SELWYN SYMPOSIUM 2007

Climate change or human impact?
Australia’s megafaunal extinction

Thursday 27 September 2007

Copland Theatre, The University of Melbourne

Editors: Dr Matthew L. Cupper & Dr Stephen J. Gallagher
The School of Earth Sciences,
The University of Melbourne,
Victoria 3010,
Australia.
Melbourne University
27th September 2007

Geological Society of Australia Extended Abstracts Number 79

Geological Society of Australia Victoria Division Selwyn Symposium 2007

Editors: Dr Matthew L. Cupper and Dr Stephen J. Gallagher

ISSN 0729 011X

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Preferred Citation:


Example Citation for papers in this volume:


Copies of this publication may be obtained from:

The Business Manager
Geological Society of Australia Incorporated
Suite 706 Thakrai House, 301 George Street
Sydney NSW 2000 Australia
Alfred Richard Cecil Selwyn (1824-1902)

The Selwyn Memorial Lecture was introduced in 1984 to commemorate the work of A.R.C. Sewlyn, the first Government Geologist of Victoria. This year represents the 155\textsuperscript{th} anniversary of the Government Geological Survey in Victoria. In recent years the Lecture has followed a symposium, involving invited speakers on a significant theme for Australian Geology, to celebrate Selwyn’s work.

Alfred Selwyn was born in Somerset, England in 1824, and had a strong Church of England upbringing. He was educated in Switzerland where he developed an enthusiasm for geology. At the age of 21 he joined the Geological Survey of Great Britain under the direction of A. C. Ramsay in North Wales and was soon entrusted with independent mapping of large areas with key Silurian rocks.

The discovery of Gold in Victoria in 1851 led Governor La Trobe to ask the Colonial Office in London for “a gentleman possessed of the requisite qualifications and acquaintance with geological science and phenomenon.” Selwyn was awarded the post at an annual salary of 500 pounds and arrived in early December 1852. Almost immediately he commenced a series of wide ranging reconnaissance trips during which he studied the geology of Victoria with excursions into Tasmania and South Australia. Among many of the early records, the Geological Survey holds an original water colour version of his 1856 map of the Yarra Basin and Western Port.

Selwyn set up the Geological Survey proper in 1856 and gathered around him and trained a team of geologists including: Alpin, Ulrich, Wilkinson, Daintree, Taylor, Brown and Etheridge. They subsequently occupied senior positions in all mainland State Geological Surveys and became renowned in the early annals of Australian geology. Selwyn and his team established the 6 mile x 9 mile Victorian quarter sheet mapping programme of which 65 were produced.

Selwyn was quiet and reserved man of indomitable disposition who carried out his plans despite all hindrances and achieved an amount of work that few could emulate. However, conflict arose from the overlapping activities of mining surveyors. The Survey often held views on scientific standards and policies opposed to those of the colonial officials and legislators, in particular that of R. Brough Smyth, Secretary of Mines.

Consequently, Selwyn resigned in 1869 and the Survey was disbanded for a year. Selwyn left Australia and was appointed the Director of the Geological Survey of Canada on retirement of Sir William Logan. He worked with distinction from 1869 until his retirement in 1894.

Selwyn was awarded the prestigious Murchinson Medal of the Geological Society of London in 1876. Other honours followed in Great Britain. The only recognition from Australia was his Clark Gold Medal from the Royal Society of New South Wales in 1884. He is commemorated in Victoria by an annual Geological Society of Australia Victoria Division lecture, symposium and medal.
Climate change or human impact? Australia's megafaunal extinction

Selwyn Symposium Summary: Ever since farmers began pulling bones of what they thought were rhinos, hippos and elephants from wells and creek banks during the earliest days of European settlement of Australia, we've been intrigued by the question of what caused the extinction of the megafauna. Some blame humans, suggesting that the first Aboriginal hunters swept across the continent killing off all the giant animals or that bushfires started by these hunters destroyed the habitats of the megafauna. Others contend that climate change of the last Ice Age was responsible. Indeed, the cause of this extinction is subject to much debate in the current scientific literature. This Symposium brings together many of the researchers in this field from around Australia to present their views on what caused the megafaunal extinction. Talks will be presented covering all aspects of the debate, including: palaeontology, palaeoclimate, dating techniques, bone taphonomy, sedimentological and archaeological evidence.

Dr Stephen Gallagher and Dr Matt Cupper, Selwyn Symposium organising committee

The Geological Society of Australia, Victoria Division

The Geological Society of Australia (GSA) was established in 1952 as a learned non-profit organisation. The Society's objectives have been expanded to promote, advance and support the Earth Sciences within the scientific and wider communities.

The GSA Victoria Division holds scientific meetings on the last Thursday of each month at the University of Melbourne University starting at 6.15 preceded by light refreshments from 5.30pm. It publishes geological books (such as the Geology of Victoria), and acknowledges geological leadership and accomplishment through various awards through the Selwyn Award and Symposia.

Anyone interested is also welcome to attend the monthly committee meetings of the GSAV, which usually begin at 4 pm in a venue near the general meeting venue. For further information check our website: www.vic.gsa.org.au.

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### Climate change or human impact? Australia’s megafaunal extinction

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NOTES:
1. The Australian prehistoric megafauna: an overview of discoveries and controversies

John A. Long

(Plenary Address)

Museum Victoria, Melbourne, Victoria 3001, Australia.
jlong@museum.vic.gov.au

Biography:

John graduated with PhD from Monash University in 1984, and spent 6 years as a postdoctoral researcher in palaeontology at universities in Canberra, Perth (as a QEII fellow) and Tasmania before being appointed at the Western Australian Museum in 1989 as Curator of Vertebrate Palaeontology. In 2004 John returned to Melbourne as the new Head of Sciences for Museum Victoria. In 2005 he was appointed as an Adjunct Professor of Earth and Marine Sciences at the Australian National University.

John’s research has focussed on the early evolution of vertebrates (fishes) as well as dinosaurs and general evolutionary theory. He has collected fossils in Antarctica (2 expeditions), Africa, throughout Asia, and has worked extensively in North America and Europe and in every part of Australia. His gruelling expeditions to Antarctica are documented in his book "Mountains of Madness- A Journey Through Antarctica" (Allen and Unwin 2000). He has published over 200 scientific papers and general science articles, and some 25 books. He has named more than 50 new species of prehistoric creatures. His most recent research papers contributed to analysing some of the biggest problems in palaeontology - what killed the Australian megafauna, and how fish contributed to the origins of the first land animals.

The first discoveries of Australian megafauna were made from the Wellington caves of New South Wales back in 1830 by colonist George Ranken and surveyor Thomas Mitchell. These were announced in the Sydney Gazette of 25 May 1830 and the specimens sent to Edinburgh to be studied by Prof. Robert Jameson. Further collecting trips by Mitchell yielded many fine specimens, and his descriptions of them first appeared in the scientific literature in 1831 (Vickers-Rich and Archbold, 1991). In 1838 he reported the presence of a very large animal, Diprotodon, which was formally named by Sir Richard Owen in an appendix to Mitchell’s report. Over the next forty years many specimens discovered in parts of Australia were sent back to Owen, who had a reputation as a meticulous anatomist.

Owen would describe such amazing beasts as the marsupial ‘lion’, Thylacoleo carnifex, from a skull and jaws found on the shores of Lake Colongulac, central Victoria, as well as many species of giant kangaroos and other extinct marsupials. In most cases his descriptions and restorations were close to the mark, verified by later, more complete finds, although in other cases he had no clear indication of just how bizarre some of the Australian megafauna were. In the case of Palorchestes, named by Owen from the teeth to mean ‘ancient leaper’ he interpreted the fossils as belonging to a giant kangaroo (and it was popularly restored like this well into the 1970s), but later discoveries demonstrated this animal to be much closer in appearance to a giant marsupial ‘tapir’, and not a close relative of the kangaroo family (Long et al., 2002). Many cave finds from various sites around Australia continued to yield good material of a wide range of megafauna species during the late 1800s, but none of this material represented articulate skeletons, only isolated bones and teeth.

Complete skeletons of Diprotodon and other megafauna were discovered at Lake Callabonna, central north South Australia, in 1892 by an Aboriginal stockman, who alerted pastoral lessee F.B. Ragless. Ragless’ collection of a few bones was sent to Adelaide to the Museum, which immediately brought out serious collectors to the site. Major field expeditions in 1893 to the site by Edward Stirling and
Amandus Zeitz would collect the first articulated material of the Australian megafauna, including the complete skeleton of *Diprotodon*, the largest known extinct kangaroo *Procoptodon*, as well as remains of the giant wombat *Phascolonus gigas*. Giant bird bones were also retrieved.

Meanwhile remains of other giant animals including ancient reptiles were being uncovered from the Darling Downs region of Queensland and sent to Owen back in London. In 1859 he described *Megalania prisca*, the giant killer goanna whose size is now estimated at around 5-7 metres, with weights of up to a tonne (Molnar, 2004). Despite the following years of misinterpreting remains of giant horned turtles (*Meiolania*) with *Megalania* remains, *Megalania* now emerges as being most likely just a large extinct species of *Varanus*. In addition to giant reptiles Australia had some of the largest birds that ever lived, the flightless thunder birds or Mihiirungs (Family Dromornithidae) first recognised as a distinctive new group of birds by Rich (1979). The Pleistocene *Genyornis* was at least twice the size of the living emu. Giant wombats like *Phascolonus gigas* grew to 1.6 metres, and the largest kangaroos were the short-faced sthenurines, particularly the species of *Procoptodon* (Prideaux, 2004).

The Australian Pleistocene megafauna, as defined by Murray (1991) includes some 40 or more species of mammals, birds and reptiles having a body mass greater than 45 kg. Today only two species fitting this description survive, both being our larger species of kangaroo, *Macropus*. The extinction of the megafauna has been the topic of debate for many years, with climate change and environmental shifts being toted as the prime cause for some years. Humans are thought to have arrived in Australia between 60,000-50,000 years ago, with the oldest dated site (still controversial) being the Devil’s Lair site in southwest Australia (Turney et al., 2001).

The Blitzkrieg hypothesis, of human arrival followed by rapid extinction of megafauna, has been championed in recent years by Flannery (1994) and Roberts (Roberts et al., 2001). Counter arguments from archaeological and palaeoecological models, in particular by Wroe and Field (Wroe et al., 2004), are that overkill hypotheses are too simplistic and do not take into account the full range of factors bringing about extinction. They instead favour a system of ecological collapse following a series of climatic shifts. Pivotal to their arguments is the absence of any well-dated kill sites showing humans and megafauna together, and that the series of ice ages throughout the Pleistocene would have had an accumulated effect on the demise of the megafauna populations across Australia. Pivotal to their arguments is that the majority of the Australian megafauna did not become extinct at around 46,000 years ago as has been postulated by Roberts et al. (2001). Instead they see this age as an artefact of sampling, and that pockets of relict megafauna should be found existing up until the last glacial maximum (~20,000 years ago). The human overkill hypothesis proponents argue that sites were sampled according to intact articulated material, hereby ruling out reworking of sites and potential dating contamination (Roberts et al., 2001). The main line of arguments for the overkill hypothesis is by comparison with historically dated scenarios in New Zealand and North America, where human occupation was immediately followed by extirpation of megafauna.

One factor that has not yet been seriously considered in either of these hypotheses is what was going on at the time of the extinction in the surrounding oceans. In reviewing the five major mass extinction episodes of the Phanerozoic we see the prime causes of these demises have been either sudden devastation from cosmic impact (e.g. Cretaceous/Tertiary boundary ~65 million years ago); widespread oceanic anoxia (Kellerwasser events, ~365-368 million years ago); possible climatic shifts through massive volcanic eruptions (Permian/Triassic boundary ~250 million years ago). In each case where well-documented extinction on land occurred, we see a similar event occurring within the marine realm. Where climate or ecologically-induced collapse has occurred the effects permeated all biomes. In Australia, the extinction of megafauna 46,000 years ago does not correspond with climatic extremes, so climate was ruled out as a major factor of extinction by the overkill proponents. A megafaunal extinction event around 46,000 years ago has no corroborating event of major or minor extinction in the surrounding oceans of Australasia. Extinction brought about by climatic shifts strong
enough to decimate a large island continent terrestrial fauna should have some impact on alteration of surrounding sea temperatures, where even slight changes can have devastating effects on ecosystems. By taking a strictly geological view on the Australian megafaunal extinction event, the evidence would not favour a disruption by climate, but by the intervention of an agent foreign to the system before the time of extinction. Human arrival followed by increased population with declining megafaunal population seems like the most likely cause from this perspective. Testing the hypothesis could be done by closer examination of the late Quaternary marine microfossil and palynological record to see if any corresponding extinction event in the marine realm is observable.

References


NOTES:
2. A review of the evidence for a human role in the extinction of Australian megafauna and an alternative interpretation

Stephen Wroe\textsuperscript{a,c} and Judith H. Field\textsuperscript{b,c}

\textsuperscript{a}School of Biological, Earth and Environmental Sciences, The University of New South Wales, New South Wales 2052, Australia. swroe@unsw.edu.au

\textsuperscript{b}School of Philosophical and Historical Inquiry, The University of Sydney, New South Wales 2006, Australia

\textsuperscript{c}Australian Key Centre for Microscopy and Microanalysis, The University of Sydney, New South Wales 2006, Australia

**Biography:**

Stephen Wroe received his PhD in the phylogeny of Australia's major marsupial carnivore radiation from UNSW in 1999. After a year holding two part-time research positions at the Australian and Macleay Museums, in 2000 he was awarded a U2000 Postdoctoral Fellowship at Sydney University. Stephen is currently a QEII research fellow at UNSW.

He has published on a range of subjects including marsupial phylogeny, biogeography, cranial mechanics and megafaunal extinction to plesiosaur feeding and pterosaur nesting behaviour. His current work centres largely on 3D computer simulation of living and extinct vertebrate skulls in order to better understand the evolution of feeding ecology. Taxa under investigation range from white sharks to hominids, as well as extinct marsupial and placental carnivores and herbivores.

*For Judith Field’s biography see abstract number 4.*

Arguments that megafaunal extinctions in Australia were anthropogenically mediated have focused on establishing terminal appearance ages. This approach has been underpinned by three principle tenets: (1) if megafauna disappeared before significant climate change, but after human colonization, then it can be inferred that extinctions were human mediated; (2) climate change within the last glacial cycle was unremarkable relative to previous cycles; and (3) all or most Pleistocene megafauna were present when people arrived on the continent. We review the evidence for human causation and note mounting evidence suggesting that the past 400,000-300,000 years in Australia has been characterised by escalating aridity and climatic variability, culminating in the breach of a hydrological threshold within the last glacial cycle. Only 21 species (35 \%) of megafauna whose disappearance has been attributed to human activity are known to have persisted after the penultimate glacial maximum (PGM; \(~130,000\) years ago), a time of undoubtedly severe climate change. Thus, 39 species of megafauna (65 \%) cannot be reliably placed within 80,000 years of firm evidence for human arrival at \(~50,000-43,000\) years ago. At most eight species (13 \%) were clearly present at this time (Table 2.1). Four or more persisted until the onset of full glacial conditions at \(~30,000\) years ago. We argue for a falsifiable model of staggered extinction in which most megafaunal extinctions predated human arrival and with the influence of people as a minor superimposition on broader trends in train since middle Pleistocene times.

### 2.1 An undemonstrated premise

Arguments for human causation categorize evidence for pre-last glacial maximum (LGM) climate change as insignificant on the basis of comparison with glacial maxima. The following rationale is applied: change in the lead up to the LGM was relatively insignificant compared with previous glacial maxima and because previous glacial maxima did not cause major extinctions only climatic change of full glacial magnitude can be accepted as significant.
In light of the evidence for a long-term deteriorating climatic trend and no evidence for the survival of most species beyond the PGM, the premise that previous glacial maxima did not cause major losses of megafauna is undemonstrated. Additionally, because the current interglacial appears to be particularly dry it is reasonable to argue that a hydrological threshold was breached in the course of the last glacial cycle. This in itself may explain extinctions.

<table>
<thead>
<tr>
<th>Species</th>
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<tr>
<td>*Diprotodon optatum</td>
<td>46.5</td>
</tr>
<tr>
<td>*Genyornis newtoni</td>
<td>50</td>
</tr>
<tr>
<td>Macropus ferragus</td>
<td>52</td>
</tr>
<tr>
<td>Megalibgwilia ramsayi</td>
<td>55</td>
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<tr>
<td>Palorchestes azael</td>
<td>164</td>
</tr>
<tr>
<td>Phascolonus gigas</td>
<td>46.5</td>
</tr>
<tr>
<td>Procoptodon goliah</td>
<td>46.5</td>
</tr>
<tr>
<td>Proguara naracoortensis</td>
<td>164</td>
</tr>
<tr>
<td>Propleopus oscillans</td>
<td>164</td>
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<tr>
<td>Protomnodon anak</td>
<td>52</td>
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<tr>
<td>Protomnodon brehus</td>
<td>52</td>
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<tr>
<td>Protomnodon roechas</td>
<td>46.5</td>
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<tr>
<td>Simosthenurus baileyi</td>
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<tr>
<td>Simosthenurus brownei</td>
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<td>Simosthenurus gilli</td>
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<td>Simosthenurus maddocki</td>
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<td>Simosthenurus newtoni</td>
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<tr>
<td>Simosthenurus occidentalis</td>
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<tr>
<td>Simosthenurus pales</td>
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<tr>
<td>*Sthenurus andersoni</td>
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<tr>
<td>Sthenurus atlas</td>
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<td>Sthenurus stirlingi</td>
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<tr>
<td>Sthenurus tindali</td>
<td>52</td>
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<tr>
<td>Thylacoleo carnifex</td>
<td>46.5</td>
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<tr>
<td>Vombatus hacketti</td>
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<tr>
<td>Wallabia kitcheneri</td>
<td>55</td>
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<tr>
<td>Wonambi naracoortensis</td>
<td>55</td>
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<tr>
<td>Zaglossus hacketti</td>
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<tr>
<td>Zygomaturus trilobus</td>
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Table 2.1 Last appearances of megafaunal species in sites considered securely dated by Roberts et al. (2001) and Miller et al. (1999). Of ~60 Pleistocene spp. 39 are not known from sites post-dating the Penultimate Glacial Maximum (130,000 years ago), 19 are not found in sites younger than 80,000 years ago, 14 are not found after 55,000 years ago and 8 are found in sites less than 50,000 years ago. Adding data from Cuddie Springs then three species (*) present within 52,000 years ago on the basis of data from Roberts et al. (2001) persisted to 36,000-30,000 years ago.

2.3 The staggered extinction of Australian megafauna

Regarding North America the presence of most genera within 1000 years of the arrival of Clovis people has not been established and this has been raised as an objection to human causation (Grayson and Meltzer, 2002; Grayson and Meltzer, 2003). These authors suggest that North American extinctions were staggered over many millennia, as was clearly the case in Europe (Grayson, 2001). In Australia, relative to North America, the temporal distance between last appearance of most megafauna and human arrival is vast.

Our analyses make one important fact clear: 65 % of extinct Pleistocene megafauna are absent from deposits younger than 130,000 years ago and only eight species were clearly present at the earliest point for which there is broad acceptance for human arrival. At least four of these taxa survived up to 36,000-30,000 years ago and the onset of full glacial conditions (Table 2.1).

While we have provided a critique of models that define megafaunal extinction as human driven, we accept that few climate mediated paradigms have been developed (Barnosky et al., 2004). At present
the most comprehensive is that forwarded by Horton (1984), who suggested that in the lead up to the LGM Australian megafauna were restricted to more coastal habitats as increasingly arid conditions expanded outward from the arid core, greatly reducing supplies of free water. There is some evidence to support the broad contention of coastward aridification (Nanson et al., 1992). Horton explained the bias toward larger species on the grounds that they are dependent on free water, while smaller taxa can obtain sufficient water from their food.

A number of amendments must be made to the hypothesis of Horton (1984) in light of more recent evidence. The most obvious are chronological. Growing evidence for a sustained increase in the severity of glacial maxima post 700,000-600,000 years ago suggests that some taxa often considered ‘late Pleistocene’ may have disappeared at this point. More importantly, Australian evidence for increasingly arid and erratic conditions since 400,000-300,000 years ago and the lack of evidence for 65 % of species post 130,000 years ago suggests that most extinctions occurred during, or in the immediate lead up to the PGM. Further staggered extinctions then occurred with a general trend toward increased aridity from ~100,000 years ago.

Additional evidence testifying to the disappearance of megafauna prior to human arrival has been tendered in an analysis of Tasmanian rockshelters (Cosgrove and Allen, 2001). Humans are not thought to have arrived in Tasmania until the development of a significant land-bridge at ~37,000 years ago (Cosgrove and Allen, 2001; O’Connell and Allen, 2004). Consequently, any anthropogenic model would predict the survival of Tasmanian megafauna to after 37,000 years ago. However, no megafauna have been found post 46,000 years ago in Tasmania and among >600,000 bones from the eight earliest Tasmanian archaeological sites, none represent extinct Pleistocene species (Cosgrove and Allen, 2001). Similarly, a recent analysis of late Quaternary deposits in the Darling Downs found no evidence of human occupation until long after the loss of megafauna (Price and Sobbe, 2005).

Low fecundity and low population densities render large mammal species more vulnerable to extinction (Cardillo et al., 2005). These traits can expose large species to a higher risk of extinction through human influence (Martin, 1984). However, these same characteristics also increase extinction risk due to climate-driven habitat loss. Geographic range size affects large species more strongly and they are less resilient in the face of population crashes (Cardillo et al., 2004; Cardillo et al., 2005).

Increasing body size is commonly a response to low quality food and/or seasonal conditions (Owen-Smith, 1988). Consequently, the gigantism apparent in many Pleistocene lineages is likely an adaptation to increasingly arid/erratic climate. It has been argued that because some Pleistocene megafauna were adapted to relatively arid conditions we might expect their ranges to expand rather than contract with further aridification (Prideaux, 2004). However, there is tension between large size as an effective response to aridification and the negative consequences of greater body mass, which demand greater habitat area to maintain viable populations (Webb, 1998). Although some degree of aridification would benefit large species adapted to semi-arid conditions it is simplistic to argue that ever escalating aridity would result in the expansion or maintenance of their geographic ranges. Even extinct megafauna best equipped to deal with relatively low/erratic rainfall were adapted to semi-arid conditions, not arid conditions in the strict sense (i.e. <250 mm/yr). As habitat declines beyond minimum thresholds, large species are likely to become extinct first (Cardillo, pers. commun. 2005).

Temperature and rainfall fell during the PGM and through the last glacial cycle. During the LGM falls in average temperature of ~8 °C were achieved across much or all of Australia (Hesse et al., 2004), broadly in line with results from analysis of the Vostok ice core, Antarctica (Petit et al., 1999). These data suggest similarly low temperatures during the PGM and that through most of the last glacial temperatures were around 3-6 °C lower than today. While specific influences are not well understood it is clear that primary productivity would have been depressed by lower temperatures and rainfall, an
effect further amplified by falling CO\textsubscript{2} levels, which were 20-40\% lower (Petit \textit{et al.}, 1999; Hesse \textit{et al.}, 2004). CO\textsubscript{2} availability influences competitive regimes between C3 and C4 grasses (Hughes, 2003) and impacts the distribution of flora and fauna. This would not simply effect redistribution of ranges because many plants are constrained by drainage and nutrient requirements (Hughes, 2003). Analysis of Australian plant endemism suggests that falling temperatures and CO\textsubscript{2} exerted a powerful limit on refugia, restricting many plants to more mountainous coastal regions (Crisp \textit{et al.}, 2001).

It is probable that the ranges of megafauna were repeatedly limited to small refugia through successive glacial cycles as occurred in Europe and North America (Hewitt, 2000). Isolation, low relief, landmass area and low rainfall further restrict the size and distribution of refugia in Australia relative to those of other continents, compounding the potential for extinctions (Wroe \textit{et al.}, 2004b). The distinction between range contraction and extinction is fine. In a continent as arid as Australia, relatively minor changes in rainfall patterns can profoundly impact the environment (Ayliffe \textit{et al.}, 1998). Further progressive and stepwise reduction in rainfall and/or the onset of more variable, erratic climate, as has been suggested for the last few glacial cycles, would have had catastrophic impacts with refugia becoming too small and disjunct to maintain viable populations of species that require large ranges. We argue that the critical factors separating surviving from extinct species were abilities to subsist on less food per individual within restricted and/or fragmented geographic ranges and/or to move rapidly and efficiently to ephemeral patches of viable habitat.

It has recently been suggested that even if we accept late survival for some megafauna, the evidence still supports human causation, although this would obviously eliminate blitzkrieg (Johnson, 2005). This is because in Johnson’s view the evidence still points to a major suppression of megafaunal populations before significant climate change and the lack of articulated material after 46,000 years ago can be explained by human butchery practices.

Operating on the assumption that 13 sites younger than 46,000 years ago without articulated remains were correctly dated, Johnson (2005) regressed last appearances against distance from the coast. He found no correlation between distance from the sea and late survival and interpreted results as contra Horton’s hypothesis.

We have several reservations with respect to Johnson’s conclusions. The validity of ages for some of these 13 sites is highly questionable. At present, among Australian sites strong cases can only be made for Cuddie Springs (36,000-30,000 years ago), Clogg’s Cave (22,000 years ago) and Seton Rock Shelter (16,000 years ago) (Field, 2004; Trueman \textit{et al.}, 2005). Additionally, human butchering activities generally do leave disarticulated remains, but this is true of fossilization in general. Moreover, humans do not always disarticulate the remains of animals they are butchering (Pickering, 1995). In the absence of any direct evidence for human intervention the more likely explanation for the paucity of articulated remains (which are always rare) in the latest Pleistocene, is that this reflects decreasing population sizes and opportunities for fossilization under increasingly arid/erratic conditions.

Horton’s hypothesis centers on declining rainfall as the actual limiting factor and distance from the coast is offered only as a descriptive proxy. In much of Australia arid-semi-arid conditions persist to the continental margins. A better test of Horton’s model is one that correlates last appearance with relative rainfall. If we include the three Australian sites mentioned above, the two youngest are within the well-watered south east of Victoria, while one falls marginally within the current arid-semi-arid zone. The two post 50,000 years ago sites considered securely dated by Roberts \textit{et al.} (2001), Ned’s Gully, Queensland (46,500 years ago) and Kudjal Yolga Cave, Western Australia (46,000 years ago), were well outside the current arid-semi-arid zone. Consequently, insofar as this meagre dataset can be analyzed, it is consistent with Horton’s model.
2.4 Conclusions

Arguments for human causation in Australia have focused on terminal appearance ages, operating on the premise that disappearance ages of the last species broadly represent those of most megafauna, that the great majority if not all species were present when humans arrived and that climates during the penultimate and last glacial cycles did not differ significantly from those that preceded them. We conclude that the evidence does not support these underlying tenets of anthropogenic mediation. Most species do not appear within 80,000 years of human arrival and in light of evidence for progressive, long-term aridification of the continent the most parsimonious conclusion is that the process was staggered, with major losses occurring by 130,000 years ago and further range contractions and extinctions throughout the last glacial cycle. To this extent our interpretation is falsifiable on the basis of further dating.

Anthropogenic influence cannot be excluded. The proposition that people could have had no interaction with megafauna is inconceivable, especially considering the Cuddie Springs evidence (Field, 2004; Wroe et al., 2004b), but the maximum extent of human culpability is currently constrained to the 13% of species that can be placed at the scene. While it may yet be demonstrated that human activities combined with climate change to press surviving populations to extinction, in such instances attempts to determine which was 'primary' will likely remain futile. In circumstances where climate change presents a major threat to biodiversity, premature acceptance of human causation for Pleistocene faunal extinctions may divert energy from potentially informative lines of investigation. In addition to the development of more comprehensive chronologies, future tests of ours and other competing explanations include the use of programmes currently used to predict the influences of future climate change to reconstruct past vegetation distributions, and the study of ecophysiology among extinct species. Further investigation of the archaeological record will provide information about human behaviour and subsistence strategies during a period of climatic flux and habitat reconfiguration.

2.5 References


3. **Megafauna, caves and climate: records from southern Australia**

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**Biography:**

Gavin received his PhD from Flinders University in Adelaide 1999, before completing a succession of postdocs at the University of California, Naracoorte Caves and Western Australian Museum. He is interested in the evolution of marsupials, particularly the herbivores, and the responses of southern Australian vertebrate faunas to environmental changes over the past few million years. Gavin has spent much of the past 15 years excavating old bones from caves or examining the contents of museum drawers across the world. He returned to Flinders University earlier this year as an Australian Research Fellow in the School of Biological Sciences.

The analysis of trends in the fossil record is the only empirical means of assessing long-term faunal responses to climate change. Fair enough, but why is this important? One could argue that this is critical to three main areas: (1) Science. Comparing patterns observed in Australia with those on other continents is scientifically interesting, especially given the uniqueness of Australia’s climatic, physiographic, tectonic and biotic histories. Understanding how Australian biotas responded to climate change provides a test of generalisations derived from the Northern Hemisphere; (2) Conservation. Many of us are concerned about climatic and human impacts on contemporary biotas. The fossil record holds enormous potential as a source of data for determining what controls faunal distributions and how species have responded, or might be expected to respond, to climate change; (3) Education. People worldwide are fascinated by life of the past, and Australia has perhaps the world’s most extraordinary continental biota, past and present. By engaging the public using examples such as the evolution of the late Cenozoic ‘megafauna’ in response to environmental change, we can increase awareness in the contemporary relevance of palaeontology, and inspire a wider appreciation of science. One particular problem combines all three of these areas more effectively than any other, and captivates scientists, media and the public alike.

The question of what killed off the megafauna on the continents has persisted for well over a century. Indeed, it was recognised as an issue by Charles Darwin during the voyage of *The Beagle* to the southern continents (Darwin, 1839). Debates over the causes – humans, climate, disease, meteorite showers, a combination of factors – have flared up episodically, but the topic has arguably never been hotter than it is right now. This is especially so in Australia, which lost around 90% of its megafauna by ~46,000 years ago (Miller *et al*., 1999; Roberts *et al*., 2001). And this is probably not surprising given the current focus on the impacts of humans and climate change on our world today. In Australia, opinions on the principal driver(s) of the Pleistocene extinctions remain strongly divided between climatic changes preceding and concurrent with human arrival (e.g. Trueman *et al*., 2005; Wroe and Field, 2006), and the activities of humans themselves via overhunting or habitat disturbance (e.g. Johnson, 2005; Miller *et al*., 2005). Perhaps the biggest impediment to any resolution of the debate is the lack of basic data on faunal change through time and on the ecologies of extinct species (e.g. Barnosky *et al*., 2004). Our understanding of the stratigraphy and chronology of Pleistocene vertebrates in Australia is poor compared with that of other continents. This results from several factors, including the lack of widespread episodic ice sheets, isolation from intercontinental faunal interchange, a relative paucity of localities yielding sufficient taxonomic diversity, limitations of conventional dating techniques, too few detailed stratigraphic studies, and insufficient basic exploration (Prideaux, 2006). In many ways, advances in dating methods have largely inspired the current surge of interest in the Australian megafauna extinction issue (e.g. Ayliffe *et al*., 1998; Miller
et al., 1999; Roberts et al., 2001; Turney et al., 2001), along with detailed investigations of key localities, such as Cuddie Springs and Naracoorte.

3.1 The value of caves

The focus of much of my research over the past decade has been on the collection of fossils from rich, well stratified, well-dated cave sites across southern Australia. Pitfall assemblages in caves are among the least biased kinds of fossil deposit (Baird, 1991), and, in many ways, serve as effective ‘time capsules’ for vertebrate communities. Animals fall into caves through roof openings and are unable to escape. Bones usually become encased in sediments that enter the cave the same way. Some deposits also incorporate or are mainly composed of bones derived from regurgitated owl pellets. When comparing cave deposits, an understanding of taphonomy (all processes between death and scientific collection) is essential for reducing biases in palaeoecological interpretations. Presence/absence data for species along with abundance data within one sediment layer can then be treated as a ‘snapshot’ of a fauna from one interval in time, and compared with those above or below in the same stratigraphic section, or with other cave deposits in the same region or different regions.

Another remarkably useful thing about caves is that climatic records are preserved in speleothems, secondary calcite deposits including stalagmites and flowstones. Extended terrestrial records of climate are uncommon; those that can be related directly to faunal records are even rarer. Speleothem deposition occurs during intervals of greater effective precipitation, and records from the caves of southeastern (Ayliffe et al., 1998) and southwestern Australia (P. Marianelli, unpublished data) reveal marked temporal fluctuations in effective moisture induced by glacial–interglacial cycling over the past 500,000 years. The speleothem climatic records act as an independent test of palaeoenvironmental inferences drawn from temporal changes in faunal composition largely derived using uniformitarian principles. Stable carbon and oxygen isotope ratios retrieved from the speleothems themselves and from the teeth of herbivorous mammals provide another climatic/environmental proxy, as does detailed study of the sediments themselves. Two recent papers (Prideaux et al., 2007a, b) focus on the records from the Naracoorte Caves in southeastern Australia and the Thylacoleo Caves from the Nullarbor Plain of south-central Australia (Figure 3.1). The results and conclusions of both papers are briefly reviewed here, along with a brief discussion of ongoing research in the Leeuwin-Naturaliste Caves (Figure 3.1).

Figure 3.1 Map of southern mainland Australia, showing mean annual rainfall isohyets (mm) and location of Leeuwin-Naturaliste Caves (triangle), Thylacoleo Caves (X) and Naracoorte Caves (diamond). [Figure modified from Prideaux et al., 2007b.]
3.2 Naracoorte
Like many deposits in the Naracoorte Caves World Heritage Area (Figure 3.1), the one in the Fossil Chamber of Cathedral Cave consists of a large sediment fan composed of several successive fossil-bearing units of different ages. Described by Brown and Wells (2000), I re-excavated the deposit in 2003–2004 with a view to obtaining a more detailed understanding of the stratigraphy and chronology, and the aim of removing all excavated sediment from the cave for wet screening. This greatly improves yields of small vertebrate remains compared with dry screening in the cave itself. Excavation revealed a stratigraphy composed of five units. The deepest exceeds 500,000 years ago, while the overlying four accumulated from 290,000 to ~200,000 years ago, as deduced from U-Th dating of interbedded flowstones and optical dating of quartz grains within the sediments (Figure 3.2). Sediments and animals entered the chamber through a single, now-blocked solution pipe (Brown and Wells, 2000), which opened and closed episodically through the middle Pleistocene.

Unexpectedly, the faunal data show a remarkable stability in overall species composition from >500,000 to 280,000-200,000 years ago; 40 of the 44 species are recorded in both the older unit and the younger units (Prideaux et al., 2007a). Moreover, 54 of 62 Cathedral Cave species have local records of 80,000 years ago or younger, and four of the missing eight species are still extant. In other words, at least 94 % of Naracoorte species persisted well into the late Pleistocene; there is no evidence for long-term, staggered, climate-mediated species extinctions (contra Wroe and Field, 2006). However, three distinct faunal trends are evident within the 290,000-200,000 years ago interval (Figure 3). More mesic-adapted species, including most megafaunal species, decline markedly in the upper units, while those adapted to drier, more open habitats show an opposing trend (Prideaux et al., 2007a).

**Figure 3.2**

A) δ¹⁸O record from the southwest Pacific (Pahnke et al., 2003), a long paleoclimate record from mid-latitude Southern Hemisphere. B) Histogram of U-Th ages for Naracoorte speleothems (see Ayliffe et al., 1998 for details). Depositional hiatuses correspond to drier periods. Megafaunal extinction interval from Roberts et al. (2001). Filled circles indicate mean optical ages for Cathedral Cave Units 3 to 1; open circles indicate U-Th ages on flowstones. [Figure from Prideaux et al., 2007a.]

This matches the shifts in effective moisture correlated with glacial–interglacial cycling highlighted by Ayliffe et al. (1998), and shows that despite long-term resilience, species populations very clearly waxed and waned within climatic cycles.

Based on the earlier part of the NCWHA record, the persistence of relatively cool, moist conditions for most of the last glacial should have favoured the megafauna, which leads to the conclusion that its local extinction by ~45,000 years ago (Pate et al., 2002) cannot have been caused solely or primarily
by climate change, especially given the persistence of all other mammals into the Holocene (McDowell, 2001).

### 3.3 Nullarbor

The Thylacoleo Caves were discovered by cavers in 2002 near the centre of the Nullarbor Plain (Figure 3.1). The three caves preserve the most diverse Pleistocene fauna yet recovered from the western half of Australia (Prideaux et al., 2007b), a discovery that provides a long-awaited historical perspective on the region that today acts as a barrier to the east–west dispersal of many taxa (e.g. Keast, 1981). Several of the 69 species (eight of which are new) are represented by complete or partial skeletons (Figure 3.4), which serve as a template for identifying hitherto indeterminate fossil fragments collected previously from Pleistocene sites across southern Australia.

![Figure 3.3](image-url)

**Figure 3.3** Species relative abundance trends across one glacial–interglacial cycle: Cathedral Cave Units 3 to 1 (290,000–200,000 years ago). **A.** Trend 1 small mammals. **B.** Trend 1 large mammals. **C.** Trend 2 small mammals. **D.** Trend 2 large mammals. **E.** Trend 3 small mammals. **F.** Trend 3 large mammals. Relative abundance is MNI(species)/MNI(total) %; MNI, minimum number of individuals.
Figure 3.4 Thylacoleo Caves and fossils. a. Flight Star Cave, showing boulder floor formed by roof collapse. b. Base of recently reopened Leaena’s Breath Cave (LBC) entrance pipe. c. Ossuary deposit, Last Tree Cave (LTC), with partial Procoptodon skeleton in foreground. d. Infill sediment in LBC, showing part of palaeochannel formed during final depositional episode. e. Complete skeleton of Baringa sp. nov. 1, LTC. This taxon is the most common marsupial in the fauna, and bore very high-crowned incisors and enlarged tuberosities above its eye orbits. f. Complete skeleton of Thylacoleo carnifex, FSC. g. Thylacoleo carnifex skeleton in fissure, LTC. h. Cranium of Sthenurus andersoni, LTC.

As with the Naracoorte Caves, most animals fell in through solution pipes or were preyed upon by raptors roosting and regurgitating pellets within the caves. U-Pb ages on in situ stalagmites in Leaena’s Breath Cave indicate that it formed prior to four million years ago (Woodhead et al., 2006), which augurs well for future excavation of the deeper infill sediments. The site has the potential to act as a benchmark section for late Cenozoic vertebrate biostratigraphy and biochronology in Australia, and is the subject of ongoing study. Fossils within the caves occur in three contexts: within sediment formed from limestone breakdown, atop or wedged between boulders flooring the caverns, and atop or buried in fine-grained infill sediments (Figure 3.4). Optical dating of surface sediments in the caves provide minimum ages of >200,000 years ago, but U-Th dating of secondary calcite crusts coating cave-floor specimens in Leaena’s Breath Cave suggests that most if not all of the surface material exceeds 400,000 years ago. Palaeomagnetic dating of the upper sediment layer confirms an age of <780,000 years ago, leaving us with a preliminary age bracket of 780,000-400,000 years ago for the fauna.

Of the 69 vertebrate and one gastropod species identified from the Thylacoleo Caves, 23 are kangaroos (Prideaux et al., 2007b). Herbivore diversity is similar to that of other Pleistocene assemblages (e.g. Naracoorte), but the higher proportion of mixed feeders and grazers is most similar to the Pleistocene fauna of inland Australia (Prideaux, 2006), suggesting dry, relatively open conditions. Remarkably, 31 of the 36 Thylacoleo Caves species that survived the Pleistocene have recent records in the region (Baynes, 1987; Strahan, 1995). Estimated from modern tolerances, the vast majority of species could have coexisted within a 230-250 mm mean annual rainfall range, and similarly, most of the 21 species that became extinct before the Holocene were widespread through drier regions (Prideaux, 2006). Strong support for the existence of dry conditions on the Nullarbor within the 780,000-400,000 years ago interval is provided by stable carbon- and oxygen-isotope ratios in herbivore teeth retrieved from marsupial herbivore teeth. These data reflect the isotope contents of
diet vegetation and ingested waters, and reveal that rainfall seasonality and effective rainfall were very similar to the present, in which an annual mean of ~200 mm falls in a largely non-seasonal, but slightly winter-biased pattern (Bureau of Meteorology, 1989). Overall, the data indicate a predominantly arid climate with a palaeo-rainfall range of 230–260 mm (Prideaux et al., 2007b). Whether or not the Thylacoleo Caves fauna accumulated at different times during the interval 780,000-400,000 years ago is largely irrelevant in this context (cf. Field and Wroe, 2007), because the entire sample so clearly and unambiguously points to a dry climate.

Nevertheless, the varied morphologies and broad size range (4–200 kg) of the 20 terrestrial browsing and/or grazing marsupials suggest a very different vegetation to the modern chenopod shrub steppe, possibly a scleromorphic woodland/shrubland mosaic incorporating a higher proportion of plants with palatable leaves and fleshy fruits (Prideaux et al., 2007b). We argue that, as in central Australia (e.g., Miller et al., 2005), an increase in wildfires best explains the conversion of a floristically diverse plant community into the modern, fire-resistant, chenopod shrub steppe. Whether or not this was caused by humans remains to be demonstrated, but it is significant that the general extinction pattern (loss of most larger herbivores and Thylacoleo) is identical to that witnessed in all southern Australian climatic zones. Certainly, the Nullarbor megafauna was well adapted to dry conditions, leaving climate change alone (specifically, increased aridity) as an untenable explanation for its extinction (Prideaux et al., 2007b).

3.4 Leeuwin-Naturaliste Region

After ten years of sporadic attention, the fossil-rich sequence in Tight Entrance Cave in the Leeuwin-Naturaliste Region of southwestern Australia is now the target of a concerted research program aimed at investigating faunal diversity prior to and subsequent to the arrival of humans in the region. The well-stratified succession preserves a diverse vertebrate fauna that accumulated via a pitfall mechanism over three major intervals: >140,000; 140,000-137,000; 50,000-27,000 years ago (Figure 3.5). A total of 11 megafaunal species appear within the sequence. Ten are represented in the second interval, which corresponds to the penultimate glacial maximum. The assertion of Wroe and Field (2006) that much of the Australian megafauna was extinct by this time is clearly not supported by our data. Locally, at least, conditions were evidently favourable for megafauna during the penultimate glacial maximum.
Following a subsequent 90,000-year hiatus in the Tight Entrance Cave sequence, only two megafaunal species (*Simosthenurus occidentalis*, ‘*Procoptodon*’ *browneorum*) are represented by remains that are unequivocally in situ. ‘*P.*’ *browneorum* is also recorded at 46,000 years ago in nearby Kudjal Yolgah Cave, a site that will be subject to detailed excavation in 2008. These two sthenurines are the only megafaunal taxa that can be firmly placed in the Leeuwin-Naturaliste Region at 46,000 years ago or younger. Fragmentary specimens of both species are represented in units ranging in age from 33,000 to 27,000 years ago, but remains of no other megafaunal species have yet been retrieved from these units. Whether these sthenurine fossils were reworked from older strata within the main chamber awaits further analysis. Although the suggested arrival of humans in the area by 48,000 years ago (Turney *et al*., 2001) is worth noting, and may be significant in terms of the local megafaunal extinctions, we presently lack sufficient evidence to draw a definitive link. Current research includes sedimentological and petrographic analyses, investigation of stable isotope changes through the sequence, establishing a more detailed chronology for the site, charcoal analysis and faunal biometric changes.

### 3.5 References


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Discussion of the timing and causes of the late Pleistocene faunal extinctions has recently been centred on an extinction window ~50,000-40,000 years ago, wherein the arrival of humans and the final appearances of most, if not all, megafauna appear to coincide. These discussions have been fuelled by a considerable increase in publications over the last decade, which have either reinvestigated or re-dated previously identified fossil sites (e.g. Field and Dodson, 1999; Roberts et al., 2001a; Cupper and Duncan, 2006). On the basis of these and other studies it would appear that the dataset available for scrutiny is now much improved. Rather than resolving either the final disappearance of individual megafaunal species or establishing their co-occurrence with humans, it has effectively highlighted the paucity of data available with which to test the current popular hypotheses (i.e. humans and/or climate). The debate continues as polarized as ever before (e.g. Field and Fullagar, 2001; Roberts et al., 2001a, b; Johnson, 2005; Koch and Barnosky, 2006; Wroe and Field, 2006). One of the reasons for this divide is the lack of consensus on the criteria used to assess whether the ages, fossils, and in two cases, cultural material, can be linked.

Some researchers have largely dismissed sites containing fossil megafauna younger than the extinction window, questioning the stratigraphic integrity or chronologies of these sites (Roberts et al., 2001b; Gillespie and Brook, 2006; Gillespie et al., 2006). Some of these analyses have been based on whether the apparent ages can be accepted on the criteria of Meltzer and Mead (1985; see Gillespie et al., 2006) and others on perceived disturbance of the sedimentary sequence (see Roberts et al., 2001b). Assessing whether the absolute ages are an accurate reflection of the age of the material is in some cases linked to sample chemistry or contamination (Gillespie et al. 2006). The conclusion drawn from these studies is that there is a relatively small time window (in geological terms), during which all megafaunal species disappeared from Sahul.

As the timing of the extinctions may be broadly coincident with estimates of first colonization of the continent by modern humans, explanatory extinction models involving humans have subsequently gained considerable currency (e.g. Miller et al., 1999; Johnson, 2005). The mechanisms involve overhunting and ecosystem disruption acting either alone or in concert. The period of interest is Oxygen Isotope Stage 3 (~60,000-30,000 years ago), with some researchers pointing to the lack of evidence for climatic flux through this time thereby eliminating the possibility of climate change as a contributing factor in the process (e.g. Miller et al., 1999; Gillespie et al., 2006).
However there is substantive evidence to suggest that in some parts of the continent, people and some species of megafauna may have coexisted well beyond the ~46,400 year age proposed by Roberts et al. (2001a). Cuddie Springs is one of these sites (Figure 4.1), and attempts have been made to dismiss the evidence recovered here on the basis of either dating or perceived site formation processes (see Roberts et al., 2001a, b; David, 2002; Brook and Gillespie, 2006). These critiques have failed to come to terms with the extensive stratigraphic, archaeological and geochemical studies undertaken at Cuddie Springs (e.g. Field, 2004; Trueman et al., 2005), where a demonstrated temporal overlap of humans and megafauna could be in the order of 10,000 years (Figure 4.2).

**Figure 4.1** Cuddie Springs.

Two sequential depositional phases have been identified where the bones of megafauna are found with flaked stone tools (Figure 4.3). There is no evidence that these fauna were hunted. It is more likely that some of these animals may have been ambushed at the waterhole or scavenged. Only a few megafaunal species have been identified at the time of initial human occupation and represent only a small percentage of the megafauna suite. The archaeology indicates a generalized subsistence economy exploiting a range of resources, including faunal species, grass seeds and other plant resources (Fullagar and Field, 1997; Field, 2004).

In the most southerly and northern reaches of the Australian continent there is no known record of a human megafauna overlap. However Nombe Rockshelter in the New Guinea highlands has yielded up to four endemic species of extinct fauna from cultural horizons, which have been estimated to date to between ~24,000-14,000 years ago (Mountain, 1991).
The archaeology of the Late Pleistocene indicates that rather than a focus on big game hunting or ‘firestick farming’, it is characterized by regional variability in subsistence strategies consistent with a range of environmental zones. This is not to say that people did not hunt megafauna if they were encountered. However, placing people and megafauna in the same place at the same time has only been demonstrated at two sites in Sahul and temporal co-occurrence can only be demonstrated for continental southeastern Australia (Field et al., 2007).

A review of the available evidence indicates that when people arrived they were met by a depauperate suite of megafauna (Wroe and Field, 2006). On further scrutiny, rather than the eight species proposed by Wroe and Field (2006), it appears that this number may be closer to 13 (Field et al., in prep.), but it still only comprises <30% of known megafaunal species.

Figure 4.2 The stratigraphy of megafauna-bearing sediments at Cuddie Springs.

The issue of whether people affected the extinction of these 13 species may never be resolved, and it calls into question whether people can be attributed a primary causative role in the whole process. At the present time there is no substantive argument for a terminal extinction age of ~46,400 years ago, the current evidence indicating that no specific time period can be identified that correlates to a single mass extinction event. Furthermore, the basis of the ~46,400 year age is the statistical analysis of seven sites, five of which have no published excavation reports, and of these, two have no excavation records at all.
The focus on proving a primary human role in the Pleistocene faunal extinctions diverts our attention away from achieving a better understanding of all facets of the fossil record. An extinction window at ~50,000-40,000 years ago can no longer be supported on the basis of the current evidence and should be discarded. We need to broaden our approach to the extinction of the megafauna and move beyond the period of human occupation. As the resolution of the last glacial cycle environmental records improve, so may our attempts at unraveling the factors responsible for the demise of the Australian megafauna.

Figure 4.3 Bones and artefacts at Cuddie Springs.

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5. Climatic forcing for Pleistocene megafaunal extinction: evidence from eastern Australia

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Biography:

Gilbert Price graduated with a PhD in late 2006 (Queensland University of Technology) and is currently employed in the Radiogenic Isotope Laboratory (specialising in uranium series dating) at the University of Queensland. His PhD research represented a multifaceted approach to understanding late Pleistocene megafaunal communities of the Darling Downs (southeastern Queensland), integrating aspects of analytical dating, sedimentology, taphonomy, and modern ecology, to provide high-resolution palaeoecological data. His combined datasets allowed the rigorous testing of extinction hypotheses and suggested that climate was a major driving factor in megafaunal extinctions, at least in eastern Australia. However, a potential role for humans in contributing towards their final demise cannot be effectively ruled out.

Currently, Gilbert is a key participant in a larger collaborative project between the University of Queensland, Queensland University of Technology, and Queensland Museum, which features innovative use of palaeontological and isotopic dating techniques for the study of the evolution and extinction of eastern Australian rainforest faunas. Knowledge of prehistoric biodiversity and the mechanisms that regulate it can provide important insights into the causes of extinction and highlight danger signs for modern species. Thus, apart from providing an important record of palaeoecology in eastern Australia over the last 500,000 years, his research has significant implications for the development of strategies for the conservation of biodiversity into the future.

During the late Quaternary, Australia lost 88 % of large-bodied terrestrial animals, compared with 83 % for South America, 72 % for North America, 35 % for Eurasia, and 21 % for Africa (Koch and Barnosky, 2006). Classically referred to as the ‘megafauna’, such animals included some of the largest mammals, birds and lizards that ever existed. Debate over the extinction of such spectacular creatures has become polarized in recent years, especially in Australia, with the cause(s) of the extinctions traditionally pinned on either natural climate change or anthropogenic influences (e.g. over-hunting, habitat modification). Such controversy is partially due to the paucity of detailed fossil records with firm chronological control.

In Australia, testing ‘climate’ versus ‘human’ extinction arguments requires the procurement of accurate chronologies of human colonization and megafauna terminal appearance ages. Traditionally, such chronologies were constructed using radiocarbon dating. However, in recent years, it has become clear that the final Australian megafaunal extinctions may have occurred near or beyond the chronological application limits of the radiocarbon dating technique (~40,000 years ago). Therefore, to effectively date Australia’s megafaunal deposits, dating methods that have the potential to break through the ‘radiocarbon dating barrier’ must be applied. Regardless, the establishment of megafaunal and human ranges has proven difficult in Australia owing to the low number of Pleistocene fossil sites.

However, one region has recently emerged as an ideal laboratory for testing hypotheses relating to megafaunal extinctions: eastern Australia. Similar to the World Heritage Naracoorte fossil deposits of southern Australia, eastern Australia contains a plethora of palaeoenvironmental archives. Principally: (1) there are abundant caves containing speleothems that are capable of archiving high-quality palaeoclimatic data; (2) there are several extremely diverse fossil faunas known from well-stratified contexts (open fluvial sequences and caves) that yield extensive palaeoecological information; and (3)
Both types of environmental archives contain a variety of materials that are dateable using a suite of dating techniques. However, a distinct advantage eastern Australia has is the sampling of prehistoric communities over a wider latitudinal (i.e. climatic) gradient.

Recently, several major megafauna localities within the Mt Etna region, central eastern Queensland, and the Darling Downs, southeastern Queensland, were examined in detail to establish an accurate, dated palaeoecological record for eastern Australia (Hocknull, 2005; Price, 2005; Price and Sobbe, 2005; Price et al., 2005; Price and Webb, 2006; Hocknull et al., submitted). Chronologies for closed sites (i.e. cave deposits) were constructed using the uranium/thorium (U-Th) dating method (with an upper effective range of ~500,000 years) by targeting flowstones (that bracket fossil deposits), stalagmites, calcite straws and bone directly (within fossil deposits). Chronologies for open sites (i.e. fluvial deposits) were established using U-Th dating of bone directly (coupled with laser ablation isotopic profiling), and accelerator mass spectrometry radiocarbon (AMS $^{14}$C) dating of stratigraphically significant charcoal and bivalves. A multifaceted palaeoecological model was constructed using the identification of specific species ecologies, ecological analogues to modern habitats and communities, measurements of diversity, and taphonomy.

The Mt Etna cave deposits preserve a biologically rich middle Pleistocene biota (Hocknull, 2005; Hocknull et al., submitted). Between ~500,000-280,000 years ago, Mt Etna was dominated by rainforest-associated vertebrate faunas (e.g. tropical frogs, striped possums, cuscuses, tree kangaroos) including several megafaunal taxa (e.g. Hill’s marsupial ‘lion’, marsupial ‘tapirs’, giant forest wallabies), suggesting relative faunal stability through several glacial-interglacial cycles of that period. However, sometime between 280,000 and 205,000 years ago, a major faunal turnover occurred that reflected the local extinction of most rainforest-associated taxa and all megafauna, but with the replacement of more arid-adapted vertebrate faunas (e.g. bilbies, western-barred bandicoots, grazing kangaroos) (Hocknull et al., 2007). Such faunal turnover implies a major local habitat change from rainforest to more open conditions after 280,000 years ago. It is also telling that >70% of speleothems U-Th dated from the region are older than 300,000 years, implying that climate conditions were wetter and more favourable for speleothem development during rainforest-dominated periods. Overall, those results record the first evidence for Australian vertebrate faunal responses to the Mid-Brunhes Climatic Event, a major climatic reorganization that has resulted in increasing aridity in northern regions since the middle Pleistocene (Hocknull et al., 2007). Another major faunal turnover occurred sometime after 170,000 years ago reflecting the local loss, without replacement, of 65% of small-sized mammals, possibly reflecting a continuation of fluctuating climatic conditions (Hocknull et al., 2007). The region is today dominated by open woodlands and grasslands, with refugial forest and vine thickets restricted to the hillsides; a stark contrast to the region’s habitats just 280,000 years earlier.

The Mt Etna record contrasts sharply with the comparably-aged Naracoorte fossil record from southern Australia, where it was demonstrated that although megafauna community composition fluctuated in concert with climate change through several middle Pleistocene glacial-interglacial cycles, significant local faunal losses did not occur until the late Pleistocene (Prideaux et al., 2007). Additionally, middle-late Pleistocene megafauna-bearing cave and fissure deposits from the Texas Caves and Gore region of southeastern Queensland also provide evidence that the most significant faunal turnovers occurred sometime during the late Pleistocene (Price et al., submitted). Most importantly, those collective results suggest that Quaternary climate change has influenced different regions of the Australian continent in different ways, and to a degree previously not recorded.

The Darling Downs has produced several exceptional late Pleistocene deposits, dominated by the most iconic of the Australian megafauna such as Megalania (largest-ever goanna), giant grey kangaroos (Macropus giganteus subsp. titan), and the largest-ever marsupial, the 2500 kg wombat-like Diprotodon. Recent collecting in the region has utilized archaeological-style excavation techniques, and thus, represent some of the few late Pleistocene megafauna deposits in Australia with
stratigraphic collecting depth (Price and Sobbe, 2005; Price and Webb, 2006). Additionally, most deposits are contained within geographically small palaeo-catchments, thus sampling very limited areas (Price, 2005). Therefore, the Darling Downs is an ideal region for examining late Pleistocene local megafauna community dynamics through time.

Most deposits examined represent stacked channel and overbank deposits, each rich in megafaunal remains, and several demonstrate significant declines in biological diversity through time. Unfortunately, at some sites (e.g. site QML1396), it could not be determined if changes in diversity simply reflected sampling biases of the late Pleistocene creek, or actual local extinctions (Price and Sobbe, 2005). However, at site QML796, it was demonstrated that each stratigraphic unit within the deposit had a similar sampling potential (Price and Webb, 2006). The basal units of site QML796 are dominated by both small-sized taxa (e.g. land snails, frogs, bandicoots, rodents) and megafauna. The ecological signal from the vertebrate fauna preserved in the deposit strongly implies a mosaic of habitats including open and closed woodlands, vine thickets, open grasslands, and riparian vegetation (Figure 1). However, up-section, the proportion of taxa with ecologies within each broad habitat type changed markedly, so that by the time of deposition of the youngest unit, the fauna was dominated by open-adapted taxa (e.g. grazing kangaroos) and those with non-obligate habitat requirements (e.g. long-nosed bandicoots) (Figure 5.1).

![Figure 5.1 Schematic reconstruction of temporally-progressive habitat changes and megafaunal declines of the late Pleistocene Darling Downs.](image)

Most browsing megafauna and smaller-sized taxa that have specific habitat requirements for woodlands or vine thickets (e.g. montane frogs) were not sampled in the youngest units (Price, 2005; Price et al., 2005).

Importantly, sequential faunal horizons show a stepwise decrease in taxonomic diversity with the loss of some, but not all, megafauna in the catchment (Figure 5.1). The sedimentologic and taphonomic data suggest a seasonally arid palaeoclimate (abundant calcrete formation and flashy discharge in an ephemeral fluvial setting, and drought-like kangaroo mortality patterns). Additionally, there is no palaeontological or archaeological evidence of a megafauna-human overlap in the region. Therefore, the data are most parsimoniously consistent with a climate change model for local habitat change and megafauna extinction, but not with a nearly simultaneous extinction of megafauna as required by the human-induced Blitzkrieg extinction hypothesis (Price and Webb, 2006).

Although dating of the deposits using U-Th and AMS $^{14}$C methods produced incongruent results, it was recently demonstrated that bivalves dated using AMS $^{14}$C (spanning >49,000-24,000 years ago) had experienced contamination from younger carbon sources (Webb et al., in press). Therefore, those results suggested that such ages, although probably unreliable, represented minimum ages of deposition (Webb et al., in press). That interpretation was supported by U-Th dating of megafauna teeth and AMS $^{14}$C dating of charcoal which suggests that the youngest deposits were laid down ~55,000-36,000 years ago (Price et al., unpub.). Most importantly, those data suggest that local habitat
change and loss of biological diversity was initiated ~10,000 years before the colonization of humans on the continent, and >20,000 years before human colonization in the region. Thus, those data provide additional support that the Darling Downs deposits accumulated in the absence of humans, and thus, posit an even greater role for climate in forcing the local habitat and faunal changes evidenced in the deposits.

Collectively, the Mt Etna and Darling Downs sequences both provide unequivocal evidence for significant faunal attenuation, driven as a direct result of the long-term drying of Australia. Perhaps the most significant observations of both studied localities are the geographic and taxic asynchronicity of the faunal losses. Importantly, the differential response of eastern Australia’s megafauna to pre-human climate change demonstrates that ‘megafauna’ as a whole cannot be considered as a single biological entity as traditionally implied. Thus, such studies strongly argue against the use of single site/taxon studies to interpret continental-wide megafauna extinction mechanisms/patterns. It is important to note that the results of the Mt Etna and Darling Downs investigations do not preclude an influence of humans in contributing to the final demise of the eastern Australian megafauna. However, determining the potential level and nature of interaction between megafauna and humans is currently not possible due to the paucity of appropriately-aged and -documented deposits, a problem that is also obviously extended to the rest of the continent. If humans did have a detrimental impact on megafauna, it is likely that they simply tipped the scale of extinction for an already vulnerable group of animals. If that was the case, then the Mt Etna and Darling Downs records are crucial in that they show that the critical conditions for extinction can be set-up long before the actual extinction event itself.

Acknowledgments

The research was only made possible through the collaboration of a research team including S. Hocknull (Queensland Museum), J. Zhao and Y. Feng (University of Queensland), G. Webb (Queensland University of Technology), I. Sobbe and family, N. Sands and family, several landowners, students and volunteers, with the additional dating expertise of R. Grün (Australian National University) and J. Hellstrom (University of Melbourne). The work was supported by Australian Research Council Linkage Grant (LP0453664), Australian Institute of Nuclear Science and Engineering Grants (02/013 and 03/123) and several industry partners including Cement Australia, Central Queensland Speleological Soc., Rockhampton Regional Development, and the Riversleigh Interpretative Centre.

References


NOTES:
6. Timing and cause of Genyornis extinction and duration of human-Genyornis overlap in Australia

John W. Magee\textsuperscript{a} and Gifford H. Miller\textsuperscript{b}

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Biography:

Dr John Magee began his role in research into Australian environmental and climate change at the ANU in the 1970's when he was part of integrated geological and archaeological research in the Willandra Lakes led by Professors Jim Bowler and John Mulvaney. After completion of that project, Magee continued to assist Bowler's research in the Willandra and other salt lakes in arid Australia while obtaining an MSc (part-time) by thesis on stratigraphy and sedimentology of the Prungle Lakes, at the downstream end of the Willandra system. Research work with Bowler culminated in the internationally groundbreaking ANU salt-lake drilling project, SLEADS, during the 1980's. After Bowler left ANU, Magee continued analyses of the SLEADS core archive and extended work at Lake Eyre as a part-time PhD project.

Magee's Lake Eyre research, conducted in a harsh and difficult environment, has elucidated a continuous 150,000 year record of environmental and lake-level changes and established Lake Eyre as an archive of monsoon climate history of global importance. During this research, Magee established close collaborative links with researchers in the USA, which have produced groundbreaking findings about the timing and process of megafaunal extinction in Australia and the impact of initial human colonisation on Australian ecosystems and climate, published in the highest impact journals and presented as invited and keynote talks at international conferences. Throughout his research career Magee has maintained a scientific advisory role in the management of the Willandra Lakes World Heritage area.

For Gifford Miller's biography see abstract number 7.

To finally resolve the extinction debate requires an unequivocal extinction chronology for a wide variety of taxa across a wide transect of climatic zones and to determine whether extinction occurred soon after human arrival and was selective for dietary preference. Determining the chronology of megafaunal extinction in Australia has been problematic chiefly because bone preserves its original geochemistry very poorly under the variable wet/dry and warm/cold environmental conditions, which have prevailed over the 45,000 to 50,000 years since the extinction event. Under Australian conditions, bone has defied all attempts at reliable direct dating because its geochemistry is an open system for exchange, loss and uptake of components of both its organic and mineral fractions. This has resulted in a reliance on indirect or associated ages (dating material associated with the animal remains or the sediment which encloses the remains). This demands certainty that the dated material must be the same age as the sediment that encloses the megafaunal remains and that the remains must come from an animal that died at the time of deposition of the sediments. Only articulated skeletal remains can be accepted as a reliable indicator of animals alive close to the event dated; disarticulated bones are very commonly reworked from older sedimentary units, especially in cave and fluvial deposits, the richest sources of bones. These difficulties are exacerbated by similar problems in reliably dating human arrival and the occurrence of both events beyond the usable limit of radiocarbon ($^{14}$C) dating (35,000 years ago). All these factors have resulted in a prolonged debate concerning fundamental questions such as the timing and duration of the extinction event, the coincidence of extinction across climatic gradients and the duration of human-megafauna overlap. Similarly, the open-system geochemistry of bone has precluded reliable application of carbon, nitrogen and oxygen.
isotopic analyses to examine questions of dietary preference and environmental conditions and stresses and the relationship of these factors to the extinction event.

Bird eggshell consists of a dense low-magnesium calcite mineral fraction (about 97%), which incorporates an intracrystalline organic framework (about 3%). The mineral fraction is resistant to diagenesis and the organic fraction resists diffusional loss. Thus, in contrast to bone, bird eggshell preserves its original geochemistry, which allows reliable direct dating and isotopic analyses. Both eggshell fractions allow reliable accelerator mass spectrometry (AMS) $^{14}$C dating to 35,000 years ago using careful standard pre-treatment (Miller et al., 1997, 1999) and beyond 40,000 years ago with rigorous pre-treatment and target production (Bird et al., 2003). Reliable and reproducible thermal ionisation mass spectrometry (TIMS) U-series dating of eggshell across a wide range of U concentrations, was reported by Miller et al. (1999). Eggshell allows greater accuracy and precision for amino acid racemisation (AAR) determinations than any other known biomineral because indigenous proteins are preserved over geological time with minimal diffusional loss or secondary uptake; epimerisation of isoleucine in eggshell proteinaceous residues follows first-order reversible kinetics almost to equilibrium (Brooks et al., 1990; Miller et al., 2000). In arid and semi-arid Australia, eggshell fragments are predominantly found in quartz-rich aeolian sediments with ideal characteristics and bleaching potential for optically stimulated luminescence (OSL) dating, though sediment and eggshell association must be addressed.

Eggshell fragments of the large flightless birds emu and Genyornis are the most commonly occurring biominerals in a large proportion of arid and semi-arid Australia indicating that the birds lived and nested in the same environments across these aeolian landscapes. Chronological and isotopic analyses of the eggshells allows comparison of the extinct Genyornis with the extant emu, which has enabled us to determine the timing and probable cause of Genyornis extinction and the duration of human-Genyornis overlap.

### 6.1 Chronology of Genyornis extinction

Miller et al. (1999) used four dating techniques (AAR, OSL, TIMS U-series and AMS $^{14}$C) to compare the age of emu and Genyornis eggshell fragments and deduce a 55,000-45,000 year age of extinction for Genyornis from three different climatic regions: southern Lake Eyre and Lake Frome in South Australia and the Darling/Murray river junction in New South Wales. The basis of this work was direct dating of eggshell by AAR a method that requires calibration of the chemical reaction for changes in temperature. We used AMS $^{14}$C, OSL and TIMS U-series ages to calibrate the AAR reaction, and the extremely large data set of AAR ages (~1000), directly on megafaunal remains, resulted in a very convincing chronology for Genyornis extinction. Subsequent analyses have confirmed and extended this finding. Genyornis eggshell AAR analyses now number more than 2000 and the reliable calibrated extinction age of 55,000-45,000 years ago now extends to four regions: Lake Eyre, Lake Frome, Port Augusta and the Darling/Murray river junction (Figure 1). This result is remarkably similar to the findings of Roberts et al. (2001) who OSL dated sediments containing the stratigraphically youngest articulated marsupial megafauna and applied statistical methods to determine an extinction age of 51,200-39,800 years ago, synchronous across the continent and taxonomic groups. These two results are now widely, though not universally, accepted to demonstrate that Australian megafaunal extinction occurred at 55,000-41,000 years ago synchronously across climatic zones and taxonomic groups (Figure 6.1).
Figure 6.1. Histograms of the numbers of *Genyornis* eggshells (vertical axis) plotted against degree of amino acid racemisation (AAR) (horizontal axis) from four sites in a climatic gradient across arid and semi-arid Australia. The data indicate abrupt *Genyornis* extinction which occurs at different values of AAR due to temperature dependency of the reaction. The age (thousands of years ago [ka]) for the extinction event at each site (in boxes) is derived from calibration of the racemisation rate by OSL, AMS $^{14}$C and TIMS U-series ages. Emu eggshell from the same sites (not shown) continue through to the present day indicating that the absence of *Genyornis* is not due to preservational factors.

6.2 Palaeodietary reconstruction and the cause of *Genyornis* extinction:

Miller *et al.* (2005) presented results from $\delta^{13}$C analyses of both the carbonate and organic fractions of emu and *Genyornis* eggshell, which reflect the dietary balance between C3 (trees and shrubs) and C4 (most grasses) vegetation types, subject to systematic fractionation within the animals. The $\delta^{13}$C results (Figure 6.2) demonstrate an abrupt change in dietary resources at the time of megafaunal extinction and shortly after human arrival (55,000-45,000 years ago); a change coeval across different climate zones. We hypothesise from these conclusions that changed fire regimes following initial human colonisation converted a drought-adapted mosaic of trees and shrubs intermixed with nutritious C4 grasslands to the modern fire-adapted desert scrub with C4 elements now dominated by largely unpalatable grasses such as spinifex and canegrass. Specialist feeders like *Genyornis*, which required a C4 dietary component, did not survive, whereas the generalist feeding emu, which could tolerate a pure C3 diet, survived. The same fire-induced ecosystem disruption may also have modified the C3 dietary resources, thus placing specialist marsupial browsing megafauna at risk, but the eggshell dietary records are not sensitive to such a change.
6.3 Duration of human-Genyornis overlap

The duration of human-megafauna overlap is an important question as it is likely that any human-caused mechanism requires a relatively short period of overlap. However, determining the duration of overlap, purely from the chronologies of extinction and human arrival, is difficult due to the relatively low precision of both of those chronologies. The very large database of emu and Genyornis eggshell collections allows us to determine whether the duration of human-Genyornis overlap is long or short even if the exact timing of the overlap period cannot be fixed. Over about 15 years of collecting widely across the arid and semi-arid zones of Australia, we have recovered approximately 5000 different emu and Genyornis eggshell collections (specifically targeted to sample different eggs), which total more than 100,000 individual eggshell fragments.

Based on the nature of preservation of fossil eggshell and observations of modern emu eggshell taphonomy, it is clear that eggshell has a short survival time at the surface, either as a whole egg or after fragmentation by hatching or predation. Accordingly, the primary factor for eggshell preservation is early burial. A corollary of this conclusion is that it is extremely unlikely that eggshell will be burnt by wildfires because it does not survive long enough compared to the fire frequency. Additionally, from the nature of fire and fuel in the arid and semi-arid zone it is intuitively unlikely
that eggshell fragments would be burned even if exposed to a natural fire. These conclusions lead us to hypothesize that burnt eggshell only occurs due to deliberate human predation, and only results from cooking or disposal in human–set fire. If this hypothesis is correct, neither Genyornis nor emu eggshell collections will contain burnt fragments until the after arrival date of humans and emu eggshell collections will contain burnt fragments from the age of the arrival of humans through to the modern day, probably at a relatively constant amount. A testable prediction from this hypothesis is that there will be a brief occurrence of burnt Genyornis eggshell in the youngest collections if there is a brief period of overlap between humans and Genyornis. We already know that we have found very few burnt Genyornis eggshell fragments but need to rigorously and quantitatively establish the relative numbers of burnt emu and Genyornis eggshell fragments and their distribution in time to provide a definitive determination of the duration of human-Genyornis overlap. Results of this analysis will be presented at the meeting.

### 6.4 Conclusions

The excellent preservation of the original geochemistry of eggshell combined with the large number of samples analysed has allowed reliable and statistically robust direct dating and isotopic palaeodietary analyses. This has resulted in determination of the timing and probable cause of Genyornis extinction. While these results may be indicative for the marsupial megafauna similar results are required from the latter before conclusions can be confidently generalised. Recent results from marsupial tooth enamel suggest that much more reliable dating and isotopic analyses are possible than for bone. This should be the focus of an intense ongoing research effort with the eggshell results providing a template for hypotheses.

### 6.5 References


NOTES:
6. Tracking late Quaternary environmental and climate histories using C, O and N isotopes preserved in avian eggshells, and contrasting megafaunal extinctions in Madagascar and Australia

Gifford H. Miller\textsuperscript{a}

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The tangled web of human-climate-megafauna interactions has its core in deep time, with the isolation of the Australian continent from the remnants of Gondwana about 60 million years ago, and its long isolation as it drifted northward across the western Pacific Ocean, with only marsupial mammals aboard. Aridity set in well before the Quaternary, as the continent moved into the Subtropical High, resulting in evolutionary change in flora and fauna as they adapted to changing climates. Superimposed on this trend were the high-magnitude, rapid climate changes of the Quaternary. Although the main amplifiers of orbital variations in insolation were at high latitudes, the climate system transferred much of this signal around the planet, and the biota of Australia, as elsewhere, was forced to adapt or evolve. The final great change impacting Australia was the arrival of humans \textasciitilde 55,000-45,000 years ago and the near synchronous disappearance of virtually all large animals from the continent. The core question that has challenged the scientific community for nearly two centuries has been to decipher the impacts of climate change and human agency on the Australian continent, and its flora and fauna.

Biography:

Professor Gifford Miller uses the record of the recent geological past, primarily the Late Quaternary, to gain a better understanding of Earth's climate system. He is based jointly at the Institute of Arctic and Alpine Research (INSTAAR) and the Dept of Geological Sciences at Colorado. Although his early research was dominantly in the Polar Regions, Prof Miller became interested in hot deserts and monsoon systems in the late 1980s while working in North Africa, and have focused on the Australian Summer Monsoon, causes of megafaunal extinction and the footprints of human colonization in Australia for the past 15 years. Recently, his research group has expanded our extinction work to Madagascar, where we are evaluating the extinction of the Elephant Bird, \textit{Aepyornis}. Prof Miller continues to maintain an active research program in the Eastern Canadian Arctic and in Iceland, and Co-Chair the PAGES Arctic Program CAPE (Circum-Arctic PaleoEnvironments).
7.1 Isotopes as proxies for climate, diet, and the status of the Australia biota

Most biological processes fractionate stable isotopes in a consistent pattern, as do many purely physical and chemical processes. The ubiquitous stable isotopes of carbon ($\delta^{13}C$), oxygen ($\delta^{18}O$), and nitrogen ($\delta^{15}N$) can be frequently isolated from fossil materials, and where they are indigenous to the animal, used to reconstruct a range of environmental variables. Our work has relied heavily on the eggshells of two of the great flightless birds of Quaternary Australia, the extant Australian emu ($Dromaius$), and the now-extinct giant bird, $Genyornis$. Eggshells of these two birds are not only the most abundant vertebrate remains across the arid and semi-arid zones, but they offer distinct advantages to most other biominerals. Eggshell calcite has far greater preservation potential than bone or teeth, and the organic molecules placed within the eggshell by the female bird are sequestered within the calcite crystals, rendering even their degraded residues virtual immunity from loss or contamination (Miller et al., 2000). In other words, they approximate a closed system with respect to the isotopes of C, O and N in both the calcite and its contained organic residues. In addition, eggshells can be dated by accelerator mass spectrometry radiocarbon (AMS $^{14}C$; the most recent 35,000 years ago, and with care, back to $\sim$42,000 years ago), by amino acid racemization (AAR) if sufficient calibration of the racemization reaction is available, and by uranium-series disequilibrium (U-series), as long as little detrital thorium was incorporated in the eggshell matrix (Miller et al., 1999). In addition, in situ eggshell can be dated by optically stimulated luminescence (OSL). The applicability of four independent dating methods offers the potential to crosscheck most ages and to provide a firm chronology for our collections.

We routinely measure $\delta^{18}O$ and $\delta^{13}C$ (referred to as $\delta^{13}C_{\text{carb}}$) in eggshell carbonate. And in the intracrystalline organic fraction we also measure $\delta^{13}C$ (labeled $\delta^{13}C_{\text{org}}$ to differentiate from $\delta^{13}C_{\text{carb}}$) and $\delta^{15}N$. For both $\delta^{13}C$ and $\delta^{15}N$ the bird’s diet determines the proportion of the heavy and light isotopes, offset by a consistent fractionation factor, but the biological reserves that are tapped for carbon in the $\delta^{13}C_{\text{org}}$ and $\delta^{13}C_{\text{carb}}$ archives differ, with each represents a different cycling time, depending on the feeding strategies of the birds. Some birds (investment breeders) may save resources over many weeks or even many months to be used for egg laying and egg incubation. Other birds (income breeders) may breed opportunistically, whenever food resources are plentiful. In this instance there is little difference in time of food consumed for the $\delta^{13}C_{\text{org}}$ and $\delta^{13}C_{\text{carb}}$. In general, $\delta^{13}C_{\text{carb}}$ reflects a time window a few days to weeks before egg laying, whereas $\delta^{13}C_{\text{org}}$ may reflect dietary sources during the weeks to months prior to egg laying.

Comparing $\delta^{13}C_{\text{org}}$ and $\delta^{13}C_{\text{carb}}$ shows a strong correlation, but substantial scatter, with a predicted offset between the two carbon reservoirs of $\sim$11 ‰ for $Dromaius$ and perhaps a bit more for $Genyornis$. The offset is because of the thermodynamic fractionation during calcification. The reason for the scatter could be due to instrumental uncertainties, variability in the parameters of biological fractionation, or changes in the seasonality of vegetation. To test this, we processed $Dromaius$ from Bass Strait islands where there were virtually no C4 plants prior to European settlement. For 13 samples, the offset between $\delta^{13}C_{\text{org}}$ and $\delta^{13}C_{\text{carb}}$ is $11.0 \pm 0.2$ ‰, compared to a 1-sigma uncertainty of $\pm 2.5$ ‰ for the regression of Lake Eyre $\delta^{13}C$ pairs, an order of magnitude more. These data confirm a constant offset between $Dromaius$ dietary $\delta^{13}C$, and the $\delta^{13}C_{\text{org}}$ and $\delta^{13}C_{\text{carb}}$ values in the birds’ eggshells. Deviations from this constant reflect seasonality in the $\delta^{13}C$ of the birds’ dietary sources. A time-series of this offset describes the evolution of seasonality through time.

Water consumed by the bird determines the $\delta^{18}O$ of the bird eggshell. The difference between the reconstructed $\delta^{18}O$ of the birds’ water sources and that of rainwater is a measure of the local aridity. Because there can be immense spatial and interannual variability in surface water $\delta^{18}O$, we expect eggshell $\delta^{18}O$ to be highly variable, which it indeed is. However, by averaging the $\delta^{18}O$ measured in at least 20 to 30 different eggshells of about the same age, it is possible to estimate the effective moisture during the time window. We define effective moisture as evaporation/precipitation.
Figure 7.1 illustrates a 150,000+ year time series of reconstructed *Dromaius* dietary $\delta^{13}$C from both $\delta^{13}$C$_{org}$ and $\delta^{13}$C$_{carb}$, and reconstructed effective moisture based on $\delta^{18}$O in *Dromaius* eggshell.

Plots of effective moisture over the past 150,000 years (Figure 7.2) from Lake Eyre and Port Augusta regions indicate generally wetter conditions during Oxygen Isotope Stage (OIS) 5 and generally drier conditions during OIS 3 and 2 with a variable state during OIS 1. The calculated effective moisture for the Port Augusta region is illustrated in the Figure 7.2. The dashed line reflects the effective moisture reconstructed from modern (AD 1970-2005) samples. The plot indicates that conditions around Port Augusta were generally wetter than present throughout OIS 5, but began to dry about 60,000 years ago and remained dry, region a maximum during the last glacial maximum (LGM), before becoming wetter than present again in the early Holocene. Condition dried out in the late Holocene, though not as dry as during OIS 3 and 2. The variability mirrors the effective moisture,
with relatively low variability during intervals of high effective moisture and relatively high variability during drier times.

![Figure 7.2](image.png)

**Figure 7.2** Plots of effective moisture over the past 150,000 years from Lake Eyre (red line) and Port Augusta regions (blue line).

This suggests that even during dry times, the occasional wet year might occur. However, the LGM (30,000-15,000 years ago) is characterized by low effective moisture and relatively low variability, suggesting that rarely were there any wet years during this interval.

Nitrogen isotopes are the least secure in their interpretation, as there are several environmental and biochemical factors that contribute to the $\delta^{15}N$ of a particular plant. Surveys of modern vegetation transects are underway to better understand the overarching controls on plant $\delta^{15}N$, so that we might use the $\delta^{15}N$ in eggshell organics as a palaeoenvironmental proxy.

Applying these new environmental proxies to our records showing ecosystem collapse indicates that the collapse is not due to a significant climate perturbation. This further reinforces our primary hypothesis that a change in fire regime related to human burning practices is the most realistic explanation for the ecosystem collapse observed in the isotopic data.

### 7.2 Madagascar as a test case for human impacts

We have recently initiated a new research campaign in Madagascar to test the primary hypotheses generated from the Australian evidence. Madagascar is effectively a small continent. It meets all of the criteria that can be used to differentiate a continent from an island, unless an arbitrary size cutoff is applied. We contend it is a small continent, a position taken by many ecologists studying Madagascar.
Human colonization of Madagascar was recent; the oldest evidence of human settlements is only 2500 years ago, and only after 2000 years ago is there widespread evidence for human habitation. Similar to Australia, Madagascar lost virtually all of its large animals shortly after human colonization, including at least two general of large flightless birds. These include Mullerornis, a Genyornis-sized bird, and at least two species of the giant elephant bird, Aepyornis. The largest of the Aepyornis species weighed 500 kg and stood 3 m high. Eggshells of Aepyornis have been reported throughout the southwestern coastal region. The youngest radiocarbon-dated eggshells reported are just under 1000 years old, indicating at least 1000 years of overlap between humans and Aepyornis, before extinction of the latter.

Our goal is to develop a time series of Aepyornis eggshells through the Holocene that captures the millennia before human arrival as well as complete coverage of the millennium of their co-existence with humans. We plan to track the dietary and drinking water habits of Aepyornis using the stable isotopes of C, O and N preserved in their eggshells, and to compare their characteristic before and after human colonization to test whether they exhibit any systematic changes. We hypothesize that the extinction of Aepyornis and of Mullerornis was due do habitat loss from landscape clearing for pastoral activities rather than due to overhunting. A testable prediction from this hypothesis is that the birds should exhibit changes in their diet or drinking habits as they are forced into ever more restricted regions before their final extinction early in the second millennium AD.

In two field seasons (2006, 2007) we have located over 500 sites with eggshells of one or both genera, including more than 100 collections from the monsoon-watered northeast, where a only a single egg had been reported (from a 1960s expedition). This research forms the basis of the PhD dissertation of Mr Stephen DeVogel (University of Colorado). Preliminary results will be reported at the meeting.

7.3 References


NOTES:
8. Quaternary extinctions of Southeast Asia’s megafauna

Julien Louys

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Biography:

Julien Louys is a doctoral candidate at the University of New South Wales. His current research focuses on the ecology and extinction of Quaternary megafauna from Southeast Asia and China. In particular, he is currently working on reconstructing palaeoenvironments of megafauna-bearing sites in Asia using multivariate methods and data from modern nature reserves.

His previous research has focused on Miocene koalas from Riversleigh, as well as the recognition of the use of bamboo tools in the archaeological record.

Southeast Asia evokes images of tropical rainforests, magnificently coloured birds and elusive primates, but only rarely does it evoke images of megafauna. Nevertheless, along with Africa, it is one of the few regions in the world where extant megafauna can still be found in a diversity that approaches that present during the Pleistocene. Even so, the extant megafauna of Southeast Asia are depauperate compared to that of the Pleistocene. In particular, many extant megafauna species currently not found in Southeast Asia were once widespread there, for example, the Indian rhino and the giant panda. Many other species became extinct, for example, the giant tapir, the stegodonts, the giant pangolin and the giant ape. Within the global megafauna extinction debate, however, little attention has been paid to Southeast Asia until recently (e.g. Louys et al., 2007; Louys, in prep.). This is surprising, as Southeast Asia has had one of the longest continual habitations by early hominins outside of Africa, making it of intrinsic interest within the megafauna debate. In particular, the evidence from Southeast Asia can be used to address the concept of prey naivety to human hunters, as prey species co-evolved with humans in Southeast Asia for only a brief period of time. In addition, Southeast Asia is of significance in our understanding of megafaunal extinction in Australasia, as the first Australasians were almost certainly Southeast Asian in origin.

Southeast Asia during the Pleistocene hosted a radically different landscape than present today. This difference was most pronounced during glacial periods, which occurred for up to 90% of the Pleistocene (Lambeck et al., 2002). In the north of Southeast Asia, the rise of the Qinghai Plateau resulted in a reduction in the intensity of the Asian summer monsoon during these glacial periods (Ferguson, 1993). Because the summer monsoon brings increased precipitation to continental Southeast Asia, during most of the Pleistocene continental Southeast Asia would have been considerably more arid than today. This aridity would have been compounded by the more southern position during glacial periods of the Inter-Tropical Convergence Zone, a low pressure belt in which maximum precipitation tends to occur (Verstappen, 1980). Finally, temperatures were approximately 3-5 °C cooler than today (Heaney, 1991; Chappell et al., 1996).

During glacial periods, sea-levels in Southeast Asia were also significantly lower than they are today (Figure 8.1). These lower sea-levels resulted in the exposure of a large, low-lying continental shelf (Figure 8.2). Because of the reduction in the surface area of the Sunda Sea, evaporation, and hence precipitation decreased, resulting in increasing aridity in the region. Heaney (1991) proposed that the low levels of precipitation led to the formation of a central savannah corridor ran through the middle of Southeast Asia, flanked on both sides by tropical rainforest (Figure 8.2). Although Heaney (1991) proposed the presence of the savannah corridor for the last glacial maximum (LGM) only, there is evidence that this corridor existed during other glacial periods (e.g. Batchelor, 1988; de Vos et al.,
The heterogeneous landscape of Pleistocene Southeast Asia enabled many species currently absent from the region to survive there. The loss of the low-lying shelf through rises in sea-level, an event that occurred several times during the Pleistocene, and the concomitant reduction and/or loss of the savannah corridor, would have severely impacted many megafauna species. The Indian rhino (*Rhinoceros unicornis*), Dubois’ antelope (*Duboisia santeng*), perhaps the stegodons, and the archaic elephant *Palaeoloxodon* were all grazers, and as such would have been threatened by the loss of the savannah. In turn, the loss of these large herbivores would have reduced available prey for the savannah carnivores, namely the hyenas (*Pachycrocuta* and *Crocuta*). Other megafaunal species in Southeast Asia, although adapted to forest environments, are reliant on freshwater sources. In particular, the rhinoceroses, the Asian hippopotamus, the tapir, the giant tapir, and to a lesser extent
the pigs, all require access to rivers, wetlands or lakes. The extreme reduction of these sources of freshwater through the transgression of the Sunda Sea on the Sunda shelf through the Pleistocene produced a negative affect on the ecology of these species.

![Figure 8.2. Southeast Asia at the LGM showing the major rivers and lakes present during that time. Heaney’s (1991) proposed savannah corridor is shown in yellow. The dotted line represents the division between Indochina (north) and Sunda (south). Adapted after Bird et al. (2005) (from Louys, in prep.).](image)

Whether the effects of sea-level fluctuations, and concomitant losses of grasslands and freshwaters, affected the megafauna gradually throughout the Pleistocene, or affected certain species more rapidly cannot at this stage be determined from the available evidence. However, it is clear that the dramatic environmental changes occurring throughout the Pleistocene detrimentally affected the abundance and distribution of megafauna in the region. Conversely, there is very little evidence to suggest that Pleistocene Southeast Asians negatively affected the megafauna until the Holocene. Direct, unequivocal evidence of human hunting of megafauna in Southeast Asia is non-existent for either *Homo erectus* or archaic *Homo sapiens*, and it appears that hunting of megafauna by modern *Homo sapiens* did not become unsustainable until the past 2000-3000 years (Corlett, 2007). Furthermore, the Pleistocene Southeast Asian toolkit appears to have been unsuited to the hunting of large game. Pleistocene stone tools from Southeast Asia consisted largely of choppers, and did not achieve the sophistication of the European toolkit until the Late Pleistocene/Early Holocene (Reynolds, 1990; Corvinus, 2004). Habitat alteration by humans also appears to have been negligible until the Holocene, and human-induced firing of the landscape appears to have become important only in the past 1400 years (Anshari et al., 2001).
The negative ecological effects of humans in region have, however, escalated since the beginning of the Holocene. Massive deforestation over the past 200 years threatens the existence of the remaining forest megafauna species. Hunting and wildlife trade in the region is also grossly unsustainable, with some researchers estimating it at six times the sustainable rate (Sodhi et al., 2004). Currently, the number of historical extinctions of mammals in Southeast Asia is small. However, a large number of megafaunal species are critically endangered, and unless action is implemented soon, we will witness another megafauna extinction event.

References
9. The contribution of long pollen and charcoal records to the explanation of Late Pleistocene megafaunal extinction in Australia

A. Peter Kershaw*

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Biography:

Professor Peter Kershaw’s research is primarily aimed at understanding the development and dynamics of both past and present day landscapes, particularly within the Australian-Southeast Asian region, through palaeoecological study. It incorporates assessment of past human/environment interactions, determination and explanation of patterns of climate change, biomass burning and biotic distributions and extinctions, and is being applied to the validation of predictive climate and ecological models.

Specific contributions, have been in the elucidation of the nature of the Victorian Tertiary brown coals, determination of the long term dynamics of vegetation types, especially rainforest, alpine vegetation and both tropical and temperate peatlands, assessment of the role of fire in the development of Australian vegetation including the relative impacts of Aboriginal and European people, determination of the time of arrival of Indigenous people, and reconstruction of regional climate change including determination of past ENSO activity. In order to refine estimates of vegetation and climate, effort has been put into the development or use of new techniques of analysis, especially the application of modern assemblages to refinement of interpretation of past assemblages and increasing the variety of proxies, that have included diatoms, macrocharcoal and beetles in addition to more traditional components of palynology. Recent contributions are in the elucidation of the development and history of both ENSO and monsoon activity, largely from marine palynology, and assessment of lake and river water quality, mainly through the sensitive indicators, diatoms.

Palaeopalynology, which includes pollen, charcoal particles and other microscopic organic material preserved in accumulating sediments, provides no direct evidence of megafauna but results of analysis have been used variously and selectively to support the major extinction models of climate change, habitat alteration and overkill in Australia (e.g. Flannery and Roberts, 1999; Miller et al., 1999, 2003; Barnosky et al., 2004; Wroe and Field, 2006). The significance of palynology is that, in contrast to megafaunal and archaeological materials, it can provide long, continuous records of change and these may inform on likely times as well as causes of extinction.

The pollen record from Lynch’s Crater (Kershaw, 1986) has been implicated in extinction debates because of marked sustained changes in pollen and charcoal that, despite dating revision (Turney et al., 2001), has tended to track that for the time of arrival of people on the continent. Consequently, a human cause for general environmental change has been advocated, a proposal supported by the lack of evidence, both locally and globally, for major climate change around this time. Subsequent records, constructed from marine sediments around northern Australia, have provided support for an event centred on 45,000-40,000 years ago (Figure 9.1), and, in combination with identified indirect changes in the composition of the vegetation of central Australia from the carbon isotopic composition of emu eggshells (Johnson et al., 1999), cemented the case for human impact. However, none of these records have indicated as clearly as Lynch’s Crater the positive relationship between fire and vegetation change, with one site actually indicating an apparent reduction in burning. Consequently, neither an argument for extinction based on a transformation of the vegetation landscape that resulted directly from increased fire activity (Miller et al., 2003) nor one suggesting that extinction led to increased burning as a result of fuel build up (Flannery and Roberts, 1999) is fully supported.
In contrast to the Lynch’s Crater record, which has received less criticism than it deserves, the record from Lake George (Singh et al., 1981; Singh and Geissler, 1985) has been attacked appropriately on its uncertain dating, degree of continuity, selective pollen preservation and inferred relationship to human activity. However, the original estimate of ~130,000 years ago for vegetation change associated with a sustained increase in burning has received support from other records, notably ODP 820 within the Coral Sea adjacent to Lynch’s Crater. It has also been revealed that the events of 130,000 and 45,000 years ago were possibly the most significant of a number of such events along a trend to increased drying and climatic variability perhaps resulting from El Niño-Southern Oscillation (ENSO) activity over the past few hundred thousand years (Kershaw et al., 2003). This has provided support for the climate advocates (e.g. Wroe and Field, 2006) with the idea that extinction of megafauna occurred over an extended period of time in response to long term climate change. It does not explain, though, why ages on megafaunal extinction and regional environmental change cluster around the time of apparent human colonization.

**Figure 9.1.** Major charcoal features and sustained vegetation changes in long palynological records from the northern Australasian region shown in relation to the SPECMAP, marine isotope record of Martinson et al. (1987) and summer insolation variation in the southern hemisphere tropics (Berger and Loutre, 1991). From Kershaw et al. (in press).
One scenario that may explain the timing, and contribute to the explanation, of extinction is derived from recent, high resolution analysis of the Lynch’s Crater record. Here, it may be suggested that the initial increase in burning was related to the arrival and impact of people but burning was not effective in changing the vegetation until there was a subsequent increase in precessionally-induced ENSO activity (Turney et al., 2004; P. Kershaw, C. Turney, S. Rule, P. Moss, N. Branch and K. Fifield, in prep.). It suggests that either both climate and people contributed to the extinction process or that climate contributed to landscape change initiated by the loss of megafauna. However, there appears to be some variation in the pattern or even detection of changes in vegetation, fire and climate within available palynological records as a whole. This could mean that records are generally insufficiently well refined or dated to resolve apparent inconsistencies and/or that the actual mechanism of extinction varied over the continent.

References


10. Late survival of megafauna in Gippsland: dated faunal sequences from Cloggs and other Buchan caves

Josephine Flood

Biography:

Dr Josephine Flood is a prominent archaeologist, recipient of the Centenary Medal and former director of the Aboriginal Heritage Section of the Australian Heritage Commission. She did her PhD on the archaeology of the south-eastern highlands of Australia and excavated megafauna in Cloggs Cave in eastern Victoria. She has published a number of influential books, including 'The Moth Hunters: Aboriginal Prehistory of the Australian Alps' (1980), 'Archaeology of the Dreamtime' (1983, 6th edn 2004) and 'The Original Australians: Story of the Aboriginal People' (2006). The latter was a finalist for the Prime Minister’s Inaugural Australian History Prize.

The limestone caves of the Buchan region in eastern Victoria have proved highly significant in revealing both past culture and environment in southeastern Australia. Excavated deposits provide the oldest human occupation in the extreme southeastern corner of the continent and a consistent, dated sequence of fauna spanning the past 30,000 years. Megafauna has been found in deposits dating to 27,500-24,500 years ago at Cloggs Cave in east Buchan (Flood, 1973, 1974, 1980). This is one of only about four Australian mainland sites to contain dated occurrences of younger megafauna; the others are Seton rock-shelter on Kangaroo Island, South Australia, and the open sites of Cuddie Springs, New South Wales, and Spring Creek, western Victoria. Cloggs Cave is therefore important in the debate about why and when Australia’s megafauna became extinct. Was it through the arrival of Aboriginal big game hunters, habitat alteration by Aboriginal burning of the vegetation, or climate change? Those who propose human agency argue that within a few thousand years of human arrival in a region, the megafauna became extinct, and that in Australia the extinctions were complete by about 45,000 years ago. The critics argue therefore that the ages on these four sites must be wrong. However, no detailed refutation of the dated occurrence of megafauna at Cloggs Cave has been made.

10.1 Cloggs Cave

Buchan lies in an intermontane valley on the southern fringe of the Snowy Mountains in east Gippsland. It is at an elevation of 76 m and 37 km inland from the present coastline at the southeastern tip of the Australian continent. At the last glacial maximum (LGM) it would have been about 100 km inland to the northeast of the Bassian land-bridge. The limestone Cloggs Cave lies near the Orbost Road 4 km southeast of Buchan and appears as a tall, dark cleft in a cliff near the top of a small hill where two geological faults intersect. The broad, 2 m high entrance passage provides easy access to the inside chamber, where there is a soft, dry earth floor and a glimmer of light.

A profile section through Cloggs Cave shows why it was such a perfect piece of prehistoric real estate. The back of the cave is higher than the entrance, which means that cold air drains out but warm air remains inside, simply rising to the back of the cave where there is a narrow passage but no exit. The temperature inside the cave would therefore always have been several degrees warmer than the outside air at night and in winter. LGM temperatures were up to 10 °C lower than now, so Cloggs Cave would have provided a welcome retreat, particularly in winter.

A 4-metre square pit was excavated in the lower cave. A 1-m square column sample and the whole of the lower layer were bagged and taken to the laboratory to be sieved under laboratory conditions and charcoal samples were obtained by flotation. The series of radiocarbon ages obtained on charcoal
from the deposit is consistent and reliable, being based on good-sized pieces of charcoal. To the north of the excavation is an occupation zone which was not excavated but the sterile top 20 cm of earth was removed to reveal a hearth layer of charcoal, ash and burnt cooking stones. The upper cave was damp and steeply sloping and seems not to have been used.

Almost two metres depth of deposit were excavated. Animal bones were found throughout. Most of the bone was small and came from the regurgitated pellets of owls sitting on ledges on the cave walls. Human occupation of the inner cave spanned from about 21,000 to 10,000 years ago. Occupation was sporadic and non-intensive, marked by small numbers of stone and bone tools, used for general chopping and scraping and also for skin working. These averaged only eight artefacts per cubic metre of deposit in marked contrast to the vast quantities of tools left in their caves by the ice age wallaby hunters of Tasmania (Flood, 2001, 2006).

The lowest level of human occupation gave an age of 21,220 ± 1040 calibrated years before present (BP) (ANU-1044). Charcoal from an intermediate layer at a depth of about a metre was dated to 16,590 ± 620 calibrated years BP (ANU-1182). The most striking feature of the stratigraphy is a dark hearth or fireplace of white ash and dark charcoal towards the centre of the cave. This was radiocarbon dated to 9830 ± 280 calibrated years BP (ANU-1001). It appears that the inner cave was not inhabited after around 10,000 years ago.

Outside the north-facing entrance passage of Cloggs Cave there is a broad ledge and rock-shelter, which Aborigines used for camping, particularly over the past thousand years. A painting occurs on the rear wall of the rock-shelter. Rock paintings are extremely rare in eastern Victoria and at first it was thought that this was a modern graffiti, particularly as the linear design resembles a cartoon smiling face in profile with an exaggerated nose. However, analysis by staff of the National Museum of Victoria and the Victoria Archaeological Survey (W. Birch, A. Oates, M. Perkins and R. Gunn, unpub.) in 1980 showed that the pigment was the rare mineral wedderlite mixed with animal fat. It is therefore almost certainly a non-figurative design of Aboriginal, not modern origin.

The Cloggs Cave painting probably belongs to the past millennium but nearby New Guinea II Cave on the Snowy River about 30 km north of Buchan contains many markings on its soft, mud-covered walls. Some are deep, vertical claw markings of animals but others are finger flutings clearly made on the soft surfaces by humans. Some grid patterns of criss-crossing lines occur and others are multi-directional, twisting and turning in similar fashion to the so-called macaroni from other Australian and European caves. The cultural significance of New Guinea II was first suggested by cavers Rudi Frank and Adrian Davey in 1976, who remarked on the similarity of its wall markings to Koonalda Cave in South Australia, where charcoal from below the markings dates to 20,000 years ago. There is no associated material to date the New Guinea II rock art but it is probably of similar antiquity given the age of occupation in the adjacent rock-shelter.

10.2 Megafauna

The megafauna at Cloggs Cave is dated by associated charcoal and fits into the cave’s undisturbed, dated faunal sequence, supported by a consistent change in colour of the bone with depth. The ages and faunal sequence correlate well with those of other limestone caves of the Buchan region. These included the rich faunal deposits excavated at Pyramids Cave by Norman Wakefield (1972) and New Guinea II Cave by Paul Ossa (Ossa et al., 1995).

Below the lowest artefacts associated with human occupation, which date to around 21,000 years ago, and separated from them by a disconformity, was a non-cultural deposit containing a humerus, mandible and teeth of some megafauna. This layer is dated to 26,070 ± 1440 calibrated years BP (ANU-1220), placing the megafauna in the range 27,500-24,500 years ago. The charcoal associated with these megafaunal bones was probably derived from natural bushfires from the trees and grasses
outside the cave, and blew in through the present short but fairly high and wide entrance passage or through a lower passage now blocked by roof fall and deposit.

All the faunal species were identified Hope (1973). The outstanding specimen was a mandible of the extinct, short-faced giant kangaroo, *Sthenurus orientalis*. Several teeth and a humerus of *Sthenurus* were also found, together with teeth of extinct giant grey kangaroo *Macropus titan* and locally extinct species *Sarcophilus* sp. (Tasmanian devil) and *Thylacinus cynocephalus* (Tasmanian tiger or thylacine). The evidence suggests that before Cloggs Cave was occupied by humans, it was a devil’s lair, which dragged their prey into the cave, leaving their characteristic chew marks on the bone.

Hope (1973) analyzed results of all the available published fauna in the Buchan region and found a consistent chronological sequence by analyzing the percentages of rodents, which change significantly over the past 30,000 years. This analysis shows that the oldest fauna is the Pyramids Cave red fraction, dated to about 30,000 years ago. This is followed by the base layer at Cloggs Cave associated with megafauna, dated to between about 27,500-24,500 years ago. This is overlain by the middle and upper layers of Cloggs Cave, dated between about 21,000 and 10,000 years ago, and finally the young fauna of the Pyramids Cave white fraction, Mabel Cave and Cloggs Cave rock-shelter, dated to the mid- to late Holocene.

The gradual replacement of one extinct species of the rodent *Pseudomys* by another is strong evidence that the faunal sequence of the Cloggs Cave is undisturbed. This is confirmed by a gradual change in the colour of the bone from white at the top to red at the bottom in both the Cloggs Cave and Pyramids Cave sequence. There is also a gradual change from fragments of stalactites to stalagmites in the Cloggs Cave deposit.

The period 27,500-24,500 years ago marks the beginning of the LGM but climatic conditions there were not particularly severe at Cloggs Cave. The cave lacks bones of the alpine pygmy possum, *Burramys parvus*, an excellent indicator of alpine and sub-alpine environments. *Burramys* was present in 30,000 year old deposits at Pyramids Cave and 25,000 years ago at New Guinea II Cave. This makes sense since New Guinea II is 30 km north of Buchan and close to high country. Further evidence comes from faeces or coprolites. Evidence from fauna, wood fragments and grasses in the coprolites of herbivores (probably rock wallabies) suggests a basic climatic and vegetational stability throughout the period represented by the Cloggs Cave sequence. The environment throughout was grassland, open woodland and dry sclerophyll forest dominated by *Eucalyptus melliodora* (yellow box), *Casuarina stricta* (drooping she-oak), *Acacia* (wattle) and *Brachychiton populneum* (kurrajong) together with wet grassy hollows and swampy alluvial flats. This makes it difficult to argue that here climate change was the main factor in megafaunal extinction.

There is a close correlation between time of human arrival and the latest occurrence of megafauna in the southeastern corner of Australia. Humans probably did not arrive in this remote, mountainous, wooded region until about 25,000 years ago. Earliest human occupation is at New Guinea II Cave, dated to 25,240 ± 1150 calibrated years BP (SUA2222; Ossa, 1995). Interestingly, occupation in other excavated sites in southeastern New South Wales begins at a similar time period. Lowest occupation at Birrigai Shelter in the Australian Capital Territory dates to 25,150 ± 440 calibrated years BP (Beta 16886; Flood 1987) and at Burrill Lake rock-shelter on the New South Wales coast to 24,850 ± 830 calibrated years BP (ANU 137; Lampert, 1971).

### 10.3 Conclusions

It is clear that the Buchan area has seen relatively little change over about the past 30 millennia apart from the extinction of the megafauna (probably by 24,500 years ago) and the arrival of human hunters by 25,000 years ago. In the southeastern corner of Australia there thus seems to be a fairly close correlation between arrival of hunters in a region and extinction of the megafauna.
The Buchan region, Kangaroo Island (which was joined to the mainland at that time of low sea-level), western Victoria and eastern New South Wales may have acted as refuge areas for the megafauna. Their final extinction in east Gippsland seems to have coincided closely with the arrival of hunters in the region, as it did in other regions in Australia.

The extinction debate in Australia has been muddied by those who are so committed to their concept of Aboriginal people as the first conservationists that they cannot accept any human causation of megafaunal extinction. Others, such as Maori people regard themselves as conservationists but are proud of their past big-game hunting that inadvertently led to the extinction of the moa.

We must look at the growing body of evidence, and all the evidence, on its merits and in context, rather than trying to dismiss, often on spurious grounds, every site that does not fit in with preconceived, politically correct theories. Conservation and hunting are not mutually exclusive and Aborigines were both accomplished big-game hunters as well as conservationists (Flood, 1973, 1974, 1980, 1987, 2004, 2006). Quoting zoologist Peter Murray: ‘A gradual attrition of these [megafaunal] populations by hunting…would seem to account for the differential nature of the extinction pattern better than any drought or fire ecology argument…The cause of megafaunal extinction…was probably due to a combination of all the above agencies, but without the influence of Aboriginal man, the megafauna would have survived until the arrival of the Europeans’ (Murray, 1991; p. 1142).

10.4 References


11. The Selwyn Medal

The Selwyn Medal is named in honour of Sir Alfred Selwyn, an eminent Victorian pioneering geologist and founder of the Geological Survey of Victoria. It is awarded, usually yearly, to recognise significant ongoing or former contributions of high calibre to any field of Victorian geology. A candidate for this medal should have made a major contribution to new knowledge of the geology of Victoria, or a significant reinterpretation of it based on critical observations, or have contributed importantly to a major mineral or oil discovery, or have produced important geological publications or have been involved successfully in the development of the geological profession.

11.1 Nomination of Prof Pat-Vickers Rich and Dr Thomas Hewitt Rich for the 2007 Selwyn Medal

by Prof. John Long, Museum Victoria

“At a meeting of the Committee for Research and Exploration of the National Geographic Society held in Washington, DC, on the eighth day of May 2000, the Chairman’s choice of Thomas Rich and Patricia Vickers-Rich as a recipient of the Committee for Research and Explorations Chairman’s Award was unanimously approved. This award recognizes the excellent work of grantees of the National Geographic Society who have provided us with new knowledge of our world.

“In their investigations of vertebrate palaeontology in Australia, Dr. Thomas Rich and Prof. Patricia Vickers-Rich have accumulated an extraordinary record of life from the Age of Dinosaurs in Australia ranging from dinosaurs to mammals. This has completely revised our understanding of Mesozoic life at high latitudes. In recognition of their tireless and virtually superhuman efforts to gather and interpret fossils of great significance, this award is given.

“In witness whereof, we have affixed our hands and the seal of the Society this fourth day of November 2000.

“Peter H. Raven
Chairman, Committee for Research and Exploration

“Richard S. Williams
Vice Chairman, Committee for Research and Exploration

“John Francis
Executive Director and Vice Chairman, Committee for Research and Exploration

The above citation from the National Geographic Society succinctly highlights the discoveries that have been made by Dr Tom Rich and Prof. Pat Vickers-Rich and their significance both to Victoria’s and global science. Below is a brief outline of those achievements, noting novelty and scientific significance:-

- Recognition of likely Early Cretaceous placental mammals in Australia
- Recognition of a monotreme with the most primitive structure known for a middle ear in mammal (*Science* 2005)
Discovery of the most diverse polar dinosaur assemblage anywhere on Earth
Discovery of the youngest temnospondyl amphibian that spotlights the early isolation of the Australian biogeographic region
Functional analysis of polar vertebrates
Successful excavation of fossils under extreme conditions over 27 years
Authorship of seven books on the vertebrate palaeontology of Australia; creating most of the prime literature from textbook to popular for this continent.
Writing of dozens of in depth articles about polar dinosaurs and mammals for popular magazines (*Scientific American, Qantas Inflight Magazine, Natural History* etc.)
Organising exhibitions centred on polar biotas, dinosaurs and vertebrate faunas of the Phanerozoic (*The Great Russian Dinosaur Exhibition, Wildlife of Gondwana, Dinosaurs of Darkness*)
Involvement in more than a dozen documentaries relating to the polar dinosaurs and the polar Mesozoic biotas of Victoria (BBC, ABC, Channel 4 UK, etc.).
Supervision of Australian scientists who began their careers as students of Tom and Pat (e.g. Tim Flannery, John Long, Andrew Constantine, Robert Baird, Charles Meredith, Sanya Van Huet, Erich Fitzgerald)

The bird and mammal fauna of Australia today are the most unique of any continent. How this biological endemism evolved has occupied the minds of not only Australian naturalists but scientists from around the world for centuries. It puzzled Wallace and Darwin in the mid nineteenth century and remains a lively discussion point in biogeographic circles to this day. Plate tectonics has radically altered the premises under which this field of enquiry operates but it has not unequivocally solved the problems posed. Rather it has changed the area of debate.

In 1978 when Tom and Pat began their search for the birds and mammals that coexisted with dinosaurs in Australia, the only evidence of either group present here was about half a dozen, tiny feathers from Koonwarra in southern Victoria. Their search for fossils targeted the southern Victorian coast where rocks of the right age and type were well exposed.

For nineteen long years the Rich’s found fossils of other vertebrates, but neither birds nor mammals. Most were dinosaurs, previously represented in southeastern Australia by only a few bone fragments and only one described and illustrated specimen. In that time, they did not find our “sought after” higher vertebrates so dinosaurs became their prime research focus. Intensive, high risk fieldwork was undertaken with the aid of literally hundreds of volunteers for more than twenty years: volunteers from all over the globe and with the long term support of the National Geographic Society. Result - the discovery of five genera of dinosaurs, almost half the dinosaur taxa known from Australia. Eight more Victorian dinosaurs were discovered, too incomplete to be given an official name, but clearly distinct.

When the work began in 1978, consensus was that during the entire Mesozoic Era, the “Age of Dinosaurs”, the climate was warm from the Equator to the poles. Contrary to that view, the geological investigations by Dr Tom Rich and Prof. Pat Vickers-Rich have identified sedimentary structures that clearly indicate frigid conditions prevailed in southern Victoria when the polar biota existed (Constantine *et al.*, 1998). This evidence strongly suggests the presence of permafrost and ice wedges, both indicating the build up of ice in soils during the late Mesozoic in Victoria.

Determining precisely how cold the winters were that Victorian dinosaurs endured plus understanding how they coped with these conditions, has been a major ongoing component of our research on this unique biota that has absolutely no modern counterpart. Why, they ask, that with these adaptations to such environmental extremes, did they not survive the Cretaceous-Tertiary catastrophe? Such curiosity leads their future research to delve into reasons for survivorship or extinction.
Their study of these palaeopolar fossils has not only demonstrated the presence of a variety of dinosaurs in what is now Victoria, under severe conditions, but that the morphology of the dinosaurs reflected that they lived within the Antarctic Circle of the day. The small bipedal dinosaurs called hysilophodontids were too small to have migrated the thousands of kilometres annually to reach significantly warmer and better lighted lower latitudes. They were, in fact, confined to the high polar latitudes. The Rich’s work suggested they must have been warm blooded in order to cope with these extreme conditions because they were tethered in polar Victoria.

Finally after nineteen years of intensive fieldwork, an Early Cretaceous mammal was found in 1997. That first specimen was tantalising. It seemed to be the most unexpected mammal to have lived in Australia at that time, a placental, like us humans (Rich et al., 1997). Today and in the past, marsupials are in Australia unlike in the rest of the world. Biogeographers have long explained this by the hypothesis that the marsupials arrived here before placentals and in their absence, radiated widely, with placentals only arriving in the last few million years. Finding a placental in rocks more than twice as old as the oldest marsupial known in Australia was quite a surprise. So unexpected, in fact, that interpretation of the first specimen as a placental was widely challenged in major scientific journals. But still to this day no convincing arguments have yet been posed that clearly invalidates the placental interpretation of the growing sample of these mammals first found in 1997.

The most radical alternative proposed was that this mammal (Ausktribosphenos nyktos) and another one in the same family from the same site (Bishops whitmorei) were part of a group of mammals from the Southern Hemisphere that although resembling placentals, were an entirely separate radiation that “mimicked” them. Marsupials and unquestioned placentals were grouped into the Boreosphenida “northern wedge-shaped teeth” and these mammals from Victoria along with monotremes and single specimens from South America, Madagascar and China were grouped together as the “southern wedge-shaped teeth”, the Australosphenida (Luo et al., 2002). This hypothesis has been solidly challenged by Dr Tom Rich and Prof. Pat Vickers-Rich and others primarily on the grounds that the morphology of the teeth of monotremes are quite unlike those of all the other austroalosphenidans (Rich et al., 2002). Monotremes are certainly found in the fossil sample from polar southern Victoria (Teinolophos), quite distinct from the probable placentals (Rich and Vickers-Rich, 2000).

Eight years after the discovery of this first possible 115 million year old Australian placental, the debate about its true affinities continues (Woodburne et al., 2003). In a book summarising the record of all mammals which lived during the “Age of dinosaurs”, Kielan-Jaworowska et al. (2004) commented: “By far the most significant and eye-opening mammalian fossils from the Cretaceous of Australia hail from the Flat Rocks site….”

This was a particularly gratifying comment because the three authors of this monographic study and disagree fundamentally from the view of Dr Tom Rich and Prof. Pat Vickers-Rich about the interpretation of the fossil mammals from the Flat Rocks locality. Their disagreement with the Rich’s interpretation led Kielan-Jaworowska and her colleagues to propose a fundamental division of mammals into the Boreosphenida and Australosphenida, primarily to place the Victorian specimens into the Mammalia, as they conceived the group.

Another interesting discovery based on the rare Victorian Mesozoic mammals involves the structure of the middle ear. One fossil discovered at the Flat Rocks site is a monotreme jaw which reflects that the articular bone still lay alongside the dentary, instead of in the middle ear. This discovery suggests that the transformation of bones from the lower jaw to the middle ear likely occurred twice, once within the monotremes, and independently in the placentals and marsupials. This strongly suggests that the monotremes are only remotely related to the other mammalian groups (Rich et al. 2005). This is the first major piece of “new” morphological evidence concerning the relationships of the monotremes to have been discovered in a century. This discovery was published in Science in 2005 and received widespread coverage in the popular media both in Australia and elsewhere; e.g. Nature, New Scientist, Science News. This media response was due mainly to the profound implications this
discovery has relating to the way in which the major groups of mammals evolved. The discovery has also ignited significant scientific debate. This is yet another outcome of Dr Tom Rich and Prof. Pat Vickers-Rich’s research on the Mesozoic biota of Victoria that has major implications.

The huge temnospondyls are a group of amphibians that thrived between 325 and 208 million years ago. They had an external appearance similar to crocodilians. They gave rise to the reptiles, which in turn gave rise to the birds and mammals. Until the discoveries lead by the Rich’s in Victoria, this group were thought to have disappeared by 208 million years ago. Left and right jaws, and girdle elements of a temnospondyl were quite an unexpected find in rocks 115 million years old in Victoria, thus extending the range of the group more than 90 million years (Warren et al. 1997). For comparison, if a living *Tyrannosaurus rex* were sighted today, that would extend their range by only 65 million years!

None of these discoveries of Victorian Early Cretaceous dinosaurs, mammals and temnospondyls were predicted when the investigations by Dr Tom Rich and Prof. Pat Vickers-Rich began. There was no guarantee that anything of significance would be found by their research, only hope. And by international standards, the collection of Early Cretaceous vertebraes from Victoria is small. But because this paltry collection comes from a time and place that is poorly known, the revelations it has provided about Australia’s biotic history is greatly larger proportionate to the size of the collection (Rich and Vickers-Rich, 2000). This is what makes the gargantuan effort to collect it so worthwhile.

Procedures required to recover the Victorian fossils were quite unlike those commonly used elsewhere to collect such fossil samples, making their work both innovative and risky. One of the two most productive sites was Dinosaur Cove. Difficult of access --- everything had to be brought down a 90 metre cliff --- made solving that logistical problem only the first step of collecting there. Driving tunnels into the cliff in order to reach the fossils was another challenge --- they had to become miners! Certainly, dinosaur bones have been found in existing mines in many parts of the world, but no where else on Earth has a mine been established for the express purpose of collecting dinosaurs, much less tiny mammals! Most people involved in this excavation were untrained volunteers, and carrying out this work with their help required both training in tasks related to the tunnelling which had to be done and at the same time insuring that it was a safe work place. This was accomplished and fossils found with only a broken leg and a broken metacarpal in the course of twenty person years of effort (Rich and Vickers-Rich, 2000). Both patients successfully recovered. Luckily, it was not necessary to tunnel at the second productive site, Flat Rocks near Inverloch. But there, with every tide, sand filled their excavation. Before starting work each day after the high tide, the team had to shovel out quantities of wet sand, not a pleasant task. Over the years, volunteers developed techniques to prevent the sand infilling at each high tide (Rich and Vickers-Rich, 2000).

Excavations began at Dinosaur Cove in 1984 and continued through 1994. The final year at Dinosaur Cove coincided with the first year at Flat Rocks, where excavations continue to be carried out annually. *In toto*, volunteers who are and have been vital to this project have donated a combined effort of 40 person years at these two excavation sites. Were it not for them and the long term sponsors such as the National Geographic Society, the Australian Research Council and Atlas Copco, assisting both in cash and in kind over the years, the fossils would still be in the ground.

Dr. Frank Whitmore was a long serving Vice Chairman of the Committee for Research and Exploration of the National Geographic Society. Together with Dr. Barry Bishop, Chairman of the Committee, they strongly supported the work of Dr Tom Rich and Prof. Pat Vickers-Rich through the long years when little was found, believing that if the project went on long enough, a good outcome would result. On the occasion of the mammal *Bishops whitmorei* being named in his and Dr. Bishop’s honour, Dr. Whitmore wrote the following letter, which summarises his view and that of the Committee for Research and Exploration of the National Geographic Society of our work over the years.
“August 4, 2001

“Dear Tom,

“I never thought I’d be a part of Cretaceous history but now I am, and very proud.

“The publication is clear, succinct, and beautifully illustrated. *In this respect you far exceed the Leakeys, with whom we have compared you.* Your scholarly approach to this problem is impeccable, and the result already is serious and productive argument in which those with other views must meet the standards that you have set. Well done!

“Thank you for your generous acknowledgement of Barry’s and my role in this fine undertaking. We are the lucky ones.

“All the best – “Frank”

Coinciding with research, both Dr Tom Rich and Prof. Pat Vickers-Rich were teaching at tertiary level as well as supervising post graduate students. They needed to provide students with a textbook giving them information not only about the dinosaurs central to their research but also about all vertebrate fossils found in Australia from the most primitive jawless fish to the birds and mammals. No text book existed so they together with colleagues wrote the text, first a preliminary volume and a decade later, a final version still in use today. Soliciting manuscripts from their colleagues with various areas of expertise, the 759 page *The Fossil Vertebrate Record of Australasia* edited by P.V. Rich and E.M. Thompson was published in 1982. This was the first textbook focused on the vertebrate palaeontology of Australia. A decade later, a revised and much expanded book (1437 pages) of the same general scope, *Vertebrate Palaeontology of Australasia* edited by P. Vickers-Rich, J.M. Monaghan, R.F. Baird and T.H. Rich was published.

Evidence of their research reaching the wider public appears in a number of popular accounts of their work. On 9 August, 1993, the cover story of *Time Magazine* was entitled, “Dinosaurs Down Under: Coming in from the Cold. In July that same year, the cover story that month in *Scientific American* was “Australia’s Polar Dinosaurs” by P.V. Rich and T.H. Rich. Besides English, it was published in eight other languages. Subsequently, it was updated twice by *Scientific American*, the article having been republished by them as recently as 2004. In addition, French and Italian publications have reprinted the article. Earlier that year, QANTAS published an article by T.H. Rich and P.V. Rich entitled “The Dinosaurs that Came in from the Cold, *QANTAS Airways Magazine* [January-February], pp. 38-44. This won the *Michael Daley Award for Excellence in Science, Technology and Engineering Journalism* for 1993 in the category "Best Entry by a Communicator not a Professional Journalist or Media Photographer". All of these publications and documentaries put our research program before the general public both in Australia and internationally.

Popularising the breadth of the fossil vertebrate record of Australia also took the form of producing a number of children’s books about various palaeontological topics including for example Vickers-Rich, P., Rich, T., Rich, L. and Rich, T. 1997. *Australia's Ancient Birds.* Book 3 in the *Little Prehistory Books Series*, Kangaroo Press, Sydney (Kenthurst). Authoritative text wound around numerous lavish colour photographs of fossil vertebrate specimens in the book *Wildlife of Gondwana* by P. Vickers-Rich and T. Rich brought the full range of the Australian record of such animals to the general reader as well as to the specialist. The Eureka Award was given for this book in 1993. A second book by the same two authors, *The Dinosaurs of Darkness*, won the 2001 Eureka Book Prize for excellence in science writing. This book summarised the scientific results of their project, gave an account of how the necessary fieldwork as well as detailing how the scientific studies were carried out.
In 1993, Dr Tom Rich and Prof. Pat Vickers-Rich were asked by Australia Post to advise on a major stamp issue focused on Australian dinosaurs. All but one of the dinosaurs illustrated is known from Victoria. As of 1993, this was the second largest stamp issue in the history of Australia Post.

Besides television news coverage programs about the work of Dr Tom Rich and Prof. Pat Vickers-Rich over the years, a number of documentaries have been made about it as well. These include three episodes of the ABC program Quantum, an episode entitled “At the Ends of the Earth” in an American documentary series When Dinosaurs Ruled the Earth and a film entitled The Terrible Lizards of Oz. The fifth episode of the highly successful series Walking with Dinosaurs is entitled “Secrets of the Silent Forest” and is focused on Victoria’s polar dinosaurs. They have also worked with the Victorian Department of Education to produce nine documentaries on palaeontology for use in primary and secondary classes. Tom’s work digging up dinosaurs in the frozen permafrost of northern Alaska is being made into another full length international documentary right this minute.

In 1981, Tom and Pat saw the opportunity to bring the first major dinosaur exhibition to Australia. Facilitated by the vital contacts they had with Chinese colleagues, they laid essential groundwork that made it possible. This was the “Dinosaurs from China” Exhibition, and it was one of the most successful travelling exhibitions to have been held at Museum Victoria or for that matter, in Australia. As a consequence of this exhibition, casts of two of the largest Chinese dinosaurs in the display were made and they stand today in the Evolution Gallery of Museum Victoria.

Twelve years later, they saw a similar opportunity to bring a collection of Russian dinosaurs and synapsid reptiles to Australia. Negotiations were carried out by Pat Vickers-Rich and Mr. Chris Tassell of the Queen Victoria Museum, Launceston. In partnership, not only did they bring the exhibition to Australia where it was shown both in Melbourne and Sydney but they also organised a number of venues in the United States. By agreement with the Russian authorities, many of the fossils were cast and these are still being sold to a number of museums around the world providing funding for continued research both in Australia and Russia.

More recently, an exhibition focusing on the polar dinosaurs of Victoria entitled, “Dinosaurs of Darkness” was mounted by the Monash Science Centre where Patricia Vickers-Rich is the Founding Director. Not only has it been shown at the Monash Science Centre in Melbourne where it was created but it has travelled to Japan, Argentina and the United States as well as most Australian capital cities and a number of country venues.

In summary it would be fair to claim that no two people, working as a team, have had such a powerful impact on the study of Australian palaeontology, and its dissemination to the general public as have Tom and Pat done. Their contributions to putting Victorian geology and palaeontology into the international arena are unsurpassed, and they in my esteem are most deserving recipients of the 2007 Selwyn Medal.

John Long, February 2007
11.2 References


11.3 RE: NOMINATION OF DR THOMAS RICH AND PROF PAT VICKERS-RICH FOR THE 2007 SELWYN MEDAL

I hereby affirm the nomination by Prof John Long of Tom and Pat Rich for the 2007 Selwyn Medal, an honour which I whole-heartedly feel they are worthy of receiving. I first met Tom Rich when I was nine years old, during a National Museum of Victoria (now Museum Victoria) ‘open-day’. Against the backdrop of a throng of children running amok that day in the palaeontology collection, recounting the number of dinosaur names they knew by heart, Tom Rich took the time to talk with me about fossil mammals and fossil hunting. To a nine-year-old fossil and natural history enthusiast, Tom and Pat Rich were legends, the couple who opened the world’s eyes to Australia’s wonderful palaeontological record and what it could tell us about the evolution of life, our planet and humankind itself. Their contributions to Victorian, Australian, indeed international, geology, palaeontology and evolutionary biology represent a lasting foundation on which all future work in this part of the world must surely start from.

All those years ago, Tom and Pat Rich seemed to me equal with the great figures of renown in the annals of palaeontology. Now, that view remains the same.

Yours sincerely,

Erich Fitzgerald, February 2007
12. GSAV SELWYN MEMORIAL LECTURE

by Australian of the Year 2007, Professor Tim Flannery BA, MSc, PhD

“A climate change update to September 2007”

12.1 Lecture summary: In this lecture Professor Flannery will be reminiscing his early start in geology and impact of uniformitarianism and Charles Lyell and early geological thinking and how it has made geologists pretty ill equipped to deal with climate change as an issue.

Then he will go into what we have learnt from the past from new kinds of records particularly ice core records which gives us detailed look at the past, never imagined before.

Then Prof Flannery will discuss the need in geology for new theory on catastrophes.

Where a lot of investigations in recent years suggest that have and can change quite quickly and catastrophically and could change again.

He will discuss the speed, nature and magnitude of coming climate change.

13.2 Biography: Tim Flannery is one of Australia’s leading thinkers and writers.

An internationally acclaimed scientist, explorer and conservationist, he has published more than 130 peer-reviewed scientific papers. His books include the landmark works The Future Eaters and The Weather Makers.

As a field biologist he has discovered and named more than thirty new species of mammals (including two tree-kangaroos) and at 34 he was awarded the Edgeworth David Medal for outstanding research in zoology. His pioneering work in New Guinea prompted David Attenborough to put him in the league of the world’s great explorers, and Redmond O’Hanlon to remark, “He’s discovered more new species than Charles Darwin.”

He received a Centenary of Federation Medal for his services to Australian science and in 2002 he became the first environmental scientist to deliver the Australia Day address to the nation. In 2005 he was named Australian Humanist of the Year, and in 2007 honoured as Australian of the Year.

In 1998-9 he taught at Harvard as professor of Australian Studies. He is a founding member of the Wentworth Group of Concerned Scientists, a director of the Australian Wildlife Conservancy, and the National Geographic Society’s representative in Australasia.

The Weather Makers has received widespread praise for its informed and balanced approach to the global issue of climate change. It has been translated into more than 20 languages and in 2006 was awarded the NSW Premier’s Literary Prizes for Best Critical Writing and Book of the Year. In the same year Tim Flannery received the US Lannan Award for his Non-fiction works.

In 2007 Tim Flannery co-founded and was appointed Chair of The Copenhagen Climate Council, a coalition of community, business, and political leaders who have come together to confront climate change.
Q: German Chancellor Angela Merkel said the clock is “five past midnight” regarding climate change. What time is it on the clock in Australia?

If you look at what’s happened in the last 20 years – we have been gradually increasing the concentration of greenhouse gas emissions in the atmosphere.

There now is about 430 parts per million CO₂ equivalent. The science suggests when we get to 450 per million, it stands about a 20 percent chance or less of triggering dangerous climate change.

So in that sense we don’t have very long. We are accumulating at the rate of 2 or 3 million parts per year. We will hit that threshold within a decade.

Q: What do you do personally to avert climate change?

My house runs only on solar panels. There is no mains power connection. I drive a Prius – a hybrid vehicle.

I try to offset air travel with a reputable company called “Climatefriendly” I do what I can in those regards.

We have our own water tank and recycling plant. It all runs off the sun. We can leave the lights on with no guilt.

Q: How can the past inform us of the future?

The key thing is – what the past is telling us is that climate can change very quickly and to a very large degree. That is the main thing. Also that climate change is not good for life on earth. Serious climate change has serious consequences for living things. The trouble is we are dealing with different circumstances in the past than what we are dealing with now.

Different climate drivers also produce different climatic outcomes. The past is useful but we have to realize it is different circumstances now.

Q: Crisis, pandemic, war – have required new ways of organizing ourselves. To avert a climate change crisis what do we have to do individually, economically and politically?

Start with politically. What we have to do is organise a global response to the crisis – because it involves pollution of a global common in the atmosphere.

So we will have to coordinate our efforts to reduce that pollution.

Economically, we have to do it in a way that is not harmful to our economy. We are beginning to see ways of dealing with that.

Nicholas Stern gives a broad overview on what economic impacts are likely to be. If we use economic instruments like carbon trading, the economic impacts will be small and manageable. Which is a very good thing to know.
Individually, we all have to fall in line with the new regulations and new ways of thinking. That will be made easier when governments get their act together.

**Q: Are humans the next megafauna to become extinct?**

I doubt it. I don’t think we will become extinct but I think we will be thinned out a bit particularly if we don’t do anything.

**Q: What else do we need to be considering about climate change?**

The way geologists have engaged in the debate. Geologists are some of the greatest skeptics on climate change and not for very good reasons. It’s part of their training causes them often to underestimate catastrophe in Earth history.

We really need a new theory of catastrophes to help us to understand what we are learning about the past.

If you look at the political process – such as in December 2009 there is a critical meeting in Copenhagen – that is where the post Kyoto treaty will be forged. It will be great if Australia had a seat at the table at those meetings.

At the moment we haven’t ratified the Kyoto protocol. It is really important to still have a voice there and that we play a constructive role.

**Q: How has it been this year in your role as Australian of the Year?**

Busy – very busy. I don’t think I have ever worked so hard. I have hardly been home this year. That is the main thing. Even getting to businesses who want brief on climate change has been challenging.

Because this is a global issue, I have been spending a lot of time overseas as well.

**Q: Do you think the message about climate change is getting through?**

We are living through an amazing social revolution at the moment, where people are coming to grips with a global pollution crisis in a way we have never seen before.

So that is really interesting and fantastic. It’s just that it would be good to have a few more hours in the day.

**Q: Are people putting things into place in homes and businesses?**

We’re waiting for the global agreement. That’s what’s holding us back. We need Kyoto to work.

People are doing small things – making pledges – some not necessarily small, but they are doing their bit.

All of this will become so much easier when we have a global commitment in place.

**Q: Did climate change cause extinction of Megafauna?**

No, humans caused that extinction.