ABSTRACT

Naracoorte Caves: a critical window on faunal extinctions and past climates

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Naracoorte Caves National Park in South Australia was inscribed onto the UNESCO World Heritage list in December 1994 in recognition of its outstanding Quaternary vertebrate fossil deposits. Listed as a serial nomination with Riversleigh in Queensland, the sites reveal much about the evolution of Australia's unique mammals including the extinct megafauna. Importantly, they provide insight into how vertebrate communities have responded to environmental change over the past 20 million years.

Spanning the last 500,000 years of this long record, the vast fossil deposits of Naracoorte Caves allow scientists to reconstruct high resolution records of biodiversity and past climate. The caves contain the most diverse and abundant deposits of Quaternary vertebrates in Australia with over 130 species from dozens of sites within the park. The exceptional preservation of the Naracoorte fossils is well known, with complete skeletons and delicate specimens preserved in all of their detail.

The first fossils were reported from Naracoorte by the Reverend Julian Tenison-Woods in 1858; but it was a discovery made by cave explorers in the Victoria Cave in 1969 that set the stage for World Heritage listing. Research has been ongoing since then and in the last ten years knowledge has increased tenfold as new scientific discoveries are re-writing the story of Naracoorte's fossil caves. From fossil plants to ancient DNA, new insights are providing a more complete understanding of Naracoorte's role in reconstructing the wonders of ancient Australia.

KEY WORDS: Naracoorte Caves, World Heritage, palaeontology, Quaternary, megafauna, vertebrate fossils, caves.

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Introduction and history of fossil discoveries at Naracoorte Caves

Naracoorte Caves World Heritage Area is situated in the Limestone Coast region of South Australia, approximately 350 km southeast of the city of Adelaide. The locality is widely renowned for its extensive fossil record of Quaternary vertebrates preserved within deep sediment deposits in a network of limestone caves (Reed & Bourne, 2000). The caves formed during the early Pleistocene within the late Eocene to middle Miocene aged Gambier Limestone (White & Webb, 2015). The largest of the caves are concentrated along the East Naracoorte Range, which is an early Pleistocene stranded coastal dune range that has contributed much of the cave sediment infill deposits. Animals accumulated in the caves via several mechanisms including pitfall entrapment, predator accumulation and deaths of cave-dwelling species. The resultant vertebrate fossil assemblages reflect a rich late Quaternary fauna and flora in the Naracoorte region, spanning at least the past 500,000 years (Reed & Bourne, 2000).

The earliest report of fossil material discovered at the Naracoorte Caves comes from a paper published in the *South Australian Register* by Reverend Julian E. Woods (later Tenison-Woods) in March 1858 (Woods, 1858; Reed & Bourne, 2013). In this article, Woods describes his visit to the 'Mosquito Plains Caves' in 1857 and his interpretation of the geology and vertebrate remains he found in Blanche Cave. Woods discovered a wealth of bone material at the base of large columns within the cave and attributed these bones to small mammals such as rodents and bandicoots (Woods, 1858). He did not find remains of extinct Pleistocene megafauna at

Figure 1 – A. Reverend Julian Tenison-Woods in 1860 (from the collection of the State Library of South Australia B33699). B. Illustrations of rodent fossils found by Woods in Blanche Cave in 1857 (Woods, 1862).

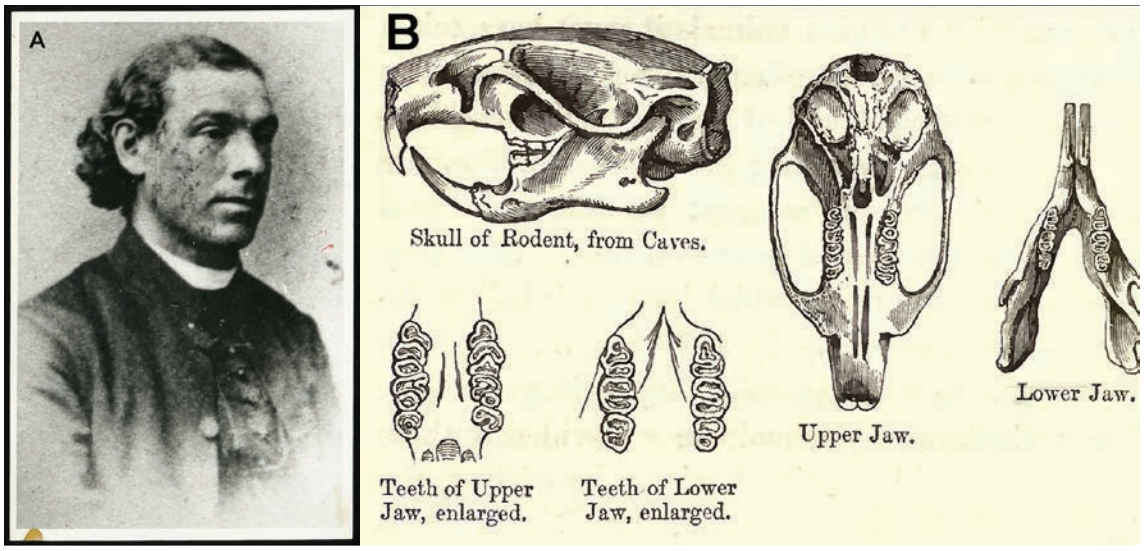

Figure 2 – Megafauna fossils scattered over the cave floor in the Upper Ossuary, Victoria Fossil Cave (photo Steve Bourne).

Naracoorte but was well aware of the discovery of these fossils at other localities, notably the Wellington Caves in New South Wales (Woods, 1862).

Megafauna fossils were first reported from the Naracoorte Caves in 1908, when the Director of the South Australian Museum Edward Stirling and preparator Friedrich Zietz visited Naracoorte. The caretaker of the caves William Reddan had uncovered megafauna bones in Alexandra Cave and Specimen Cave and reported his findings to the museum. This prompted the visit by Stirling and Zietz who recovered fossils of the extinct marsupial predator *Thylacoleo carnifex* (Reed & Bourne, 2000).

The formation of the Cave Exploration Group of South Australia in 1955 initiated a new era of exploration and scientific investigation at the Naracoorte Caves. Fossil material was recovered by cavers during systematic exploration of the cave system and these finds were reported to the South Australian Museum (Reed & Bourne, 2000). In 1956 a partial skeleton of *Thylacoleo carnifex* was uncovered during quarrying operations in James Quarry. Similar activities led to the discovery of a large fossil deposit in a cave at Henschke's quarry in Naracoorte township in 1969 (Reed & Bourne, 2000).

The most significant discovery at Naracoorte Caves was made in 1969 when previously unknown areas of Victoria Cave were discovered by cave explorers. Within this new extension was a large sediment floored chamber containing thousands of bones of Pleistocene vertebrates including exceptional specimens of megafauna species. The discovery led to the first ongoing research project at the caves, led by Rod Wells and colleagues (Wells et al., 1984). Opportunities for tourism and education were soon recognised

and the cave became an important site for visitors and researchers alike. The focus of interpretation at the Naracoorte Caves shifted towards explanation of the scientific values of the park rather than focussing just on aesthetic values (Reed & Bourne, 2013).

Heritage values and recognition

In December 1994, around 300 hectares of the Naracoorte Caves Conservation Park (now National Park) were listed as a UNESCO World Heritage site. A serial nomination with Riversleigh in northwest Queensland, it is inscribed as the Australian Fossil Mammal Sites (Riversleigh/Naracoorte). The sites are considered of outstanding universal value, meeting two of the ten criteria for World Heritage listing:

> Criterion (viii): to be outstanding examples representing major stages of earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features.
>
> Criterion (ix): to be outstanding examples representing significant on-going ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals.

The World Heritage values relate specifically to the Quaternary vertebrate fossil deposits and their associated values (Bourne & Reed, 2009). The park also has other values that are significant at a state and national level including biological, historical, scientific, geological and cultural. These values are recognised in additional heritage listings including National and State heritage (Reed & Bourne, 2013). In 1984, Blanche Cave and Victoria Fossil Cave were registered on the South Australian Heritage Register. The sites demonstrate evolving attitudes towards natural history, moving from the 'Victorian' attitude of nature as a curiosity to conservation and appreciation of scientifically important values. In 2016, an expanded State Heritage nomination recognised a broader range of the park's values (South Australian Heritage Council, 2016). The Australian Fossil Mammal Sites were added to the National Heritage List of Australia in May 2007.

Why is Naracoorte an exceptional vertebrate fossil locality?

The Naracoorte Caves World Heritage Area provides an extraordinary window into late Quaternary biodiversity and environment. It is unrivalled among Quaternary localities in Australia for the diversity of fossil species, quality of preservation, continuity of the fossil record and association of multiple palaeoenvironmental proxies. The caves contain finely resolved, deep sediment sections which have had minimal disturbance from dynamic process such as high energy water flow. Vast accumulations of sediment within the caves are largely derived from Quaternary dune sediments overlying the caves, and other additional regional sources (Forbes & Bestland, 2007). Isotopic and elemental geochemistry of these sediments can be used for reconstruction of the environmental context for the vertebrate faunas (Darrénougué et al., 2009).

A particularly striking feature of the Naracoorte locality is the occurrence of multiple, contemporaneous fossil sites in the one relatively small geographic area. Dozens of fossil deposits within many different caves span an extended time period over at least the past 500,000 years. This enables patterns of biodiversity and environmental change to be verified, tested and correlated in time and space (Macken et al., 2013; Macken & Reed, 2014). Furthermore, there are hundreds of caves outside of the World Heritage Area within the Limestone Coast region allowing a broader regional perspective.

The vertebrate fossils found at Naracoorte are exceptionally well preserved, with the most delicate features of skulls and skeletons maintained. In some sites, fossils have been found as articulated skeletons or with elements in close association. The density of fossil material within deposits is high, with relatively small excavations yielding large numbers of bones. In some of the younger sites (<20 ka) ancient DNA has been recovered from bones (Grealy et

Figure 3 – Immense sediment cones in Sand Cave, Naracoorte (photo Steve Bourne).

al., 2016) and also macro plant fossils (Estrada et al., 2018). A range of palaeoenvironmental proxies are preserved within the sediments in direct association with the faunal remains allowing fine-grained reconstruction of past climate.

A high diversity of vertebrate species is preserved in the Naracoorte cave deposits. Over 130 species of amphibians, reptiles, birds and mammals have been identified (Reed & Bourne, 2000, 2009; Macken & Reed, 2013). As new research unfolds in the next few years this number will no doubt increase. Naracoorte has a rich record of extinct Pleistocene megafauna including nine species of sthenurine kangaroos (Prideaux, 2004) and the giant herbivores *Diprotodon optatum, Zygomaturus trilobus* and *Palorchestes azael*. The madtsoiid snake *Wonambi naracoortensis* was first described from specimens excavated in the Victoria Fossil Cave (Reed & Bourne, 2000). Fossils of the marsupial predator *Thylacoleo carnifex* are found in nearly all of the cave deposits and include articulated skeletons (Curry et al., 2014). Less common species are the megapode *Latagallina naracoortensis*, the giant monitor *Varanus priscus*, the koala *Phascolarctos stirtoni*, the long-beaked echidna *Megalibgwilia ramsayi* and the massive bird *Genyornis newtoni*.

From the perspective of reconstructing palaeocommunity responses to environmental change, the key faunas at Naracoorte Caves are the small mammals (Macken & Reed, 2013, 2014). Largely derived from owl pellet accumulation, the abundance, diversity and sheer volume of material for these species allows statistical assessment of palaeocommunity

composition and resilience to changing conditions (Macken & Reed, 2014). The small mammal (<2kg body mass) assemblages contain around 40 species overall; but are dominated by murid rodents both in terms of diversity and relative abundance (Macken & Reed, 2013). Some of these species were driven to extinction rapidly following European settlement of Australia including the Long-eared Mouse *Pseudomys auritus*, the White-footed Rabbit-rat *Conilurus albipes* and Gould's Mouse *Pseudomys gouldii*. Marsupials account for the remaining small mammal species, with diverse assemblages of insectivorous and carnivorous dasyurids (Dasyuridae), bandicoots (Peramelidae) and possums (Phalangeridae, Burramyidae, Pseudocheiridae).

The Naracoorte Caves contain an array of materials that can be dated using numerical techniques to constrain the age of the deposits. These include speleothems, quartz sediments, bone, charcoal, macro and micro plant fossils. Recent research has resolved the chronology of several key sites in Blanche Cave, Wet Cave, Robertson Cave, Grant Hall and Cathedral Cave (Prideaux et al., 2007; Darrénougué et al., 2009; St. Pierre et al., 2009, 2012; Macken et al., 2011; Macken et al., 2013; Grealy et al., 2016). The oldest dated sediment deposits are from Cathedral Cave and fall within Marine Isotope Stage 13 (mean age 528 ±41 ka obtained via Optically Stimulated Luminescence – Prideaux et al., 2007). The youngest deposits span the late Holocene with ages <1 ka (Grealy et al., 2016).

A new era of research at Naracoorte Caves

Palaeontological research at the Naracoorte Caves has increased over the past decade, with a renewed focus on refining the chronology of key sites and placing vertebrate faunas within a palaeoenvironmental context. Important new discoveries include the presence of a palaeovegetation record preserved as pollen, phytoliths, leaf waxes and macro plant fossils (Darrénougué et al., 2009; Reed, 2012; Estrada et al., 2018). Recent excavations in several caves, and the discovery of new cave sites, has yielded additional vertebrate faunal assemblages (Reed & Bourne, 2009).

Recently, the University of Adelaide was awarded an Australian Research Council Linkage grant for four years of research into Naracoorte's fossil deposits (Reed & Arnold, 2017). This work builds on research undertaken by the author and colleagues since 2008 and capitalises on new directions developed since 2015. The project has four key aims:

1. Establish a high resolution, continuous chronostratigraphic framework for biodiversity and environmental proxy records at Naracoorte spanning the last five glacial cycles.
2. Evaluate palaeocommunity structure and dynamics of vertebrate faunas over middle–late Pleistocene timescales to elucidate megafauna extinction drivers and community responses to local, regional and global climate patterns.
3. Reconstruct long-term palaeoclimate, palaeoenvironment and palaeovegetation records from multiple, high resolution proxies preserved in the Naracoorte cave deposits.
4. Utilise project findings to promote Naracoorte's unique fossil heritage and build much-needed capacity for natural resource management, conservation, training and education.

The Naracoorte fossil record spans two major waves of extinction, namely the Pleistocene megafauna extinction around 45,000 years ago and more recently those associated with the arrival of European settlers into Australia. Elucidating the timing and causes of megafauna extinction in Australia has been a focus of research in Quaternary palaeontology for the past two decades (Roberts et al. 2001). Key shortcomings of existing datasets across Australia include the paucity of sites with high quality dates within a well-resolved stratigraphic framework and the lack of detailed taphonomic and palaeoenvironmental data associated with megafauna records. The Naracoorte fossil deposits are uniquely placed to help unravel the mysteries of megafauna extinction and the current research will yield critical data that will allow palaeontologists to test major extinction hypotheses.

Since European settlement, nearly 30 species of native mammals have become extinct in Australia. The Holocene record at Naracoorte provides critical information on faunal baselines prior to significant disruption of the distributions and structure of native mammal communities. Conservation palaeobiology is a rapidly expanding field within palaeontological research. It involves using data obtained from the fossil record to inform the conservation of modern species and ecosystems (e.g. Westaway et al., 2019). As Naracoorte's fossil record covers the last 500,000 years, the preserved faunas and environments are essentially modern and allow reconstruction of communities prior to the arrival of humans into the region. The wealth of palaeoclimate proxies in direct association with the fossil faunas allow finely resolved assessment of community level responses to climate change.

As new research generates increasing interest in the Naracoorte Caves, it will be important for management of the park to ensure there is a balance between tourism, conservation and scientific research. Naracoorte's fossil deposits are finite resources and minimal impact techniques should be applied when undertaking field sampling and excavation. Currently research includes detailed 3D scanning of the caves in order to understand spatial relationships between the caves and associated infill deposits. This minimally invasive technique provides a means to map the cave system without disturbance of fragile deposits. The conservation and realisation of the World Heritage values through appropriate research and management must remain the driving force behind activities at the Naracoorte Caves.

The integration of science into the presentation and interpretation of the park's values has always been a great strength of Naracoorte Caves. Science is dynamic, keeping pace with new evidence, questions and technologies. It brings old bones to life and unlocks the stories contained in the many layers of time preserved within the caves. One of the core aims of the current research is to use the project's scientific findings to promote and present Naracoorte's extraordinary fossil heritage to a broad audience. Since Julian Tenison-Woods first set foot into Blanche Cave over 160 years ago, some of the most passionate advocates for the site have been the palaeontologists and this tradition is still strong today.

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References

Bourne, S. and Reed, E. 2009 The Australian Fossil Mammal sites (Riversleigh/Naracoorte). *World Heritage*, 52: 46-47.

Curry, M., Reed, L. and Bourne, S. 2014 Catching the marsupial lion by the tail: *Thylacoleo carnifex* and the Naracoorte Caves. *Journal of the Australasian Cave and Karst Management Association*, 97: 6-16.

Darrénougué, N., de Deckker, P., Fitzsimmons, K., Norman, M., Reed, E., van der Kaars, S. and Fallon, S. 2009 A late Pleistocene record of aeolian sedimentation in Blanche Cave, Naracoorte, South Australia. *Quaternary Science Reviews*, 28: 2600 – 2615.

Estrada, O., Breen, J., Richards, S. and Cooper, A. 2018 Ancient plant DNA in the genomic era. *Nature Plants*, 4: 394–396.

Forbes, M. and Bestland, E. 2007 Origin of the sediment deposits of the Naracoorte Caves, South Australia. *Geomorphology*, 86: 369–392.

Grealy, A., Macken, A., Allentoft, M. Rawlence, N., Reed, E. and Bunce, M. 2016 An assessment of ancient DNA preservation in Holocene-Pleistocene fossil bone excavated from the world heritage Naracoorte Caves, South Australia. *Journal of Quaternary Science*, 31:33-45.

Macken, A. and Reed, E. 2014 Post-glacial reorganization of a small mammal palaeocommunity in southern Australia reveals thresholds of change. *Ecological Monographs*, 84: 563-577.

Macken, A., Jankowski, N., Price, G., Bestland, E., Reed, E., Prideaux, G. and Roberts, R. 2011 Application of sedimentary and chronological analyses to refine the depositional context of a Late Pleistocene vertebrate deposit, Naracoorte, South Australia. *Quaternary Science Reviews*, 30: 2690-2702.

Macken, A., Staff, R. and Reed, E. 2013 Bayesian age-depth modelling of Late Quaternary deposits from Wet and Blanche Caves, Naracoorte, South Australia: a framework for comparative faunal analyses. *Quaternary Geochronology*, 17: 26-43.

Prideaux, G. 2004 Systematics and evolution of the sthenurine kangaroos. University of California Publications in Geological Sciences 146: 1–623.

Prideaux, G., Roberts, R., Megirian, D., Westaway, K., Hellstrom, J. & Olley, J. 2007 Mammalian responses to Pleistocene climate change in southeastern Australia. *Geology*, 35:33–36.

Reed, E. 2012 Of mice and megafauna: new insights into Naracoorte's fossil deposits. *Journal of the Australasian Cave and Karst Management Association*, 86: 7-14.

Reed, E. 2016 The mystery photographer and the unknown engraving: new information on the first photographs of the Naracoorte Caves. *Journal of the Australasian Cave and Karst Management Association*, 103: 5-10.

Reed, E. and Arnold, L. 2017 Naracoorte, where half a million years of biodiversity and climate history are trapped in caves. *The Conversation*, June 6 2017.

Reed, E. and Bourne, S. 2000 Pleistocene fossil vertebrate sites of the South East region of South Australia. *Transactions of the Royal Society of South Australia*, 124: 61-90.

Reed, E. and Bourne, S. 2009 The Australian Fossil Mammal sites (Riversleigh/Naracoorte). *World heritage*, 52: 46-47.

Reed, E. and Bourne, S. 2013 'Old' cave, new stories: the interpretative evolution of Blanche Cave, Naracoorte. *Journal of the Australasian Cave and Karst Management Association*, 90: 11-28.

Roberts, R., Flannery, T., Ayliffe, L., Yoshida, H., Olley, J., Prideaux, G., Laslett, G., Baynes, A., Smith, M., Jones, R. and Smith, B. 2001 New ages for thelast Australian megafauna: Continent-wide extinction about 46,000 years ago. *Science* 292:1888-1892.

South Australian Heritage Council, 2016 Summary of State Heritage Place, Register entry in the South Australian Heritage Register. Naracoorte Caves Complex, Place 26459.

St Pierre, E., Zhao, J., Feng, Y. and Reed, E. 2012 U-series dating of soda straw stalactites from excavated deposits: method development and application to Blanche Cave, Naracoorte, South Australia. *Journal of Archaeological Science*, 394:922-930.

St Pierre, E., Zhao, J. and Reed, E. 2009 Expanding the utility of Uranium-series dating of speleothems for archaeological and palaeontological applications. *Journal of Archaeological Science*, 36: 1416-1423.

Wells, R., Moriarty, K. and Williams, D. 1984 The fossil deposits of Victoria Cave, Naracoorte, South Australia: the geology and fauna. *Aust. Zool.*, 21:305-333.

Westaway, M., Price, G., Miscamble, T., McDonald, J., Cramb, J., Ringma, J., Grun, R., Jones, D. and Collard, M. 2019 A palaeontological perspective on the proposal to reintroduce Tasmanian devils to mainland Australia to suppress invasive predators. *Biological Conservation*, 232: 187-193.

White, S. and Webb, J. 2015 The influence of tectonics on flank margin cave formation on a passive continental margin: Naracoorte, Southeastern Australia. *Geomorphology*, 229: 58-72.

Woods, J.E. 1858 South Australian Geology No. 3: The Caves at Mosquito Plains. *The South Australian Register*, March 29th page 3.

Woods, J.E. 1862 Geological observations in South Australia: Principally in the district South-East of Adelaide. Longman, Green, Longman, Roberts and Green, London).