )                                        | $1117 \pm 76$   |
| p enamel                                                                    | -0.16           |
| p dentine                                                                   | 0.00            |
| US-ESR age (ka)                                                             | $55 \pm 5/4$    |

**Table 3.** Data associated with the US-ESR age calculations. All errors are given at the 1 $\sigma$  confidence level, calculations based on Monte-Carlo beta-attenuation factors from Marsh (1999), dose-rate conversion factors from Guérin et al. (2011), and considering a tooth geometry of sediment/enamel/dentine. Post-RN equilibrium was assumed in the dental tissues and sediment. The dose value used for age calculation corresponds to the DE4 estimate reported in Table S1 (see [Supplementary Material](#) for explanations), to which a 2.3% additional relative error from the dose rate of the gamma source was added.

(1) from Grün and Katezenberger (1994).

(2) A 10% error was assumed.

(3) Corresponding to 38 % dry weight, which is the average derived from the various in situ measurements (Table S4).

(4) Using the sediment attached to the dated tooth for the beta dose rate evaluation (Table S3) and the combined LC14-LC18 in situ measurements for the gamma dose rate evaluation (Table S5).

(5) Using the sediment attached to the dated tooth for both the beta and gamma dose rate components.

green clays that constituted the lake floor. The presence of wood (Tedford, 1973) along with putative food remains such as twigs retrieved from within the gut region of Diprotodon skeleton 7/VII (Stirling, 1894) led to several attempts to use  $^{14}\text{C}$  to determine the age of the deposit. It is clear, as the results in Table 1 indicate, that there are no finite radiocarbon ages from the four different laboratories that have measured the Zietz-collected gut contents (three results), or the Tedford-collected *Eucalypt* sp. wood from the same blue-green clay context where the extinct megafauna is found. Our  $\delta^{13}\text{C}$  measurements on the gut contents GC-1 demonstrate that the only likely fodder being consumed by Diprotodon 7/VII just before it died are *Atriplex* spp. saltbushes (Table 2). This finding is consistent with the preliminary pollen analysis conducted by Dr Gurdip Singh at ANU on sediments surrounding the eucalypt wood found by Tedford in 1970, of a *saltbush-dominated savanna with scattered wattle, sheoak (Casuarina sp.), and native pine (Callitris sp.) crossed by eucalypt-lined water courses* (Tedford, 1973). These findings are also consistent with the observations of living flora made by Brown (1894). Our results suggest that, despite the impact of megafaunal herbivores, extinct or extant, these drought-hardy and salt-tolerant chenopod shrublands (Specht 1972) have existed around these saline South Australian lakes for at least 55,000 years.

Summarising the evidence: Diprotodon 7/VII was eating *Atriplex* sp. salt bushes before it died. Presence of the bones of a juvenile (P10558, P10560, P10562, P10563 all belong to #4) and three pouch young (P58513 #3, P58514 #1, P58515 #2) among the 1893 Callabonna death assemblage suggests a population in which not all adults were under sufficient food stress to inhibit reproduction. Our US-ESR date ( $55 \pm 5/4$  ka) on a molar tooth from Zeitz specimen 7/VII overlaps with OSL ages of  $50.4 \pm 3.5$  ka and  $54.2 \pm 3.8$  ka on sediments enclosing large dromornithid bird skeletons from Lake Callabonna (McInerney et al. 2022). These authors proposed that the birds *probably became entrapped during a protracted drought phase*.

Remaining questions: What is the probable cause of death of so many Diprotodon in this 'necropolis'?

They were feeding (gut contents), although we have no way of judging the quality and abundance of forage; at least four individuals were reproducing (one juvenile and three pouch young); based on the sequence of molar eruption and tooth wear within the Callabonna collection, a number of different age classes of Diprotodon are represented, with a bias to older individuals. This is similar to the Australia-wide fossil sample, but in contrast to the Bacchus Marsh Diprotodon sample with its bias towards younger individuals (Williams, 1982; Long and Mackness, 1994).

## CONCLUSION

Although radiocarbon dating was not able to provide finite ages for the gut contents, the application of combined U-series/ESR methodology to the  $M_2$  molar from the skeletal remains containing the gut contents was able to give a finite US-ESR age of  $55 \pm 5/4$  ka for the 1893 Hurst and Zeitz-collected *Diprotodon optatum* 7/VII recovered from Lake Callabonna sediments. Our  $\delta^{13}\text{C}$  measurements on the gut contents and modern comparison plants near the lake clearly show that *Atriplex* spp. saltbushes were the plants being eaten by this particular Diprotodon before it died on, or mired in, the lake surface to be subsequently buried by wind – and/or water-borne sediments. Although miring may have been the *coup de grâce* for many animals in this 'necropolis', it does not account for the spreadeagled Diprotodon, for example, shown in our Figure 2 above.

Supplementary Information is hosted on the AQUA website at: <https://aqua.org.au>

## ACKNOWLEDGEMENTS

RTW thanks Tim Flannery, then Director of the SA Museum, for encouraging this study, to Mary-Anne Binnie, Curator SAM, for access to the 1893 collection, to Fran Zilio, SAM Archivist, for access to correspondence relating to the 1893 Lake Callabonna expedition, to the late Paul Lawson and Richard Tedford for many discussions regarding the history of excavations at Lake Callabonna. RG thanks Dawn Chambers from the Rafter Laboratory in New Zealand for supplying archive material from that radiocarbon facility. MD is grateful to María Jesús Alonso Escarza, CENIEH, for providing technical support throughout the analytical procedure, and to Isidoro Campaña Lozano, University of Málaga, for making it possible to use DATA under a Windows environment. M. Duval is the recipient of a Spanish Ramón y Cajal Fellowship RYC2018-025221-I funded by MCIN/AEI/10.13039/501100011033 and by "ESF Investing in your future". The dosimetry research undertaken by L.J. Arnold was supported by an Australian Research Council (ARC) grant (DP180101913) and a Future Fellowship project (FT13010019). RTW and RG are self-funded.

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# DO LATE MIS 6 LAKE SEDIMENTS AT LORINNA, TASMANIA INDICATE DAMMING OF THE RIVER FORTH DURING THE MIS 6/MIS 5E TRANSITION?

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## ABSTRACT

The River Forth valley in northern Tasmania (Lutruwita) displays several glacial features, including moraines and erratics. Prior to this study, no glacial deposits in the valley have been accurately dated. A recently exposed road cutting at 359 m a.s.l. near Lorinna in the River Forth valley has revealed a section of quartzose fine sands and silts stratified at 2–5 mm scale, which indicates a likely lacustrine origin. The deposit is located 140 m above the present artificial Lake Cethana and about 240 m above the now-drowned River Forth channel. LIDAR imagery reveals evidence of past landslides on the valley slopes north of the study site. We propose that landslides may have dammed the River Forth, trapping glacial meltwater and associated deposits behind a natural dam, and that sediment in suspension settled out to form the layered deposits, which were dated  $143 \pm 11$  ka by optical dating of quartz.

## INTRODUCTION

The River Forth valley is at present glacier-free but contains evidence of several glacial advances (Colhoun 1976; Kiernan & Hannon 1991; Colhoun 2004; Colhoun & Barrows 2011). However, no deposits in the valley have been dated, although the age of likely major advances can be inferred from studies in the Mersey River catchment to the east (Slee et al. 2022) and from deposits in the intermontane Boco Plain (c. 400 m a.s.l.) in western Tasmania (Augustinus et al. 2017).

At Railton (c. 40–50 m a.s.l.) in the lower Mersey River catchment Slee et al. (2022) dated extensive glacial outwash deposits to 237 ka (the MIS 8/MIS 7e transition); chemical analysis of the sediments indicated their derivation from siliceous rocks in the upper Mersey catchment, implying the valley was occupied by a major glacier of unknown extent during MIS 8. Elsewhere, in the Boco River valley in western Tasmania, Augustinus et al. (2017) dated glacial advances but concluded that there was “no evidence for MIS 2, 4 or 6 affinity glacial advances onto the Boco Plain”. These conclusions do not

necessarily conflict with the observations of Slee et al. (2022) because the outwash noted at Railton may have been derived from a glacier terminating and melting tens of kilometres upstream, at a higher altitude than the Boco Plain.

## AIM

In this research note, we briefly describe finely layered silty fine sands exposed at Wilks Road, Lorinna (Figure 1), date them by OSL methods, and discuss their implications for late Quaternary geological processes in the River Forth valley.

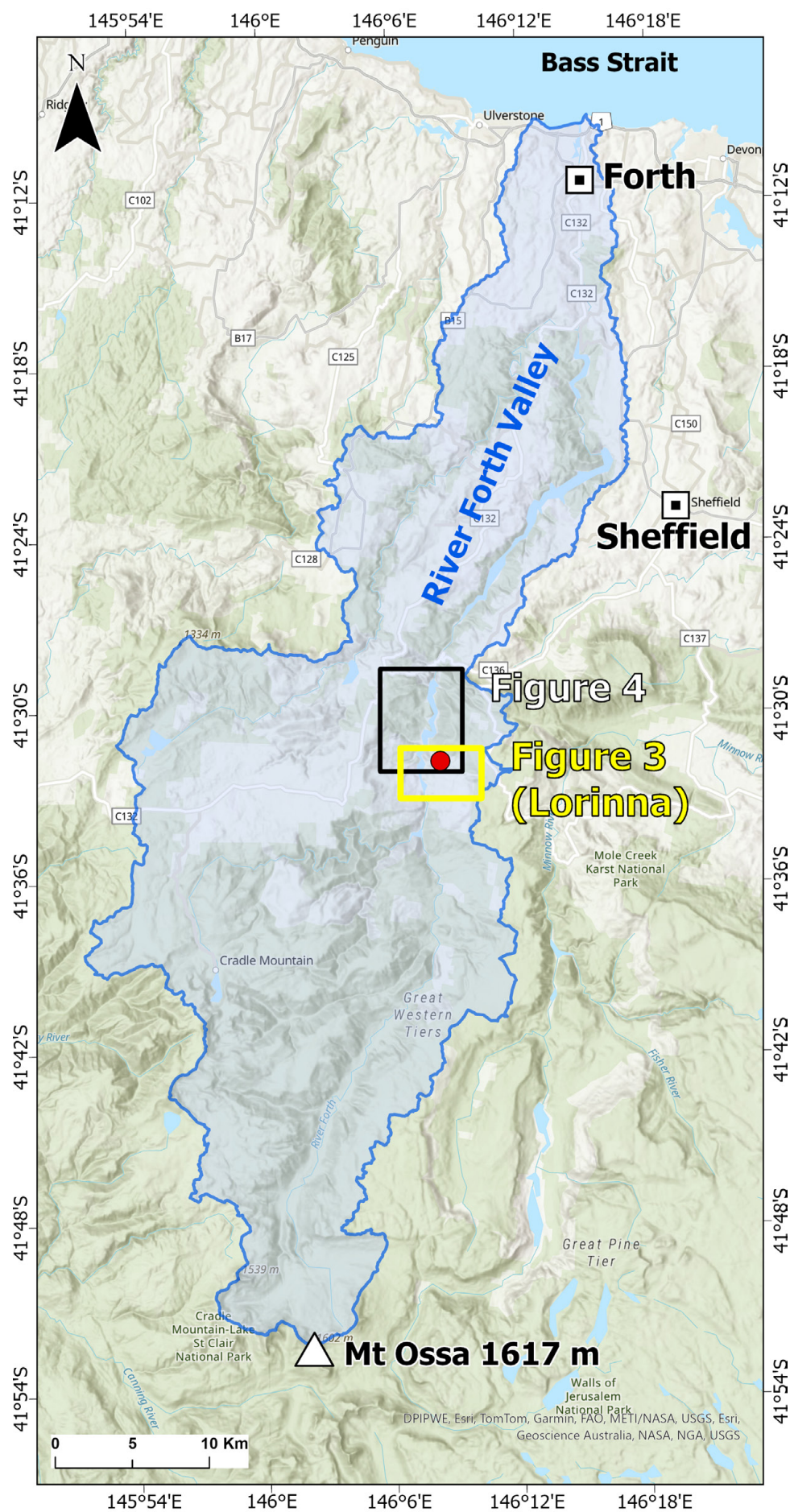
## OBSERVATIONS AND METHODS

### FIELD SURVEY

A road cutting (base at c. 359 m a.s.l.) on Wilks Road, Lorinna, in the middle River Forth valley at 41.528828°S, 146.1384594°E in northwest Tasmania, has exposed finely layered silty fine sands which are c. 3 m thick in the visible exposure (Figure 2). The deposit is on the upper midslope of a steep-sided ridge and is overlain by c. 1 m of slumped weathered basalt (originally of Paleogene origin) (Figure 3). The dammed Lake Cethana to the west has a nominal height of 222 m a.s.l., and the natural level of the River Forth is about 100 m below this, i.e. the deposit is about 240 m above the pre-dam river level. The base of the silty fine sand exposure is not exposed at the study site but may be related to the ‘terrace gravels’ noted in a quarry face 200 m west of the road cutting, at 329 m a.s.l. (Figure 3). The quarry site is within the Qha unit (undifferentiated Quaternary alluvium) mapped north and south of Wilks Road (Figure 3), with its upper limit approximating to the 330 m contour.

The gravels in the quarry consist of rounded quartzofeldspathic gravels and cobbles (20–50 mm diameter) derived from quartz schist and quartzite in a matrix of coarse sand. These are overlain by 2 m of weakly



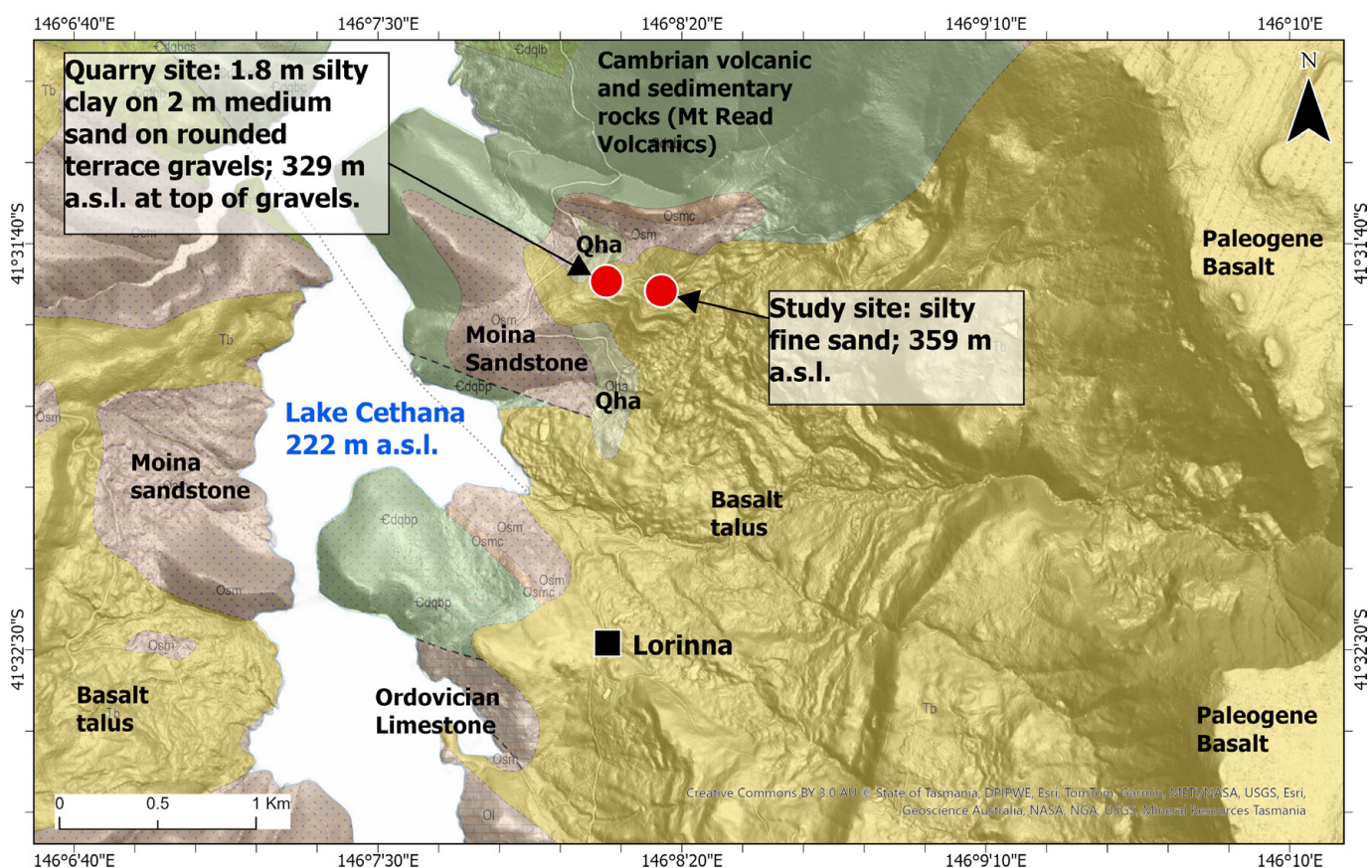


**Figure 1:** General location map. The red circle shows the location of the study site.





**Figure 2:** Details of the layering in the Lorinna silty fine sands. This image has been enhanced to emphasise the contrast between the darker silty layers and the pale fine sandy layers. Actual Munsell colours are very pale brown (10YR7/3) for the silty layers and light grey (2.5Y/2) for the fine sandy layers.



**Figure 3:** Location of the study site in relation to local geology. Basalt 'talus' refers to slumped weathered basalt. Qha = undifferentiated Quaternary alluvial deposits. Background LIDAR image is from ListMap (2025). Geology is from McClenaghan et al. (2008).



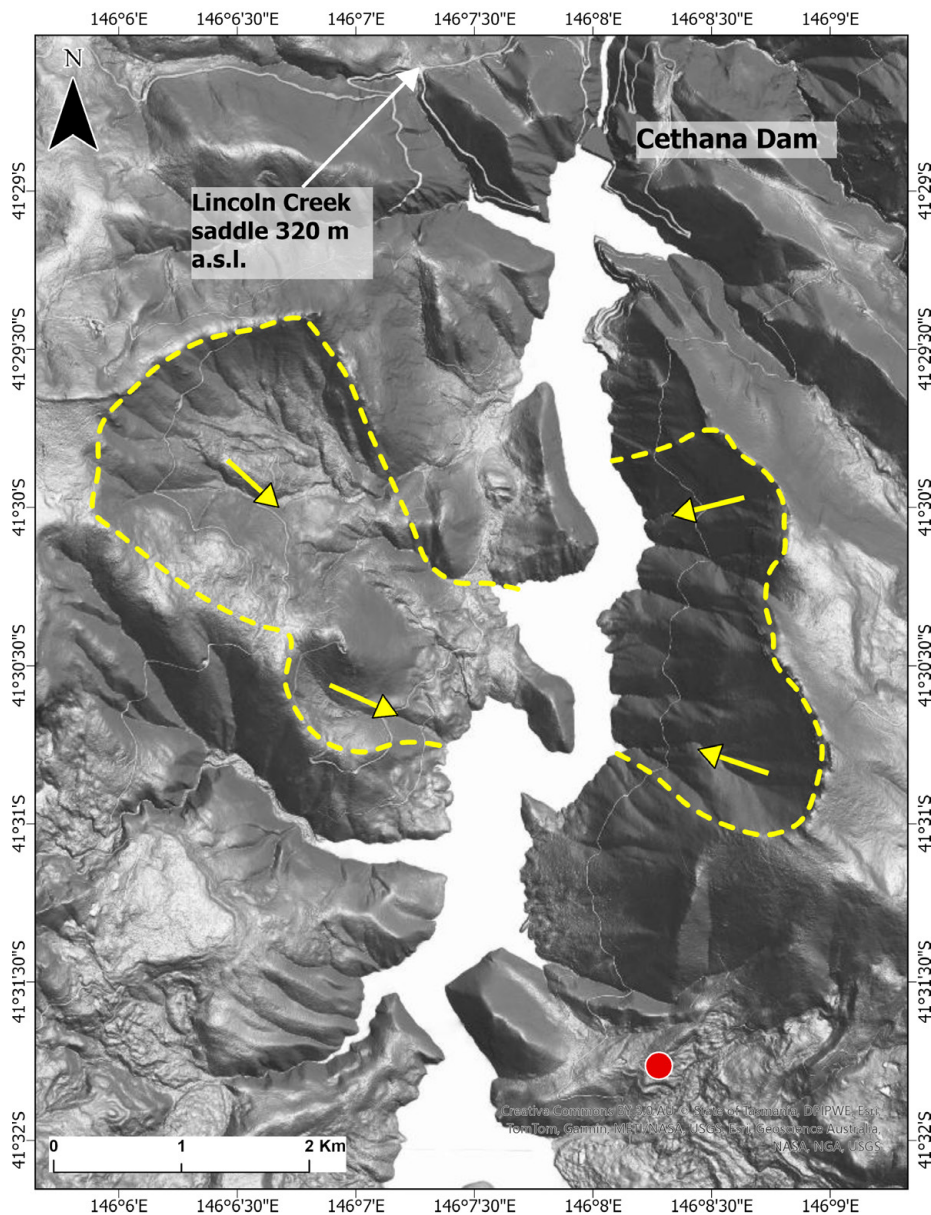
**Table 1:** Site details for calculating total environmental dose rate.

| LAT.       | LONG.      | ALTITUDE<br>(m a.s.l.) | ESTIMATED<br>DEPTH<br>(cm) | FIELD<br>WATER<br>CONTENT <sup>1</sup><br>(%) | COSMIC-RAY<br>DOSE RATE<br>(Gy/ka) | TOTAL<br>ENVIRONMENTAL<br>DOSE RATE (Gy/ka) | n <sup>2</sup> | OVER-<br>DISPERSION<br>% | De <sup>2</sup><br>(Cy) | AGE <sup>3</sup><br>(ka) | DOSE<br>RECOVERY<br>RATIOS |
|------------|------------|------------------------|----------------------------|-----------------------------------------------|------------------------------------|---------------------------------------------|----------------|--------------------------|-------------------------|--------------------------|----------------------------|
| -41.529419 | 146.137996 | 355                    | 250                        | 25.93                                         | 0.169 ± 0.017                      | 1.687 ± 0.071                               | 23/41          | 47 ± 8                   | 221 ± 23                | 131 ± 15                 | 0.93 ± 0.05                |
|            |            |                        |                            |                                               |                                    |                                             | 22/41          | 26 ± 6                   | 242 ± 16                | 143 ± 11                 |                            |

<sup>1</sup> Assigned an uncertainty of ±10%;

<sup>2</sup> Accepted aliquots vs measured aliquots;

<sup>3</sup> Equivalent doses and ages are calculated using the Central Age Model (CAM)



**Figure 4:** Possible sources of damming material downstream from the silty fine sand deposits. The red circle shows the study site on Wilks Road. The damming material may have been landslide debris originating from the cirque-like features east and west of the River Forth, indicated by the dashed lines and arrows.

cemented medium sand and a further 2 m of silty clay, which may transition laterally and upwards to the silty fine sands at the study site, in which case the deposits are over 30 m thick.

Upslope of the deposit, extensively slumped Palaeogene basalt is mapped; to the north and south are areas of cross-bedded Ordovician Moina sandstone (typically medium and coarse sands weathered reddish-brown and weakly cemented) surrounded by Cambrian volcanoclastic rocks (Mt Read Volcanics: Bull Creek Formation) (McClenaghan et al. 2008).

At the base of the exposed face at 359 m a.s.l. (Figure 2) an undisturbed sample was taken with an aluminium tube and dated by OSL methods. The particle size of an adjacent sample was determined by dry sieving.

## OPTICAL DATING METHODS

The sample was prepared using standard laboratory procedures (Wintle, 1997) at the Luminescence Dating Laboratory at the University of the Fraser Valley, Abbotsford, BC, Canada. Quartz grains 180–250  $\mu\text{m}$  diameter were extracted. An equivalent dose ( $D_e$ ) value for each aliquot (50–100 grains per aliquot) was determined by repeatedly measuring and dosing each aliquot using the single aliquot regenerative-dose (SAR) protocol and measuring the OSL signal (Murray & Wintle 2000, 2003; Table 1) first suggested by Murray and Roberts (Radiation Measurements 29, 503–515, 1998). Radionuclide contents of U, Th and K were determined using Neutron Activation Analysis (NAA) on ~10 g of dried and milled representative bulk sediment. The field water content was estimated using bulk sediment collected at the time of sampling. Detailed descriptions of laboratory methods can be found in supplementary notes available from the corresponding author (PDM; file NRE/FPA/2009/00718/1) or author MS.

## RESULTS

Most sediment grains in the deposit are fine sand (<250  $\mu\text{m}$ ) and 22% of the total sample by weight has a grain size of less than 63  $\mu\text{m}$ . Hand texturing established that this fine fraction is largely silt. The deposit is horizontally layered at approximately 2–5 mm intervals (Figure 2). The darker bands contain more silt than the pale bands. Vertical cracks in the deposit are up to 8 mm wide and filled with grey fine sand. Under a binocular microscope, quartz was observed to dominate the sand fraction. Rare flakes of muscovite were also noted.

The optical age was determined to be  $143 \pm 11$  ka (with one outlier aliquot excluded from the analysis) (Table 1), i.e., the silty fine sands were deposited close to the end of MIS 6. Using the rationale of Medialdea et al. (2014), we

define outliers in an objective way as those  $D_e$  values that fall outside of  $1.5 \times \text{IQR}$  (Interquartile Range), with the IQR equal to those values falling in the 75% quartile ( $Q_3$ ) minus those that fall within the 25% quartile ( $Q_1$ ). In this case, we refer to ‘outliers’ as aliquot  $D_e$  — extreme values that likely contain grains with large inherent signals (cf. Medialdea et al. 2014).

## DISCUSSION AND CONCLUSION

The sediments are interpreted to be lacustrine. Their fine layering is typical of deposits resulting from intermittent supply in a low-energy environment.

A local (upslope) source for the sediments must be considered. The Cambrian volcanoclastic rocks (Bull Creek Formation) have highly variable composition, including ‘quartz-feldspar’ porphyry, bands containing epidote, hornblende, magnetite, sedimentary layers, biotite, chalcopyrite, and chert (Jennings, 1963). These rocks near Cethana invariably weather to gravelly brown clay loams, and the dominant fine sand and silt components of the sediments at the study site rule out both the coarser-grained Moina sandstone and weathered basalt as a source. It is unlikely that any of these three possible source rocks, either eroding locally in isolation or (more probably) in combination, created the well-sorted quartzose fine sands and silts observed. However, conglomerates within the Moina sandstone could account for the rounded gravels and cobbles at the base of the quarry site.

The most likely source of the fine sands and silt is glacial rock flour derived from Proterozoic metamorphic rocks such as quartzite, quartz-schist and mica schist of the Tyennan Group, which are extensive in the River Forth catchment, 5 km or more upstream (Vicary, 2023).

The possibility that the silty fine sands were deposited at the lateral margin of a large glacier filling the valley to Cethana during MIS 6 is rejected as there is no evidence of an MIS 6 glacial advance of this magnitude in the Forth valley, nor did Augustinus et al. (2017) find evidence of for MIS 6, 8 and 10 glacial advances to 370–450 m altitude on the Boco Plain in western Tasmania.

The remaining possibility is that the silty fine sands were deposited in a lake extending c. 24 km upstream (south) to the vicinity of Hartnett Rivulet, where the River Forth valley floor is at approximately 360 m a.s.l. A lake with a surface at 360 m or higher at the study site implies that the River Forth must have been dammed, possibly for a short time, as there are no traces of lake-margin beaches or cliff lines at c. 360 m a.s.l. further up the Forth valley. A 320 m saddle in the Lincoln Creek catchment, 1 km west of the Cethana hydroelectric dam (Figure 4) and the



absence of landslide evidence on River Forth valley sides below the dam constrain the location of the postulated natural dam — it must have been between the location of the hydroelectric dam and the study site. Inspection of LIDAR imagery (ListMap 2025) shows scars (Figure 4) on either side of the River Forth, which may have resulted from large landslides that dammed the River Forth.

If the dam hypothesis is accepted (and we recognise that further studies are required), outflows when the dam was breached are likely to have been strong. Unusually strong river flows could explain some of the undated deposits in the lower River Forth valley described as till by Colhoun (1976, figures 8 and 9).

## ACKNOWLEDGEMENTS

Authors PDM and AJS were supported by funding from the Forest Practices Board, Tasmania. MS and OBL were supported by a Canadian Natural Sciences and Engineering Research Council Grant and an NSERC Research Tools and Instruments Grant. CMN was supported by a Hakai Postdoctoral Fellowship from the Hakai Institute and Tula Foundation. We thank Nick Roberts, Mineral Resources Tasmania and two anonymous reviewers for suggestions for improving the submitted manuscript.

\*[Supplementary material](#) available on AQUA website.

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## THESIS ABSTRACTS

### PALAEOECOLOGY AND ISOTOPIC GEOCHEMISTRY OF QUATERNARY VERTEBRATE FAUNAS FROM NARACOORTE CAVES, SOUTH AUSTRALIA

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#### ABSTRACT

The Naracoorte Caves World Heritage Area (NCWHA) and surrounding area has yielded a wealth of information about past fauna and flora through time. The caves that lie within this extensive karst system have been accumulating material for the last 500 thousand years (ka), spanning the middle to late Pleistocene. Fossilised fauna and flora material, speleothems, cave sediment and charcoal have previously been studied to determine changes in the faunal community, as well as the climate and environment of the region. Investigating how these changes have affected the palaeocommunities of the past is important for understanding extinction events, such as the Pleistocene megafaunal extinction. Traditional techniques of palaeontology, geology and ecology, to name a few, have been important in the reconstruction of the south east of South Australia during the Pleistocene. Pairing traditional techniques of palaeontology with modern geochemical analysis of fossil material, namely stable isotope analysis of carbon ( $\delta^{13}\text{C}$ ) and oxygen ( $\delta^{18}\text{O}$ ) on tooth-derived bioapatite, enables an understanding of faunal paleoecology, climatic and environmental changes and how they have influenced/ driven changes in communities through time. Analysis of  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  from fossils is commonly used to elucidate not only climatic change, but also the past life habits and preferences of fauna that are now extinct.

This thesis presents fossils obtained from two sites on the NCWHA to determine community change, palaeoecology, and climatic and environmental change through time using both palaeontological and stable isotope analyses. Palaeoclimatic and palaeoecological proxies commonly used in Australia are reviewed with a case study of their use at the NCWHA and the application of stable isotope analysis at the locality (Chapter 2). Stable isotope analysis of  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  from Blanche Cave was conducted on rodent bioapatite to determine climatic change from ~ 65 to 16 ka, which was compared to regional climatic records (Chapter 3) and palaeoecology of two extinct rodent species (Chapter 4). The first systematic palaeontological excavation was conducted in Alexandra Cave to determine the species present in this deposit, as well as the age and depositional environment of the sequence, utilising traditional palaeontological and geological techniques (Chapter 5). Finally, a stable isotopic palaeoecological study was conducted on the abundant rodent species in the Alexandra Cave excavation to gain a greater understanding of palaeodiet and niche partitioning of co-occurring species (Chapter 6).

The major research outcomes of this thesis showed that pairing stable isotopes of fossil remains with palaeontological context can aid our understanding of changes in climate and environment derived directly from the fauna through time. It also showed that stable isotope analysis can be used to determine the palaeoecology of now extinct fauna at the NCWHA, and can aid in our understanding of palaeocommunities and how they have changed through time, life habits and the possible effect of climate and environmental change. Advancing our knowledge of the past using traditional and modern techniques, such as palaeontological excavations and stable isotope analysis, allows for greater understanding of this continent's climate and how its unique fauna have endured or vanished.



## RECENT PUBLICATIONS

Journal of Quaternary Science Special Issue: Southern Hemisphere records of Late Quaternary climate change, people and dust

*This Special Issue of Journal of Quaternary Science is in honour of a stalwart of the Australasian Quaternary community, Dr Lynda Petherick, who died unexpectedly, aged 40, early in 2022. Lynda was a driving force behind research into late Quaternary climate change and human-environment interactions in the Southern Hemisphere and undertook pioneering work on using dust records for reconstructing atmospheric circulation. As President of the Australasian Quaternary Association (AQUA) up until the time of her death, Lynda was actively engaged in promoting stronger demographic and gender balance within the Australasian Quaternary community. In recognition of Lynda's outstanding contributions and tragic loss, this Special Issue represents a tangible and lasting tribute to Lynda's outstanding career contribution to Quaternary Science.*

[https://onlinelibrary.wiley.com/doi/toc/10.1002/\(ISSN\)1099-1417.Southern\\_Hemisphere\\_records\\_of\\_Late\\_Quaternary\\_climate\\_change\\_people\\_and\\_dust](https://onlinelibrary.wiley.com/doi/toc/10.1002/(ISSN)1099-1417.Southern_Hemisphere_records_of_Late_Quaternary_climate_change_people_and_dust)

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