

# *Quaternary* AUSTRALASIA



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- NEW ZEALAND GLACIATION
- AUSTRALIAN-CHINESE QUATERNARY CONNECTIONS
- CARBON ISOTOPE VARIABILITY IN AUSTRALIAN GRASSES

# Quaternary AUSTRALASIA

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COVER The cover photograph shows late Pleistocene fine deposits unconformably overlying Proterozoic Rocks of the Brachina formation in the Flinders Ranges. This section forms the basis for microfossil and stable isotope studies discussed in the research paper by Peter Glasby and others in this issue. (Photo: David Haberlah)

BELOW Oblique aerial view of the coarse-grained sand beach ridges at Cowley Beach, 100km south of Cairns. Numerical cyclone surge and wave modelling by Jon Nott combined with OSL dating by Ed Rhodes suggests that these ridges are cyclone-built features extending back to about 5.5ka. (Photo: David Hopley)





Dear Fellow Quaternarists,

I would like to introduce myself as the new Editor of *Quaternary Australasia*. AQUA recently handed the baton to me from Kale Sniderman, and also charged Peter Almond with the position of Vice President (taking over from Brent Alloway). It is a daunting task to live up to Kale's standards, and even more daunting still to be producing a special issue in time for the INQUA conference in Cairns.

In honour of the upcoming INQUA conference, we have prepared a bumper issue, showcasing the varied and active Quaternary research taking place across Australasia. The feature article in this issue is an interview between Professor Jim Bowler of Australia and Professor Liu Tungsheng of China. In addition to providing a fascinating insight into the development of Quaternary science in China throughout the country's tumultuous history, Professor Tungsheng celebrates the strong scientific connections between China and Australia, which began with the visit of the Australian Quaternary delegation to China in 1975. From there began numerous exchanges and collaborations which further highlight the Australasian Quaternary community's involvement in international scientific endeavours.

This issue also includes several research papers, covering topics as diverse as Peter Glasby and colleagues' studies of microfossils in late Pleistocene wetlands of the currently semi-arid Flinders Ranges, and Donald Pate and Evelyn Krull's work on carbon isotope discrimination by pasture grasses in southern Australia. New Zealanders Olivia Hyatt and colleagues reconnoitre previously glaciated karst on the South Island, investigating locally distinctive glacial landforms and processes. Thanks must go to the reviewers who managed to complete their reviews in the limited time available.

Australasian Quaternarists have also been busy debating their respective sub-disciplines at meetings, and making use of the networks provided by such meetings. This issue contains reports on the Southern Connection Conference (which brought together scientists from across the Southern Hemisphere), the Australian and New Zealand Geomorphology Group Rivers Workshop, the International Young Scientists' Global Change Conference in Beijing (which a young Australian palaeoclimatologist, Joëlle Gergis, attended) and a Plant Macro-fossil Workshop held in Adelaide. Richard Gillespie also provides an insightful review of Chris Johnson's new book on Australia's mammal extinctions.

I sincerely hope that you will enjoy this special issue of *Quaternary Australasia*. Please feel free to contact me if you wish to contribute to future issues.

Kind regards,  
**Kathryn Fitzsimmons**



Dear Friends of the Quaternary,

Hopefully this will be a highlight year for AQUA. The INQUA 2007 conference is upon us, at the exciting location of Cairns in Queensland.

I remember how as a youngish Dutch student I attended INQUA in Beijing in 1991. As a PhD student in Quaternary science, INQUA was a huge attraction to present what I thought was pretty cutting edge science (which it probably wasn't). It turned out to be one of the best moves I made. The pre-conference fieldtrip was a tour from Kathmandu to Lhasa in Tibet. We had terrible delays in getting out of Tibet and Cheodu, but still made it to the conference. The most important experience from this trip and conference was to meet excellent scientists from different backgrounds. I met up with my future Australian colleagues in the lobby of the hotel in Beijing, which turned into the local watering hole. Only later did I realise that I had spent more time with Australian scientists than with my colleagues from the Netherlands. At subsequent INQUA conferences we were always happy to meet up and chat about our research. I have used this initial international networking throughout my career.

As a Dutch student I also used the British Quaternary Association to get in contact with scientists for samples to be tested for my thesis. No wonder the first thing I did when landing in Sydney on St Patrick's Day in 1993 was to join AQUA. It was a good move, as it brought me into contact with other Quaternarists in this region.

Hopefully the next generation of young Quaternarists in Australasia will also see the INQUA conference in Cairns as an opportunity for international networking. This was the most important reason for AQUA to support five PhD students to attend INQUA.

This bumper issue of *Quaternary Australasia* shows that Quaternary science is alive and kicking down under. Congratulations to our new editor Kathryn Fitzsimmons for putting this excellent issue together. Last but not least, the AQUA Executive is planning the Biannual conference for early 2008, where we can all chat about the good times we had in Cairns.

See you in Cairns!!!!!!

**Henk Heijnis**  
President of AQUA

# Professor Liu Tungsheng: Australian-Chinese Quaternary connections

An edited interview by Jim Bowler

School of Earth Sciences  
The University of Melbourne

## Preface Donald Walker

After excursions in both directions beginning in 1975, the Australian National University (ANU) and the Chinese Academy of Science (CAS, Academia Sinica) formally established the ANU – Academia Sinica Quaternary Studies Programme in 1980, primarily to explore the similarities and differences of the two land masses during the Quaternary period. It provided for collaborative research in both countries, particularly in salt lake studies, palynology and palaeo-anthropology. Although it formally ended about 1988, the joint work which it initiated, and which has diversified and spread far beyond the parent institutions, continues to this day.

The leader of the party that greeted the first Australian delegation at Beijing airport in 1975 was Professor Liu Tungsheng, and he remained the prime facilitator of activities in China throughout the joint programme. Without his scientific initiative, experience and ability to get things done – often on a grand scale – it would have been a far less successful undertaking. Distinguished though he is in several fields of Chinese geology, it is his pioneering and detailed work on loess which has gained most international acclaim. In 1987 he was awarded an honorary Doctor of Science by ANU. He was President of INQUA from the Beijing meeting of 1991 to the Berlin meeting in 1995.

Long association and common interests have led to warm and enduring friendships between the participants and their families from the two countries. One such friendship is that between Liu Tungsheng and Jim Bowler, from which arose a series of interviews in 2004. Now in his ninetieth year, Tungsheng muses on the life and times of a geologist in China during several decades of troubles and changes, and on the importance of geology in the modern world. It is a remarkable account of steadfast intent for which we are all indebted to Tungsheng himself and also to Jim. What follows is an abbreviated version of the whole set of interviews which can be read in full at: <http://www.aqua.org.au>

Donald Walker is Former Chair of the Australian component of the ANU – Academia Sinica Quaternary Studies Programme

## Interviewer's Note Jim Bowler

An early approach to Professor Liu Tungsheng to record his reflections of life was greeted by characteristically generous but modest response. The interview was conducted in October, 2004 at the Institute of Geology & Geophysics, Chinese Academy of Science, Beijing. This condensed record of the interview is published with Professor Liu's permission.

The problem of reducing the full interview to half its original length for publication poses a number of problems. What to omit without losing the connecting flow? Toward resolution of that problem the following guiding principles have been adopted. Firstly, as Professor Liu came prepared in the best Socratic or perhaps Confucius tradition with a large sector packaged into six stories; these stories, as central to the dialogue, have been retained almost intact. Secondly, for reader interest, the following thematic links have been identified:

- Early years, youth and the rise of patriotism
- Emerging science: Beijing Man discoveries at Zhoukoudian
- Openings with the West
- Early loess developments
- Cultural Revolution interruptions
- The Australian connection
- Vision for the future

We are particularly indebted to Dr Han Jiamao, Institute of Geology & Geophysics, CAS, Beijing for his meticulous assistance in editing the final text details of Chinese names and spelling.

# Interview with Professor Liu Tungsheng, May 24, 2007

## Early years, youth and the rise of patriotism

I will begin with personal experiences while in my home town. I was born in the year 1917. The hometown of my grandfather was in the north of China, Tianjin, but I was born in Shenyang in the northeast. My father had become a station master of Shenyang. The station, Huanggutun, was where the Japanese bombed the railway and killed the warlord, Zhang Zuolin, who at that time was the governor of northeast China. That was the start of the Japanese military invasion from 1928.

My father was a self-educated man, and paid much attention to the education of his children. I learned from my father the qualities of diligence, hard work, honesty and generosity. All these virtues or characters were also taught at primary school. My mother, a traditional woman, came from the countryside from a family of farmers.

My lasting impression of my primary school education and of that age, during the 1920s and 1930s, is a kind of national humiliation. At primary school we had 'national humiliation days' because of the unequal treaty between China and Japan, Britain and other countries like France, Russia and Italy. So, for the primary school stage of my life there were two major impressions. There was the traditional education from school and also from family about diligence, hard work, honesty and generosity. On the other side was patriotism through being under Japanese control.

In 1930, the Japanese military first occupied the northeastern part of China, so my family fled from Shenyang to live in Tianjin and Beijing. We moved to the interior part of China during the second World War.

Twenty years later I went back to Shenyang, and I discovered that in the 20 years from 1930 to 1950 no engineers had been educated. China had universities and high schools; medical doctors were trained but no civil engineers, no mechanical engineers, and of course no geologists. So all the geology was being conducted by Japanese geologists. They had trained only some of their subordinates to look for the outcrops of some ores or mineral deposits. The information was collected so the Japanese geologists could decide whether the deposits were useful or not. So it seems there was a degree of intellectual control of China through the Japanese



Figure 1: Memorial stamp and envelope struck by China's national government to commemorate the award of China's National Science Prize, awarded and presented to Prof. Liu Tungsheng in 2004.

occupation. That's why most people of my age group developed a strong sense of patriotism.

The bombing of Shenyang in 1928 killed the leader of Chinese government in the northeastern part, the father of Zhang Zuoliang. Zhang Zuoliang then took control of the military in the northeast and retreated into northern China. When the Long March passed through northern China to the northwest he was in Shaanxi Province and Jiang Jieshi [Chiang Kai-shek] was controlling the southern part of China, and the communist army passed through the eastern and northern part into Yan'an. The son of the older marshal (Zhang Zuoliang) talked with Chiang Kai-shek during a visit to his headquarters, then they had negotiations between the communists and the governor. From that time in 1937 the Japanese resistance really began, after they had occupied Beijing, Tianjin and Shanghai.

We left Shenyang, my hometown, for Tianjin and my middle school. This school recently celebrated its one-hundredth year; Nankai Middle School. The school is very proud of its alumni because two prime ministers were graduates, one being Premier Zhou Enlai, the other Premier Wen Jiabao.

Many of my generation shared similar life experiences. I learned quite a lot about nature when I was very young because we lived in the countryside where there was no entertainment such as movies or theatres. The only thing we did enjoy was nature, so at the small river we could swim and catch insects or other animals.

In 1937 I graduated from middle school, but there was no chance to enter university due to the start of the war. Some graduates moved to the northwest to the communist-occupied area. The war started in 1937 and ended together with the second World War in 1945. After four years of university life, 1938 to 1942, I was sick for some time (until 1944). In 1946, I started my career as a geologist.

After the war (in 1946), I enrolled in the Geological Survey in Chongqing in the southwest in Sichuan Province, which was the wartime capital along the Yangtze River. The Geological Survey was in the countryside. Then they moved back to the old headquarters in Nanjing, then the government capital.

After liberation in 1949, the Geological Survey expanded as the Ministry of Geology. Some of the people from the Geological Survey established the Institute of Geology in 1953. This Institute continued the geological research work of the former Geological Survey. Some of the research, exploration and geological survey mapping work expanded greatly in the Ministry of Geology, although during the 1950s there was little opportunity for research. At that time the Institute reported to the Academy of Science and also to the Ministry of Geology. This was the continuation of the former Geological Survey with people like Professor Hou Defeng and Professor Ye Lianjun. We had six senior geologists who came from the Geological Survey including myself. Altogether there were no more than 100 geologists during the establishment of the 'new' China.

## OPENINGS WITH THE WEST

**Story 1** The first story was the one my grandmother told me during the 1920s. It is the story of the 'southerners', of people who I think are actually 'foreigners'. She described these foreigners who in very hot weather were wearing wool coats and high boots speaking some kind of language or dialect that local people did not understand. They came to a local hill trying to find something from it. At last after three days of looking one of them knocked at a rock, found a golden frog and took it away. I think the foreigner was a geologist, perhaps Ferdinand von Richthofen or Bailly Willes.

The actions my grandmother described were about finding fossils in rock; of course not a golden frog but fossils of other animals, insects or such like. My interest was sparked that we couldn't find the golden frog and that she'd said we have such precious things in our country that were taken away by the southerners, by the foreigners. This attitude persists to this day among Chinese regarding exploration and use of our resources by foreigners.



Figure 2 (right): Occasion of first visit by Chinese scientists to the Walls of China, Lake Mungo, in the Willandra Lakes World Heritage area, western New South Wales, in 1977. The Lake Mungo lunette, the only distinctive feature in the region, derived its early "Walls of China" name from its proximity to the community of Chinese shepherds working on the original pastoral lease in 1869. From left, Prof. Liu Tungsheng (Chinese Academy of Science), Mme Wang Zunji (Foreign Affairs, Beijing). Dr Bao Haosheng (Karst geomorphologist from Nanjing, then studying at the ANU). (Photo: Jim Bowler)

It is this kind of culture which has limited the growth of Chinese economics and the progress of Chinese culture to the outside world. A similar kind of 'restricted view' or 'protective thinking' occurred during the opium war. During the opium war the people of the Qing Dynasty didn't want to open the door; they resisted everything from the outside world.

Of course some Chinese would have liked some western culture, but many of the officials and others resisted the foreigners, just like my grandmother. She held the notion that the foreigners took all the precious frogs away. They saw that the foreigners were very capable and thought that the Chinese couldn't do it. While they admired western technological and exploration powers, at the same time there was an awareness and regret that so many precious things had been taken away. This was the sentiment during my young days. I find this story particularly interesting because she was describing a geologist; maybe that influenced me to become a geologist as well!

**Story 2** The second story is about a very famous proponent of Chinese geology, Professor Ding Wenjiang [Ting Wen-chiang]. He was educated in Britain and graduated from Glasgow University. He finished his studies in both zoology and geology. He was a very good geologist, maybe a student of a very famous English geologist who studied the parallel mountains ('dry valleys') in Yunnan Province. There are many stories

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about Dr Ding [Ting]. He was the first director of the Chinese Geological Survey; he established the first Chinese Geological College, and is considered one of the founders of Chinese geology.

Professor Ding Wenjiang returned to China soon after 1910. In 1919, as Director of the Chinese Geological Survey he published the first Chinese geological magazine, the *Bulletin of the Geological Survey*. On the first page in the first issue of volume one of that journal he printed a quote from Richthofen, who essentially wrote that *'Chinese intellectuals like to sit at their desk in their very neat and clean rooms that are full of sunshine and write poems and make paintings'*. They enjoy this kind of intellectual life; they don't like to go out in the field. So many years later other disciplines of science had developed but not geology.

Professor Ding Wenjiang printed Richthofen's quotation at the front of the first Geological Bulletin to encourage young Chinese geologists to go into the field. This was a very good story, especially for people of my age. I always tell this story to young geologists, especially now because some of them don't want to do field work. During the 1930s and 40s geologists liked to go to places like the Himalayas; they were very ambitious. What Ding Wenjiang and Richthofen had said about the Chinese intellectuals back then is still relevant to some young Chinese geologists who don't like fieldwork in the present time. However with this warning most young Chinese geologists now work hard in the field.

Ding was proud of those he trained at Peking University during the 1920s, who became the first generation of Chinese geologists. There were students like Yang Zhongjian [*C.C. Young, Yang Chung-Chien in early spelling, frequently abbreviated to C.C. Young in English publications. JMB*] who graduated in 1923 and Pei Wenzhong who graduated in 1927.

## EMERGING SCIENCE: BEIJING MAN DISCOVERY

**Story 3** This is the story of Pei Wenzhong and the discovery of Peking Man. Pei graduated from the university in 1927. At that time he couldn't find a job in geology. Then came support from another founder of Chinese geology, Professor Weng Wenhao [WH Wong], who was the first Chinese person with a doctorate degree from a western country. Professor Weng supported Pei Wenzhong to work as a secretary for the excavation in Zhoukoudian.

Just before that, in the early 1920s, JG Andersson from Sweden had purchased some 'dragon's bones' used in Chinese traditional medicine. The 'dragon's bones' were actually fossil bones and teeth. Andersson sent them back to Sweden, where paleontologists found that some of the teeth may be from an arthropod, a primate, some

type of monkey. Andersson was sharp and a very good observer. That was the time of the Java Man discovery. Andersson thought that perhaps he could find fossil man in China. So he explored the surroundings of Beijing and found in Zhoukoudian a place that local people called the Chicken Bone Mountains, because fossils of birds were present in deposits.

Andersson excavated in Zhoukoudian, and was followed by the Austrian palaeontologist, Otto Stansky and a Swedish palaeontologist, Birge Bohlin, in 1924 and 1925. Weng hired Pei in 1927 to take charge of the excavation management. At that time Pei knew nothing about the work in palaeontology but he was very diligent at taking care of the excavation. He first learned from the archaeologists new methods for excavation where they created a grid system and excavated from level to level. This was the first grid system Pei applied, then he made a sort of pulley from the lower part of the mountain to facilitate the work. At the end of 1929 he discovered the first skull of Peking Man.

Others involved in the excavation such as Davidson Black, Teilhard de Chardin and Bohlin had all thought they would find human fossils quickly. They were ready to stop the excavation in late December of 1929 because it was very cold but Pei insisted they try another day. On that very last day they found something different, maybe a kind of skull. Pei examined it himself and at last they thought it was a skull of fossil man. They wrapped it and carefully transported it to the Department of Anatomy at the Peking Union Medical School.

Pei's discovery was an important turning point for Chinese geology and palaeontology. Before that we had important works by Grabau and Teilhard de Chardin, but none were conducted by Chinese palaeontologists nor discovered by the Chinese themselves. So this finding of the fossil skull by Pei is a kind of declaration of independence for Chinese geology! For many years I wondered if that's why there is a kind of phenomenon about Pei, because if people were talking about the discovery of Peking Man, everyone said that Pei was the discoverer. I called this 'the Pei phenomenon'. The Chinese realised we made a discovery of worldwide importance.

**Story 4** At university between 1938 and 1942 we had a German professor, Peter Misch, who was a student of Hans Stille. Peter Misch taught us structural geology and the ideas of Hans Stille on regional metamorphism. These were very distinguished people.

At that time, the Chinese translation of Sven Hedin's book on the exploration of the Taklimakan Desert was translated and published. It was a very popular book for young students. It contains a very famous story about Hedin's rescue of his guide by finding some fresh water and taking it to him in his boots. For me Sven Hedin and

Hans Stille were big figures for young students of geology. Sven Hedin explored nature, while Hans Stille explained nature including the structure of the earth. So, geology not only explores but also explains earth.

For me, that is the importance of geology; it captured my interest and led me later to study palaeontology. So this is the story of my professor, Peter Misch, who at that time taught geology in the Southwest Associated University in Kunming, which was a collective university including Tsinghua, Peking and Nankai Universities – three universities together.

**Story 5** The fifth story is about Teilhard de Chardin and comes from Yang Zhongjian [C.C.Young] who was a very good friend of Teilhard de Chardin. Yang Zhongjian learned a lot from Teilhard de Chardin who was about 10 years older than him. Teilhard de Chardin is a very special man for the Chinese.

Most Chinese geologists and others, especially in those days, knew him as a vertebrate palaeontologist. He worked in palaeontology, structural geology, Quaternary geology, petrology and even botany and zoology. However in France, the French knew Teilhard de Chardin as a philosopher. Many still think of him as a philosopher and don't know about his palaeontological work. He is actually one of the founders of Chinese vertebrate palaeontology. He trained Yang Zhongjian and Pei and many others. I didn't have the chance to meet him personally.

During the Japanese occupation of Beijing, Teilhard de Chardin's ideas about the *noosphere* and the 'Phenomenon of Man' were completed. Yang Zhongjian gave me a monograph where Teilhard de Chardin described his idea of the *noosphere*. In that paper he described the lithosphere, then came the Stone Age, then the Bronze Age, followed by the industrial age and then came the *noosphere*, 'the age of consciousness'. These were very interesting ideas of Teilhard's but were neglected by Chinese palaeontologists.

**Story 6** Was Teilhard de Chardin's philosophy or ideas influenced by the Oriental philosophers? In his work he has very good summations of the Indian, Japanese and Chinese philosophies; I think he was influenced by the philosophy of the Chinese. The most famous Chinese educator and philosopher, Confucius, had the idea the world will become a common country and that mankind has to have friendship and love for others. I found these ideas also in Teilhard de Chardin's 'The Phenomenon of Man' whose omega point in a future world will be the uniting of all people into a big family where the end goal in their evolution and development must be love.

This is of importance in understanding his 'earth systems concept' for he created another layer of the earth, the *noosphere*. I'm really interested in that because in recent years with environmental and global change issues, people have become more aware, especially during the last 10 to 20 years. It seems the earth is becoming smaller; people have a view of the globe in its entirety.

*[On a 1964 visit to the Tibetan Plateau with Prof. Shi Yafeng, Prof. Liu discovered high altitude fossil Quercus leaves, clear evidence of uplift...JMB]*

So we have to consider all work not only of the loess or the Tibetan plateau, not only of the northern plain, of the coast or other areas. We have to consider the geology of the world, of the whole globe, especially if we are working on environmental issues.

Environmental issues involve humanity as a geological agent: the human influence on the environment is increasingly important. That's why I am interested in the *noosphere*. In 2000 a short paper written by Crutzen et al. appeared in the bulletin of the IGBP (International Geosphere and Biosphere Program). Paul Crutzen is in the field of atmospheric physics. He studied Antarctic ozone depletion but as an atmospheric chemist he raised a problem for discussion. After the Holocene, humans today live in a geological epoch he called the *Anthropocene*, beginning in 1846 when James Watt invented the steam engine.

The idea of the Anthropocene is a very attractive one even though many Quaternary geologists consider the appearance of humans as the beginning of the Quaternary. Paul Crutzen's idea to start from the beginning of the industrial age is supported by ice cores in which carbon dioxide and methane increase due to human activity.

From a geological point of view, human agency influences geological processes, for example, through exploration and soil disturbance by humans, the dunes return to active desert. This is not only interesting scientifically, but more importantly, politicians, policy makers and land managers must be aware of such geological impacts.

Even though these changes are actually natural responses to humanity's geological agency, it is especially important for the Chinese because China is so populated. We are always saying that if China had 20% or even 10% less people, then the problems of cereals supply and water shortages would be solved more easily. We may have to wait another 30 to 50 years for the birth rate to stabilise. Yet after 50 years or more the population will again increase and the only way to solve the problem of population growth and shortage of resources is for people to be aware of human environmental impacts. This remains a critical issue for future generations. That's why I'm in favour of Paul Crutzen's idea of the Anthropocene.

So this is a summary of my contact with science as a Chinese looking at science from the west.



Figure 3: The first Australian visitors arrive at Yenan in the centre of the loess plateau in 1975. From left, Mr Shou Mingshen (translator), Alan Thorne, Joe Jennings, Mrs Yu, Donald Walker, Mr Chien (Foreign Affairs), Dr Lu Yanchou, Jim Bowler. (Photo: Ian McDougall)

## EARLY LOESS DEVELOPMENTS

My first contact with the loess issue was when I was a young palaeontologist in Nanjing in 1946. Some of the pedologists at the survey sent me a segment of bone they found from the loess in Nanjing. I also met the pedologist Professor Song Bartran who studied palaeosols in the loess near Nanjing at the source of the Yangtze River, the *Xiashu loam* or *loess*. That was the name used in the 1920's and 30's by the American soil scientist James Thorp who studied palaeosols in both the United States and China.

I became acquainted with the fossils from the loess and then in the museum I found the fossil described by Teilhard de Chardin. He had found it beneath the Malan Loess. Beneath the loess of the last glaciation and above the *Hipparion* red clay is a group of geological formations which he designated as a reddish clay and not as loess. I wondered why Yang Zhongjian and Teilhard de Chardin, who worked together, had not recognised the nature of the loess? Maybe they didn't notice or pay much attention to the buried soil, the palaeosol, or they were influenced by the loess deposits in Europe which are mostly younger, from the last glaciation. Maybe that's why they considered it a new geological formation, the reddish clay. Teilhard de Chardin divided the reddish clay into three subdivisions, A, B and C. Actually reddish clay 'A' is stratigraphically equivalent to the Wucheng Loess while units 'B' and 'C' correlate with the Lishi Loess.

Among the fossils were various kinds of mammals, especially *Myospalax* rodents of the steppe region, a mole rat which evolved from the lower to upper part of the sequence into several different species, identifying three subdivisions. When I was studying the fossils of

*Myospalax* I discovered Teilhard de Chardin and Yang had studied the reddish clay, but at that time I didn't know it was loess.

However, in 1954 I began to study the Quaternary in the Sanmen Gorge region which is the biggest dam on the Yellow River, and also a big failure [*Constructed by Soviet engineers, the dam quickly filled with loessic silt from the Yellow River...JMB*]. I was to study the loess over the Sanmen Gorge region. One evening after a rainy day with Professor Zhou Mingzhen [*recently deceased distinguished archaeologist and vertebrate palaeontologist, well known and loved by many Australian and overseas colleagues...JMB*] we went for a walk. I discovered in the nearby loess gully about two or three levels of lights. I thought it couldn't be a three or four storey building in that region because at that time it was still a backward rural area. Were there people living there? It was very strange. I was in the southwest of China during the second World War and was familiar with the night illusion of the 'mountain cities'.

The next morning we went to have a look for the source of the lights. Then we discovered they were cave dwellings and the light was from the lanterns used by the residents of the caves. We then discovered a number of caves located at the same level. Why were these caves built in levels? Each level had its ceiling just beneath a layer of calcareous concretions. We asked the pedologist, the soil scientist Professor Zhu Xianmo. He said that was the buried soil, the palaeosol, which is why we couldn't find any reddish clay only loess with intercalated buried soils in the loess plateau. The so-called reddish clay was recognized as a series of loess beds interbedded with buried soils.

In 1954 some famous soil scientists from the USSR visited China. One of them was the soil scientist

Professor Kovda who at that time was the consultant general or adviser to the president of the Chinese Academy. Another one was Professor Gerasimov, a famous geographer and soil scientist. When they were in Beijing many leading Chinese soil scientists took them on a trip in the vicinity of Beijing and then to the loess plateau. I accompanied them also with Professor Yang Zhongjian. In the train Kovda and Gerasimov wanted to talk with Professor Yang Zhongjian and me about the issue of the loess in China.

At that time I didn't know that Professor Gerasimov considered the Chinese loess a kind of pluvial deposit [*\*pluvial: a Russian term for flood outwash deposits along the foothills in arid or sub-arid regions...JMB*]. So I just reported to him my observations from Shanxi Province where there is one layer of loess and another layer of soil, with several layers altogether. I had discovered eight layers of interbedded loess and soils. We now know that each loess-palaeosol pair represents a 100,000 year interval. That's in the upper part of the whole soil-loess section, although Professor Yang insisted that was the 'reddish clay'.

Many Chinese studying loess wanted to follow the Soviet hypothesis. I held to the idea that it was an geologically old deposit, otherwise you couldn't explain the alternating development of the loess and the soil. Professor Yang disagreed although he had little knowledge about soils. Gerasimov was really very bold; even though he was younger than Professor Yang he said to me 'you are right, but I need some specimens to prove it'. Professor Yang sat over there and I was here and he was on the opposite side, and the interpreter said 'no matter whether it is a great authority you have to insist on your own observation'.

I mailed Gerasimov the samples I collected from the Shanxi section. Then he wrote a paper about the genesis of the loess and the loess plateau in China. He used my section and the evidence of the soils but his final conclusion was that it was a pluvial deposit, an alluvial fan over the mountains in the northern part of China. However our conversation stimulated me very much; I became confident enough to insist that there was an alternative view of soil development in loess.

In 1961 the sixth INQUA Congress was held in Warsaw, Poland. Professor Gerasimov was a very generous man, so around two years before the congress he came to China to urge Chinese scientists to join this international meeting. At that time we were quite isolated with very few international contacts, except with the former Soviet Union and other socialist countries. He wanted to introduce us to the Polish Quaternary scientists. Professor Gerasimov also guaranteed there would not be any trouble for us because at that time China held no regular position as a member of the United Nations.

So I prepared my thesis for the meeting. It was the first paper I wrote about the geomorphology of the loess plateau, the so-called Yuan, Liang and Mao. People said it would not be very interesting to international scientists. At that time I had a copy of the science journal published by the American Academy of Sciences. It contained a paper by Emiliani about an oxygen isotope study of the Caribbean Sea. I noticed that there was something similar between his curve and the Chinese loess-soil sequence. I prepared a draft of the loess reflecting climatic fluctuation. Unfortunately I had so many cycles of glaciation (more than the accepted four glaciations) that Professor Li Siguang [Lee Sze-kwang, JS Lee] along with many others was not in favour of this work. He had no previous knowledge of such climatic variations and, moreover, I was not confident about it either. I also thought it may not be appropriate to propose alternating changes of the climate.

So I changed my idea and handed the new paper into Professor Li Siguang. He was one of the older generations of scientists. He read it and then had a long talk with me.

It was a very probing conversation. Professor Li asked me 'where is the best profile?'. I was working in the Lishi county of Shanxi Province, so he suggested I use the name Lishi Loess. He listened carefully to my description of the loess profile, then advised me to make a typical stratigraphic section of the loess from the upper part of the Lishi Loess because it was the best exposure in the Shanxi Province, and also the Wucheng Loess in Wucheng, Shanxi Province (a town not very far from Lishi) where had fossils had been studied by Teilhard de Chardin and Yang. That was the paper I delivered in Warsaw at the 6th INQUA conference.

Professor Hou Defeng, the director of the institute, thought it may also be beneficial to include the work of Professor Zhang Zonghu from the Ministry of Geology. So Professor Zhang Zonghu and I both prepared the paper which I presented in Warsaw. Julian Fink was very interested in the paper, and also BTU Smith from the United States who had developed a fluvial origin for the Mississippi loess. I had a section with me and also some samples from each layer that I had obtained through a technique of 'peeling' from the loess. A Russian Quaternary scientist, Madam Kes [*a strong proponent of the 'pluvial' theory...JMB*], also gave a talk on Chinese loess. Dylik from Poland was also interested. Dylik had the idea that loess deposits were from periglacial deposits. Fink, a very kind person, had experience of the Paudof soil in Europe and thought that may provide an answer to the Chinese loess. This gave us confidence to further study the loess in China. We undertook a collective study and published the books *The loess in the middle reaches of the Yellow River*, *The loess of China* and also *The texture and composition of loess*.



Figure 4: Dinner in Luikiang, 1975. From left, Liu Tungsheng, Mr Shou, unknown, Donald Walker. (Photo: Ian McDougall)

## CULTURAL REVOLUTION INTERRUPTIONS

But then came the cultural revolution. Initially it wasn't so bad for me because I had little trouble with the young people working with me. However, at a later stage they wanted to be sure about the political history of each pupil. So one day some of these young people, the Red Guards or suchlike, declared that I was some kind of special agent. I was detained and placed in a cowshed with others. That was a kind of protective measure by the government, because many people committed suicide in isolation.

Many of my friends like the late Professor Li Pu, a graduate of Cambridge, committed suicide. He was once a party member but later separated from the communist party and people said he was a kind of rebel from the party. At that time his wife was not in Guiyang so he committed suicide. Another good friend Professor Su was a graduate from the Moscow Exploration and Mining University. When he was younger, his family was a landlord so he became a landlord. He committed suicide also, because he was isolated like Professor Li.

The government wanted to stop the cultural revolution. After two or three years they asked the workers to go back to their factories to produce, the students to go back to their schools, and the scientists to go back to their laboratories. But they couldn't stop the situation so in 1973 or 1974, there was a movement to try to restore the regular life of the society. That was around the time Mao Zedong invited ping pong players to China; he tried to contact the US, and President Nixon sent delegates to contact the Chinese. This was a kind of turning point.

## VISION FOR THE FUTURE: THE AUSTRALIAN CONNECTION

1975 was the turning point for renewing studies. The Australian delegation was coming to China, so we had to do some basic work to show others. We had a few loess studies in Guiyang and Beijing but only work from before the cultural revolution. So in 1975 I came back to loess and we undertook palaeomagnetic and other studies.

Our Australian friends were interested in the Chinese loess studies and other scientific studies. After 1975, the Chinese Academy included Madam Wang Zunji and myself on its visit to Australia. After that visit Donald Walker and the Chinese, including Huang Bingwei, discussed a program of collaboration. That was the start of training for young people like An Zhisheng, Sun Xiangjun, Huang Qi, Yuan Baoyin and many others. They studied in Australia for one or two years. This type of collaboration had never been practised before.

So there was a very concentrated study of loess during the late 1980s and the early 1990s. This intensive strengthening of Quaternary studies in China laid the foundation for the advance of Quaternary scientists in later years, like An Zhisheng who went on to develop a separate loess laboratory, Wen Qizhong who developed geochemistry in Guiyang and Guangzhou, and Sun Xiangjun who specialized in palynology. This kind of collaboration really brought a magnificent result. So thanks go to our Australian colleagues. It is a collaboration worth remembering and exploring further.

*[Palaeomagnetic studies generously supported by Ken Hsü and Freidrich Heller led to a new stage of loess work with additional sections studied, as by Han Jiamao and Ding Zhongli on new profiles in Jixian and Bojee, Shaanxi Province, and by Liu Xiuming at Xifeng, Gusu Province as well as the Luochuan section. Studies by Guo Zhengtang have identified what appears to be loess of Miocene age...JMB]*



Figure 5: Prof. Liu Tunsheng enjoys a point in discussions with Dr Alan Thorne and Prof. Joe Jennings, near Yangsu, Kwangsi Province, 1975. Interpreter, Mr Shao Mingshen partly obscured. (Photo: Ian McDougall)

In the late 1950s I was asked to be a director of the laboratory of Quaternary Studies. That was the time of establishment of the new People's Republic, a newly established government with new priorities. Reconstruction of the government, restoration of industry, and the improvement of agriculture were priorities. The recently established government was not interested in the advancement of science or the arts. For my part, if I chose to be an eminent palaeontologist and study foreign languages I would have to do many things that the political environment would not allow. So I decided I would not go that way. I chose to dedicate my experience and time to the education of young people, to build up a group of people, a team who could work in this field.

I believe that was the right choice. Not only was I elected vice-President and President of INQUA in 1991, I was elected President of the Chinese Quaternary Association and appointed head of the Chinese group in the Australia-China collaboration. I didn't have time or the opportunity to advance my studies during that collaboration but I helped others to improve their ability, like An Zhisheng and Sun Xiangjun, to collect a group of people to work together. The prizes I was awarded (including the Tyler Prize) are to me a reward for the collective or team work of the group. Without that team, I would not have achieved these accomplishments. Even the National Supreme Award of Science and Technology of China, the highest science and technology prize, was bestowed on me because I had a group of people working together. We had the beginnings of an innovative program of cooperative work on the loess.

I became interested in the loess because I solved the problem of the palaeosols which were erroneously called reddish clay of fluvial origin. Other opportunities, such as Ken Hsü inviting me to Switzerland, gave me the chance to discover magnetic susceptibility records as proxies for climatic cycles.

*[Liu addresses issue of specialization, a very interesting and important one that has to be addressed in China requiring multi-disciplinary approaches in the context of the need to respond to issues of social importance...JMB]*

## VISION FOR THE FUTURE

Younger scientists have to influence politicians or policy makers and be aware of their responsibility to society. People still remain concerned with themselves or their own family or their own small group rather than the outside world. That's why many geologists focus on mineral resources and want to specialise in this area; other issues of land and environmental resources are neglected.

Last year at the presentation ceremony of the Li Siguang prize – JS Li was a very distinguished geologist in China – one of the governors said that '*the Geological Society has to change, a change in orientation and priorities*'. That is, geological science should adopt an approach to earth systems. The geological community must broaden its view to include environmental issues.

I'm really very pleased about these new developments. At the 32nd Geological Congress people were talking about the Planet Earth program. In that program attention is being paid to environmental studies; people will pay more attention, not only to pollution and other environmental aspects, acknowledging human impact or human activity as a kind of geological agent. I'm expecting a renaissance of geology. Global change has the ability to be one of those issues that breaks down the barriers. I think that is why the Tyler prize and the National Prize considered our work, because we brought the issue together as a kind of collective work, a convergence. Just as Teilhard de Chardin mentioned in his work, no matter where you are, environmental issues are the same.

I believe these issues are timely for China, although I'm not sure if we have much influence. At a recent meeting in Tianjin the main concerns were urban geology, geological hazards, the geology of agriculture and land planning, and the geology of surficial deposits. So there is a move away from classical mineral deposits to more environmental issues.

Thank you. This has given me a chance to explore many areas I have not previously documented.

# A Reconnaissance Study of Glaciation on the Owen Massif, Northwest Nelson, New Zealand

Olivia M Hyatt, James Shulmeister, Chris C. Smart

Olivia M Hyatt (corresponding author), Department of Geological Sciences, University of Canterbury, New Zealand

Fax: +64 3 364 2769 Email: omh13@student.canterbury.ac.nz

James Shulmeister, Department of Geological Sciences, University of Canterbury, New Zealand

Email: james.shulmeister@canterbury.ac.nz

Chris, C. Smart, Department of Geography, Social Science Centre, University of Western Ontario, Canada

Email: csmart@uwo.ca

## Abstract

A preliminary investigation of past glacial activity on the Owen Massif in northwest Nelson, New Zealand is presented. There is good evidence for extensive ice accumulation on the massif. Glacial erosional features such as U shaped valleys, ice smoothed bedrock knobs and glaciokarst pavements are widespread. Preservation of glacial depositional landforms is poor, because of the extensive karst processes operating on the massif and fluvial action in the valleys. Sediment accumulation was concentrated in large pre-existing karst depressions centered on and around Sentinel Hill. The glacial landforms and processes appear different from surrounding northwest Nelson landscapes. No true terminal positions have been identified, though it is clear that ice did flow off the massif and advanced at least a few kilometres down the upper Granity and Owen valleys. Fluvial valley forms dominate the valleys radiating from the massif where initial U shapes valleys quickly become fluvial incised. Further investigation is warranted in the caves, where sediments and speleothems potentially hold the best archives of glaciation.

## Introduction

Mount Owen is the highest peak of a spectacular up-thrusted marble massif at the southern end of Kahurangi National Park, northwest Nelson, New Zealand (Figure 1). The Owen Massif has been stated to be the best example of glacial karst in New Zealand (Williams, 1992), but there has been no specific study on the glacial landforms or sediments on the massif. This paper presents the results of a reconnaissance glacial study of the Owen Massif.

Glaciation was widespread in the mountains of South Island during the Quaternary (e.g. Suggate, 1965) but the main ice cover was confined to the Southern Alps and splay ranges. To the east and south of Mt Owen, ice sourced from the Nelson Lakes area (Figure 1) extended into the Buller River. These ice advances have received much attention from Suggate (1965, 1988 & 1993) who has mapped out a series of moraine limits (near the Nelson Lakes) and inferred correlations along the Buller River using terrace slopes and levels.

Evidence for glaciation in northwest Nelson was first mentioned by Dobson (1872), with more a substantial survey by Henderson (1923 & 1931). Most of this work concentrated on the Arthur Range and Tasman mountains (Figure 1) to the north. More recently, Shulmeister et al. (2001; 2005) published in depth studies of the glacial history and chronology of the Cobb Valley, in the Tasman Mountains. Work by groups from Canterbury and Victoria Universities is ongoing in the Tasman mountains and adjacent areas. Published work on the Owen Massif is sparse. Henderson (1931) inferred glaciers of about three kilometres in length draining the northern Owen massif into Nuggety and Blue creeks and ice draining from the southern half of the massif into the gorges of the Fyfe and Owen rivers. No terminal positions were identified.

Coleman (1981) briefly mentioned moraines on Mt Owen and terraces relating to the last glaciation in the Wangapeka and Owen valleys. The aggradational terraces were loosely related to two aggradational

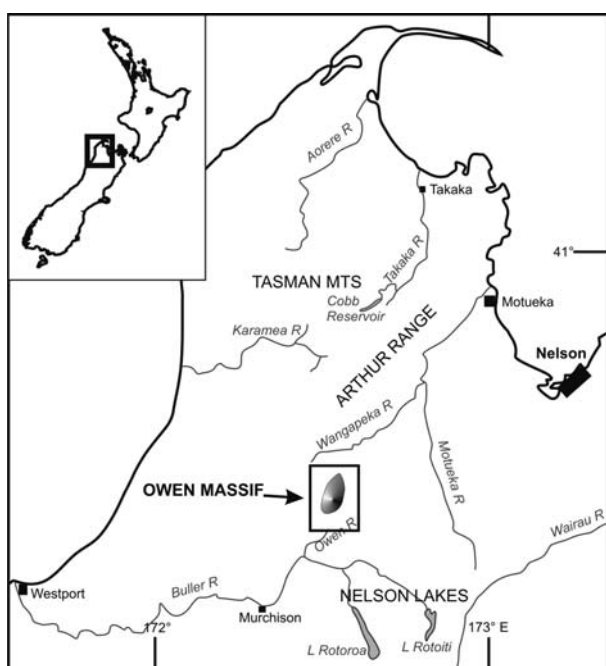


Figure 1 (left). Location of northwest Nelson and Owen Massif, with major rivers, lakes and mountain ranges in the area.

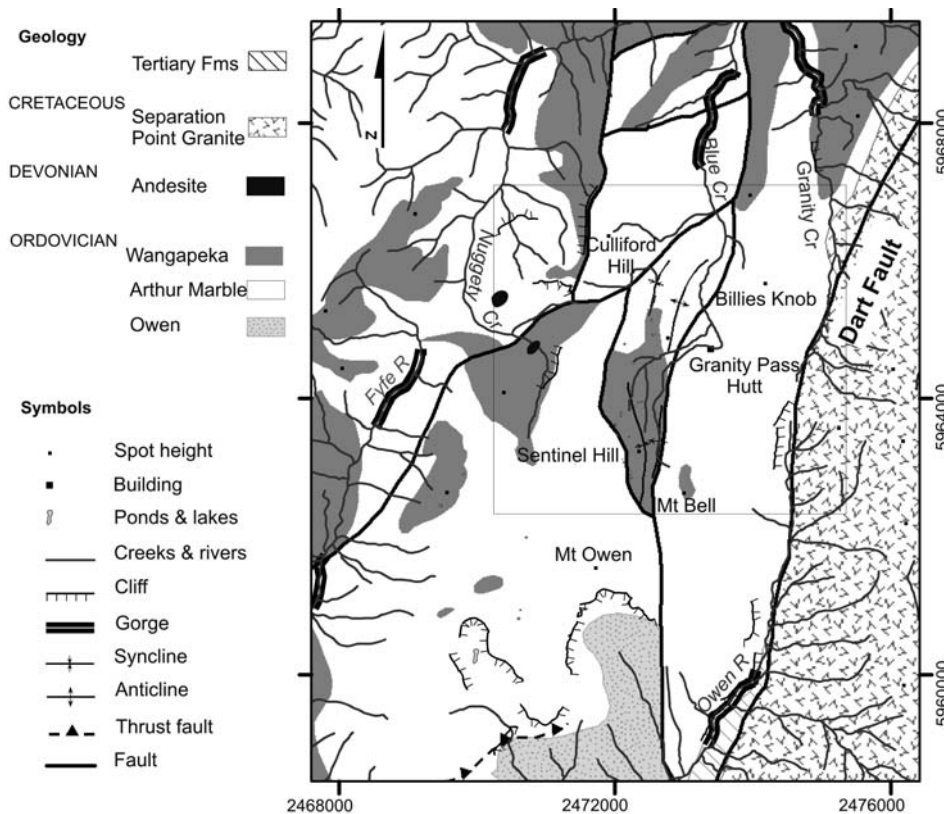


Figure 2 (left). Geology of the Owen Massif (modified from Coleman, 1981) and location of the major gorges adjacent to the massif.

Figure 3 (right). Simplified geomorphological map centered on Sanctuary Basin, with insert of the main Owen Massif landmarks.

sequences of Speargrass and Tophouse formations defined by Suggate in the Nelson Lakes area. Correlation into the upper Owen valley was tentative as Coleman could not link the moraines on the massif to the terraces in the Buller. Williams (1992) in an overview of New Zealand karst, mentions some glacial and karst landforms on the massif. A map of ice extent and location was included. He described small scale glaciation on the massif and a central ice-field in the Sentinel Hill area, which had small glaciers radiating to the north, west and east of this central accumulation zone. He also states that 'the topography of the region appears essentially freshly glacial'. In summary, the existence of glacial features on the massif is widely accepted but absence of any coherent marginal features has prevented any fuller description and interpretation.

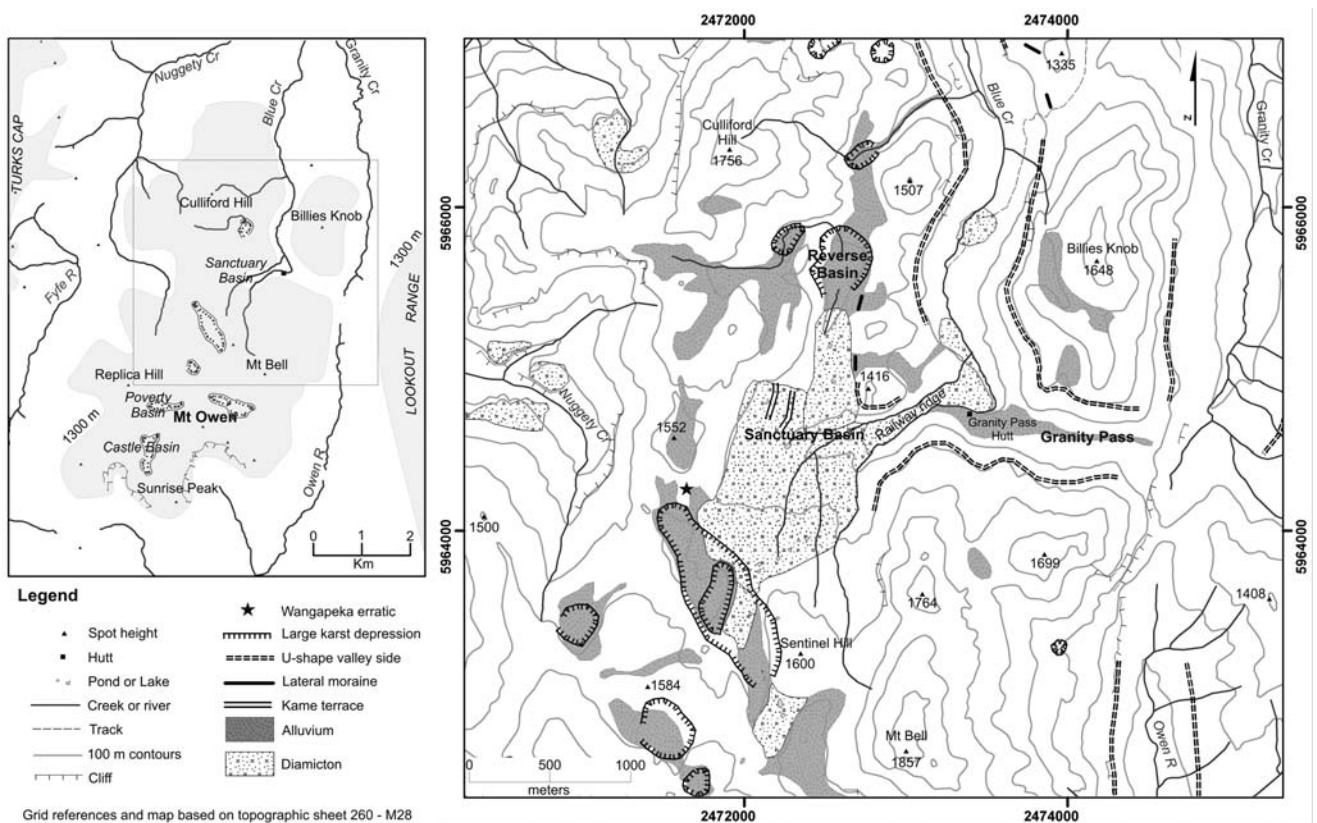
### Physiography & Geology

The Owen Massif is a raised block of marble, c. 35 square km in area, roughly 4 km wide and 9 km long aligned about a northeast–southwest axis. Most of the massif is above 1300 m and it has a number of peaks above 1700 m with three over 1800 m (Figure 3). The edges of the massif are very steep, locally vertical, and there is a 300–500 m drop to the valley floors that ring the massif. NW Nelson contains many of the oldest rocks in New Zealand and is part of the Australian plate. As such it contains extensive areas of granites, metamorphosed limestones (marbles) and volcanic meta-sediments of Palaeozoic and Mesozoic ages

(Rattenbury et al., 1998). Major faults dissect the landscape into a number of fault bounded structural slices. The Mt Owen massif is up-thrusted between the Owen and Dart faults (Coleman, 1981), both running north to northeast. The massif is composed of Takaka Terrane (Figure 2) rocks including the Owen, Arthur Marble and clastic Wangapeka Formations (Rattenbury et al., 1998).

The Owen Formation, a largely siliceous unit and outcrops on the south side of the massif (Figure 2), conformably underlies the Arthur Marble Formation (Coleman, 1981 & Rattenbury et al., 1998). The Arthur Marble Formation is primarily a light grey coarse-grained marble, with some dark siliceous sandy beds and chert nodules. It is intensely deformed, and has a thickness of about 1500 metres (Coleman, 1981). It composes most of the Owen massif (Figure 2). The Wangapeka Formation conformably overlies Arthur Marble and outcrops locally over parts of the massif (Figure 2). On the massif it is composed of laminated siliceous dark grey pyritic siltstone and lighter sandstone beds with black carbonaceous horizons and thin quartzite beds (Coleman, 1981). These clastic sediments are important as they preserve a record of glaciation more strongly than the carbonates.

The eastern side of the massif is bounded by the Dart Fault (Figure 2). To the east of the fault highly weathered Separation Point Granite outcrops as the rounded Lookout Range. The contact roughly runs along the



**Geomorphological Map of the Northern half of the Owen Massif, northwest Nelson, New Zealand**

upper valley floors of the Owen and Granity valleys (Muir et al, 1995). In addition to the Separation Point Granite in the Lookout Range, two small inliers of hornblende rich Andesite of slightly older age (Riwaka Igneous Complex) crop out on the western side of the massif itself (Figure 2).

There is extensive glacial karst including some of the longest, deepest and oldest caves in New Zealand. The surface is a classical “rundhocker” karst composed of glacially sculpted roche mountonees variously solutionally etched by a range of karren, particularly in beds of purer marble. Between ridges is a wide spectrum of dolines some over 500m in diameter. Some dolines are merely sinks for local karren fields, others are abandoned karst shafts truncated by glacial erosion, while others are choked by debris and many doline fields are developing in recent alluvial deposits that floor larger doline forms. Some dolines are aligned and may reflect geological lineaments and contacts promoting caves.

### Climate

There are few formal climate records for this area. The two closest stations are at Wangapeka (elevation 259m, decommissioned), about 16km northeast of Mt Owen and Murchison township (elevation 158m), south west of the massif (Figure 1). From 1941 to 1970 the station at Wangapeka recieved an average of 1771 mm per year, and Murchison had 1558 mm per year (NZMS, 1970). There is a strong orographic and west-east precipitation gradient in northwest Nelson. The Owen massif inter-

rupts this westerly flow and will have a much higher precipitation total due to its higher elevation. For two summers (1967/68 and 1968/69) minimum and maximum temperatures were measured intermittently by Bell (1970) at Granity Pass Hut. Daily temperatures ranged from about -1°C to 26°C. Even more limited daily readings in winter ranged from about -5 to 10°C.

### Methods

Field work was undertaken over the summers of 2004 and 2005, based largely from Granity Pass Hutt (Figure 3). Areas of the north and southwest of the massif were covered during a number of multi day trips. Glacial and karst geomorphic features were mapped at a scale of 1:30 000 on aerial photographs and the Wangapeka topographic map sheet (M28). Because of limited field time and the nature of the area not all parts of the massif were fully field checked. The majority of the glacial deposits and other substantial glacial evidence is concentrated in the northern part of the massif, which is presented here as figure 3. A glacial geomorphological map of the whole massif is presented as an appendix online ([www.aqua.org.au](http://www.aqua.org.au)).

In the field, hand specimens of rocks from inferred moraines were examined for glacial phenomena (striations, faceting etc), though outcrops were poor and sparse. Some samples from boulders on the northern flank of Sentinel Hill were recovered for cosmogenic exposure dating, though the results from this are not yet to hand.

## Results

A simplified geomorphological map (Figure 3) of the main features of the central Owen Massif is presented (and see online appendix). The major glacial features identified are U shaped valleys, rounded bedrock hills, lateral moraines, kames, hummocky ground moraines and fluvio-glacial veneers. Accessory features include erratics, and glacio-karst features dominantly suffusion dolines and glaciokarst pavements. Due to their size and quantity, dolines and glaciokarst pavements have not been included in Figure 3. These features have been divided into glacial erosional and glacial depositional groups.

### Glacial erosional landforms

U-shaped valleys, virtually box canyons, are widespread on the massif (Figure 3 and online appendix). Some of these valleys are consistent with regional N-S alignment such as Blue Creek, but others cross cut the structure, such as Granity Pass. All the U shaped valleys transition into V-shaped valleys down stream, in some cases, this is marked by gorges incised into the U shaped valley floor. The U shaped valley floor shoulders above the gorges sometimes have a cover of hummocky ground moraine. The U-shaped valleys terminate abruptly at the massif edge but a north-south aligned U shaped valley extends 1.5 km north and about 3 km south along the contact with the Separation Point Granite (Figure 2, 3 and online appendix).

Glacially smoothed hills and knolls are widespread. These occur on all scales from a few metres to many hundreds of metres in size. Bedding control is important but many of the smaller features align with the local U shaped valley systems. Knobs between Reverse Basin and Blue Creek (Figure 4 and 5,a) are the best examples of ice smoothed ridges. We do not specifically identify cirques, though several good candidates exist, because of the difficulty of separating karst basins from true cirques.

Glaciokarst pavements are dotted around the massif. They form parallel or sub-parallel to bedding and joints. Very locally glacial striations and chatter-marks are preserved on the pavements (Figure 5,b). Most of the pavements, however, have had some dissolution since formation and some display frost shattering. Excellent examples occur north of Replica Hill (E 2471130, N 5963330) and on the east side of Blue Creek (E 2473630, N 5967120), near the lateral moraine of figure 5,c.

### Glacial depositional features

Lateral moraines and kame complexes are present in internal valleys on the massif between Sanctuary Basin and Reverse Basin and north of Billies Knob (Figure 3 & 4). The composition of the kame terraces and terminal moraines is unknown, due to a lack of exposure. They

comprise ridges that flank the valleys and have a hummocky surface. The amplitude of the hummocks is in the order of a few metres.

Hummocky ground moraine (represented by diamicton in Figure 3) is present on some of the floors of the internal valleys on the massif and on some of the valley floors leading to the edge of the massif. The best known glacial feature on the massif, the so-called railway ridge near Granity Pass Hut (Figure 3, 4 and 5), is in fact remnant ground moraine dissected by drainage to create a ridge like feature. This ridge is composed of at least 15 m of diamicton with frequent striated and faceted clasts and contains Wangapeka lithologies as well as rare hornblende rich Andesites. West of the head of this feature is a series of fluvio-glacial kame terraces (Figure 3 and 4) which host a set of minor ponds a few tens of m above the valley floor. The low lying position suggests that these were associated with the very last ice occupying the valley floor.

Moderately sorted large pebble to cobble size clastics, with well-rounded, Wangapeka insoluble gravels mantle many surfaces and benches perched above valley floors (alluvium on Figure 3) indicating fluvial overflow adjacent to former glaciers (Figure 3 and 5,d). There are also some coarse cobble and gravel remnants on some sharp ridge crests (e.g. between Blue and Granity creek). Valley floor fills are more complex (Figure 6), ranging from morainic ridges dissected by streams, clastic and organic pond and channel deposits. Valley side materials and talus are also encroaching onto valley floors. Many of these deposits are now becoming pock-marked by suffusion dolines, except in areas of thick accumulation like in Poverty Basin (Figure 5,d).

Striated and faceted clasts have been collected from a matrix supported, pebble to boulder diamicton outcropping in poorly exposed, suffusion modified moraine west of Sentenal Hill. The striae in the clasts are aligned at orthogonals along the A-B plane. A single striking example of a Wangapeka erratic lodged directly onto karstified Arthur Marble has been observed at grid reference E 2471633, N 5964225 (Figure 3).

A notable absence is that of marble clasts. None have been recorded in any of the outcrops. An important question is why? Where has all the eroded marble gone?

### Other Landforms

Like many alpine karst areas, the glacial molding of Mt Owen is gradually being modified by processes of solution and suffusion that lead to re-establishment of karst. Frost shattering and mass movements are competing with these karst processes (Smart, 2004a).

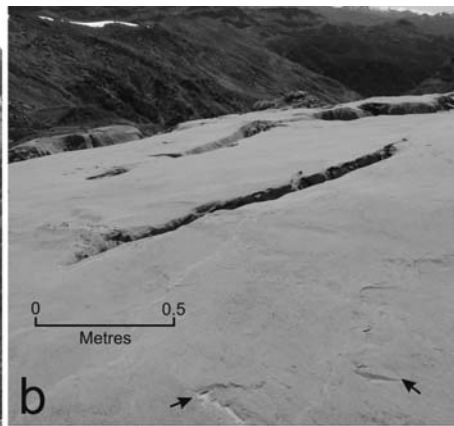
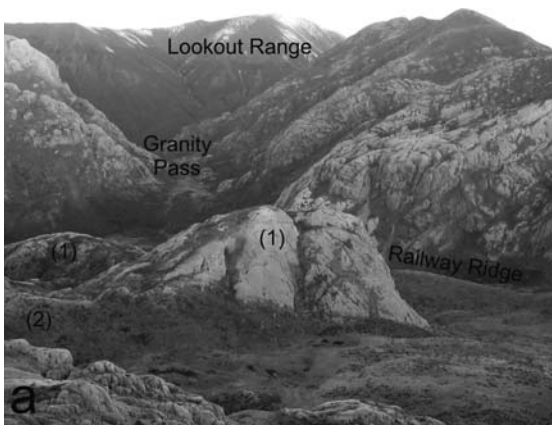
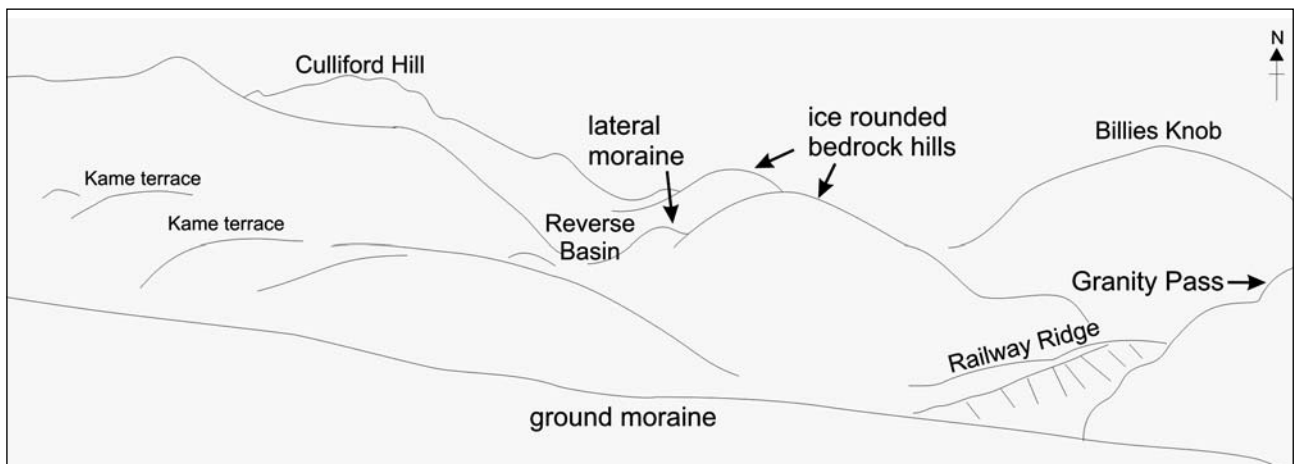


Figure 4. (above) Photo of Sanctuary Basin in foreground, with annotated landmarks of Railway Ridge, ice rounded bedrock hills, kame terraces and a lateral moraine.

Figure 5. (left) Four photos of common landforms on the massif. (a) Ice smoothed hills (1), with the largest over 120 metres high and a lateral moraine (2). (b) Glacio-karst pavement, north of Replica Hill, with Mt Patriarch in the background. Note the small indentations in to foreground marked with arrows and the truncated karren. (c) Lateral moraine (approx. 6 metres high) north of Billies Knob, with Culliford Hill in the clouds, left background. The arrow points to a half of a person for scale. (d) Poverty Basin, approximately 500 metres across, with a thick clastic fill.

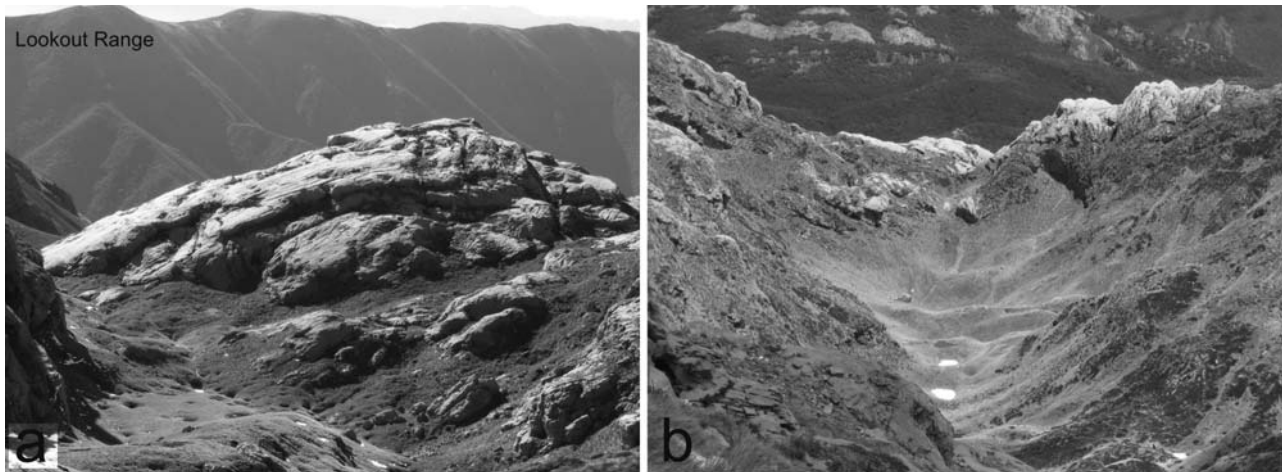


Figure 6. Two photos of common landforms on the massif. (a) A valley south of Mount Bell (left of photo) showing suffusion dolines along the valley floor in the lower and left middle ground. The ice rounded knob in the middle background is approximately 40 metres high. (b) Castle Basin a large closed depression viewed from its northern end. The valley walls range up to 160 metres high, with hummocky sediment along its base and sides, in places pocked with suffusion dolines.

## Discussion

The physiognomy of the area studied is heavily influenced by local geology and its structural characteristics. Many curious landforms like linear ridges and shear cliffs are related to structural elements (Figure 2 & 3), while the manifestation of glacial landforms depends on whether marble or clastic siltstone is the bedrock. The composition and structure of the marble also varies. The more massive and pure, the more karstic processes dominate, whereas in areas with more defects and insoluble inclusions, processes like frost shatter dominate. This composite landscape is typical of glaciated karst (Smart, 2004b).

The marked glacial sculpturing, landforms and sediments indicate that the whole of the massif was heavily glaciated during late Quaternary glaciations. Well developed cirques are present in the northwest Nelson region at elevations between 1250 and 1400 metres above sea level. These head well defined and substantial U-shaped valley forms, like those of the headwaters of the Karamea River. Given that the whole of the massif lies at 1300 m + (Figure 3 and online appendix) the massif must have been a major source of ice during pleniglacial periods.

As with any glacierised karst, there is competition between underground and surface drainage mediated largely by sediments that may choke caves. Low flows may be accommodated underground, but higher flows lead to ponding and overflow, leading to a peculiarly acute erosional flow regime. The marble, like many massive carbonates does not appear to generate large amounts of debris under glaciers, and the Wangapeka is inferred to be the primary source of the majority of clastics. The presence of fluvio-glacial deposits on

elevated benches and cols indicates that substantial ice marginal streams were operating at grade elevations well above the valley floors. These overflow streams would have been extremely erosive given their clastic load and steep gradients, and were presumably responsible for the radial gorges in the outlet valleys. Despite these general inferences, there is little apparent concordance between these sedimentary remnants, so detailed glacial reconstruction is not possible.

The elevated position of the plateau makes it likely to experience significant snow accumulations during wetter and cooler conditions. However, classical alpine cirque morphology has not developed here as it has on adjacent ranges. This implies that ice accumulation was not governed by simple altitude-governed lapse rates. The geomorphic evidence suggests that ice accumulated in the centre of the plateau and other large depressions, radiating out through resistant bedrock hills. Diminishing ice was preserved in the lower ground in the central plateau which indicates ice recession was not a retreat to higher attitude.

The existing morphology of the plateau core is dominated by the insoluble Wangapeka inlier constituting Sentinel Hill (Figure 2). Streams gathering on this area would have flowed off the hill sinking into the surrounding marble. The large (approx. 300 by 400 metres) closed depression of Reverse basin (Figure 3) was presumably the dominant sink point. This basin was apparently the focus of glaciation even though it lies hundreds of metres lower than the surrounding peaks, e.g. over 400 metres lower than Culliford Hill to the northeast (Figure 3). Where the host basin is as large and deep as that inferred on Mt Owen, a considerable

volume of ice would have accumulated before outflow to lower altitudes would have occurred. Outflow to warmer, lower altitudes is the primary mechanism by which glaciers achieve neutral mass balance. Thus Mt Owen may have accumulated an unusual thickness of ice occupying the central plateau.

Williams (1992) has inferred the presence of a number of radiating glaciers from the Sentinel Hill core. Initially these may have been numerous, lapping over every low point in the encircling divide. A number of outlet cols conveyed ice from Reverse Basin into Blue Creek (figure 3). Competition between outlets will be regulated by their ice discharge, velocity and erosion rate. The deep, steep flanked cut through Granity Pass to the Granity Creek appears to have eroded down. The Granity Pass route was finally captured by Blue Creek. This is somewhat surprising as the overall terrain gradient is not steep. This indicates significant ice accumulations in the Sanctuary Basin. Culliford Hill ice would have overflowed into an occupied Blue creek, forcing Sentinel Hill ice out into Granity creek. Under late glacial conditions, ice no longer flowed directly into Blue Creek from Culliford Hill and the Granity lobe reverted down Blue Creek. Sanctuary Basin was the last point of conspicuous ice on the northern part of the plateau as is indicated by the low lying ice contact deposits.

There are significant morphological incompatibilities between the land surface and presumed ice flow: deeply incised valleys such as Blue Creek and closed depressions such as Poverty Basin and Castle Basin (Figure 3, 6 and online appendix). Ice flow is primarily controlled by surface gradient, so basal slope means that ice cannot readily flow through closed depressions. However, sediment fills adjacent to these depressions indicate that there were occupied by sediment subsequently swallowed by the underlying karst.

This sediment fill concept is readily transferred to radial valleys where incision slots can be occupied by sediment during ice advances, and re-excavated on retreat. The Railway ridge is inferred to be a fill occupying the head of Blue Creek when ice flow was focused through Granity Pass. Off the plateau, post-glacial erosion of steep slopes and dense forest cover make detailed mapping of outlet valleys difficult. The radial valleys were occupied by glaciers with very large gross mass balances (massive accumulation of  $1\text{--}5\text{m.m}^2.\text{a}^{-1}$  and mean annual temperature of  $+5^{\circ}\text{--}+10^{\circ}\text{C}$ ). Such ice is unlikely to have well defined stable termini and would be dominated by sandurs (in valleys) and alluvial fans (at outlets). Most of the glacial evidence in the engorged valleys was probably destroyed by fluvial processes (floods) during the deglaciation.

The style of glaciation inferred here diverges from that in other parts of north-west Nelson. In Cobb Valley, a full

suite of valley glacier phenomena are recorded including a large sequence of terminal moraines and numerous lateral moraines and roche mountonee fields (Shulmeister et al., 2001). On the Owen Massif the evidence is much more fragmentary, largely because karst processes have modified or destroyed much of the evidence.

Provenance analysis is quite revealing. The Wangapeka clasts found in the Railway ridge crop out near Sentinel Hill while the clasts of andesite should come from the only known outcrop which is 3–4 kilometres west of Granity Pass. The Wangapeka clasts imply that ice flow into Granity Pass was sourced from the major peaks to the south of the Pass and, rather more surprisingly, the andesite requires eastward flowing ice derived from the very western most limits of the massif. This not feasible if ice flows were minor and implies either a) that other unmapped outcrops of the Andesite occur on the massif or b) that reversals of ice flow occurred at times of substantial ice cover. We cannot discriminate between these hypotheses based on our data. We conclude that ice flows involved at least two stages. During the early stages of advances ice flowed into the basins on the massif. As ice built up in the basins, divides were overtopped, flows locally reversed and a small ice cap developed over the massif, directing flow off the massif in a roughly radial pattern.

The four main rivers (Granity, Nuggety, Fyfe and Owen) that drain the massif flow through at least one deep gorge within a few kilometres after leaving the massif (Figure 2 & 3). There are inset V-shape profiles in U-shape valleys. These are represented by terraces above or on top of gorges. This V in U topography has been noted elsewhere in northwest Nelson (Henderson, 1931 and Shulmeister et al., 2005) and was inferred by Henderson to indicate an earlier, much larger glacial phase. In order for a V-shaped profile to develop within the U there are two possibilities. The first, as per Henderson, is that the U-shaped valleys have not been extensively occupied by ice during recent glaciations which suggests that the scale of glaciation is diminishing in NW Nelson. Since this area was more tectonically active during the early Quaternary, such an inference is reasonable. However, an alternative hypothesis that the V's are either filled with ice, or more likely aggradation gravels during glacial advances, and that active ice may over-run an occupied V-shaped valley without eroding the V out. This model has been proposed on the European Alps (De Graaf, 1996).

## Conclusions

The weight of evidence suggests that the whole of the Owen Massif was an ice accumulation zone at times during previous glaciations. We infer that accumulation was focused on pre-existing karst closed drainages and accumulated as a central ice body until ice overflowed

into adjacent valleys. There is little direct evidence of glacial maxima as U shaped valleys quickly become incised and there are no marginal or terminal deposits identified in the valleys off the massif. It is inferred that the outlet glaciers headed extremely active river systems. During advances the valleys became filled with outwash gravels now preserved as terrace remnants far downstream, while on retreat the valleys were rapidly incised removing the valley fill. Further work is needed to define the ice limits, although the prospects for locating key features are not promising.

The glacial-karst morphology and process suite were quite distinct from those on surrounding non-karst landscapes. The closed depressions appear to have promoted ice accumulation and outlets have competed for dominance. The role of ice versus fluvial-glacial erosion remains equivocal, as there is very poor surface preservation and outcrops of glacial deposits. It is expected that the best long-term archive will be preserved in caves under the massif. A combined surface and sub-surface investigation is the only likely way of determining the glacial history more detailed than presented here.

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# Late Pleistocene environments in the Flinders Ranges, Australia: Preliminary evidence from microfossils and stable isotopes

Peter Glasby, Martin A.J. Williams, David M. McKirdy, Rex Symonds, Allan R. Chivas

Peter Glasby, David M. McKirdy: Geology & Geophysics, School of Earth & Environmental Sciences, University of Adelaide, Adelaide, SA 5005

Martin A.J. Williams: Geographical & Environmental Studies, School of Social Sciences, University of Adelaide, Adelaide, SA 5005.

Rex Symonds: Darwin High School, Darwin, NT 8000

Allan R. Chivas School of Earth Sciences, University of Wollongong, Wollongong, NSW 2500

Corresponding author: [pglasby@picknowl.com.au](mailto:pglasby@picknowl.com.au)

## Summary

A spectacular eight-metre vertical outcrop of flat-lying Late Pleistocene non-marine silts and clays forms the northern bank of Brachina Creek at the eastern entrance to Brachina Gorge in the now semi-arid Flinders Ranges of South Australia. Deposited between ~35 and ~18 ka, these wetland sediments therefore encompass the Last Glacial Maximum (LGM,  $21 \pm 3$  ka) which was a time of colder, drier climate throughout Australia. Quantitative analysis of the microfauna in fifteen bulk sediment samples indicates a fluctuating freshwater environment and reveals a hiatus between the lower and upper parts of the section. The lower massive clay unit was laid down during a period of climatic stability and has a diverse assemblage of ostracods and molluscs, comprising both free-swimming and benthic forms. Faunal diversity decreases in the laminated silty sediments above the hiatus; fossil numbers fluctuate more markedly and shell fragments are more abundant, suggesting a somewhat more energetic and less stable environment. Carbon and oxygen isotope analyses show comparable values for co-deposited molluscs and ostracods, both indicating a fresh water regime.

The locality provided a moist refuge during a time of extreme regional aridity. The environmental perturbations recorded in its sediments are relevant to the wider investigation of global climate change during the LGM and immediately prior to the Holocene.

## Introduction

Aquatic microfossils have been used extensively as indicators of past fluvial or lacustrine environments (Holmes, 2001; Miller and Tevesz, 2001). Two different approaches are commonly employed. First, the fossil assemblage and the size distribution of individuals within a given species can help distinguish high and low energy settings (Holmes, 2001). Second, the stable isotopic composition and trace element geochemistry of calcareous shells provide a quantitative record of the temperature and salinity of the aquatic environments in which the parent fauna lived (Ito, 2001).

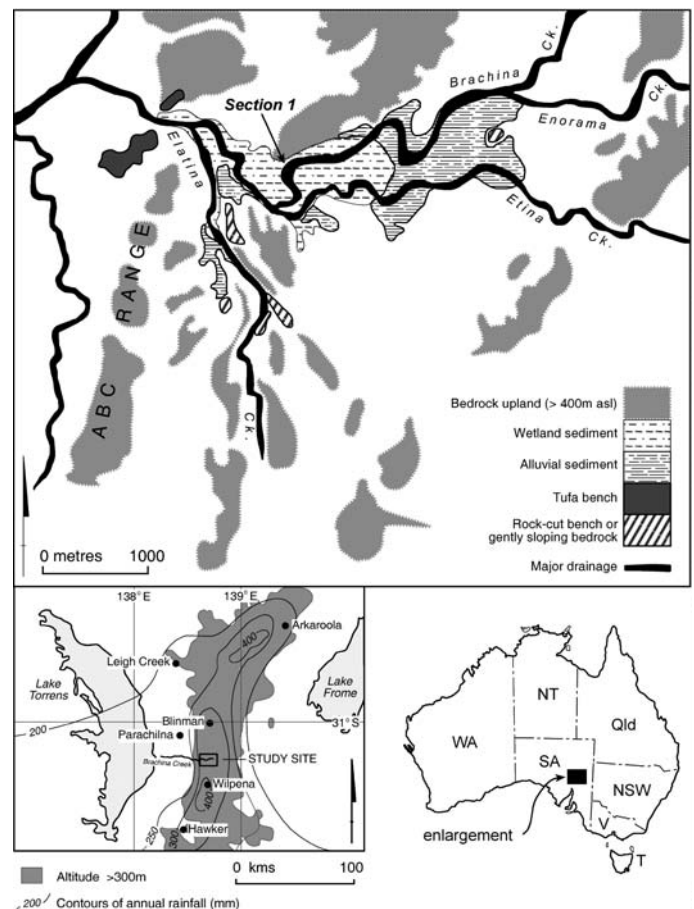


Figure 1. Map showing location of Section 1 in the central Flinders Ranges, South Australia.

The Flinders Ranges extend approximately 400 km north-south between 30°S and 33°S, along a mean meridian of 138.5°E (Figure 1). They rise abruptly 600 m above the level of the adjacent plains to the west, the east, and the north. These plains are arid lowlands covered by gibber (stony desert), fields of longitudinal sand dunes and salinas intersected by mainly ephemeral drainage channels that ultimately discharge into Lake Torrens, Lake Eyre and Lake Frome (Twidale, 1996; Williams et al., 2006). The Ranges are best known for their thick succession of weakly metamorphosed,

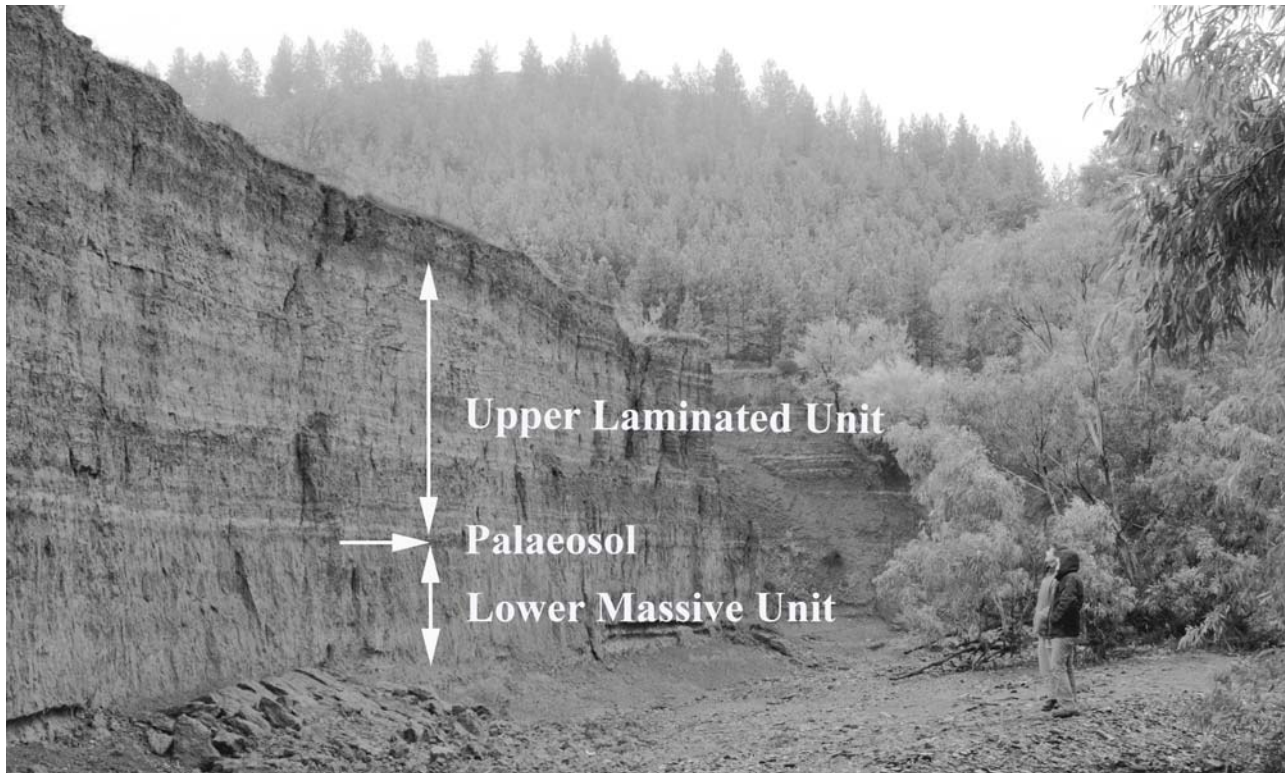


Figure 2. Photograph of the Slippery Dip locality showing the lower massive unit, the palaeosol, and the upper laminated unit.

uplifted and folded Neoproterozoic to Cambrian rocks (Lemon, 1996). However, overlying these older rocks in places is a thin cover of Quaternary sediments which have drawn the interest of various researchers (Singh, 1981; Williams, 1973) because they contain evidence of past climate change and its role in landscape evolution. The succession of sediments that is the focus of this paper (Section 1, Figure 2) is located within a topographic low of the central Flinders Ranges near the eastern entrance to Brachina Gorge (Figure 1). Known locally as the ‘Slippery Dip’ site, it comprises a 8 m-high vertical outcrop of flat-lying Late Pleistocene sediments. At this location, these grey, very thinly bedded, slightly calcareous sediments unconformably overlie the Proterozoic Brachina Formation. Dalgarno and Johnson (1965) proposed a lacustrine origin for these younger sediments. This interpretation was followed by Symonds (1987), who made the first palaeolimnological investigation of the site focusing on its ostracod and mollusc faunas, but did so without a chronology for the section.

By the late 1990s the deposits were still regarded as lacustrine deposits, of interest because of their potential for integrating information about Pleistocene environments (Cock et al., 1999).

Cock et al. (1999) were the first to obtain radiocarbon ( $^{14}\text{C}$ ) ages (gastropod and charcoal) for the sediments and called them Late Pleistocene valley-fill. They dated the Slippery Dip section and a second section ~300 m to the south and ~500 m above the confluence of Brachina Creek and Etina Creek. Williams et al. (2001) obtained additional  $^{14}\text{C}$  ages from both sections and a suite of six OSL ages from the SD site. The OSL ages were consistent with the  $^{14}\text{C}$  dates.

### Table 1: Revised $^{14}\text{C}$ Ages for Section 1

Williams et al. (2001) further investigated and surveyed the Brachina valley fill sediments, concluding that the deposits are those of a fluvial wetland system, not a lake. The valley-fill therefore covers the time interval of  $21 \pm 3$  ka defined by Bard (1999) as the age range of the Last Glacial Maximum (LGM), as well as the climatic events leading up to the LGM and the events of the ensuing deglacial. The palaeosol (P) marks a possibly brief and still poorly dated depositional hiatus and signifies a change in depositional regime at the SD site.

### Aim

The aim of this paper is to test the hypothesis that the massive lower unit was laid down under relatively humid conditions and the upper finely bedded unit under drier conditions punctuated by events such as overbank floods that caused the repeated deposition of thin beds.

Lab Number	Measured Radiocarbon Age (yr BP)	Calibrated Age (cal yr BP)	Depth (m)	Material Dated
Beta-96169	16150±80	19336±86	1.45	shell
Beta-96168	16200±80	19373±70	1.75	shell
Beta-96167	17070±70	20256±45	2.20	shell
Beta-96170	20650±80	24840±177	4.80	shell
Beta-96679	29080±180	34045±456	5.95	charcoal
Beta-96166	28120±160	32824±151	5.95	shell

Table 1: Revised  $^{14}\text{C}$  Ages for Section 1.

The revised ages were calibrated using the package from Fairbanks et al. (2005).

The locations of the dating samples on the section are shown in Figure 3.

## Materials and Methods

Bulk sediment samples were collected from Section 1. Several attempts to recover spores and pollen from these sediments proved unsuccessful. Thus, the data reported herein pertain only to the Ostracoda and Mollusca, and the carbon and oxygen isotopic composition of their respective carbonate valves and shells. At 360 cm above the base of the exposed section (Figures 2 and 3), a dark grey-brown palaeosol separates the vertical section into two units, namely, a laminated clayey silt upper unit and a lower more massive and homogenous silty clay unit. For the purposes of the present study, ten roughly even spaced (7–18 cm) samples were taken from the lower unit and five samples from the upper unit.

Subsamples of 40 g were soaked in 3% hydrogen peroxide solution for up to 3 days to remove the labile organic matter. When effervescence ceased, the residues were washed over a 90µm sieve. The retained sediments were oven dried at 60°C and set aside for microscopic examination. Using standard micropalaeontological procedures, fossil ostracods (single valves), rare charophyte oogonia and gastropods were extracted, identified and counted.

Stable isotope analysis of selected, weighed and cleaned ostracod and mollusc tests was carried out in the School of Earth Sciences, Wollongong University, under the direction of Professor Allan Chivas. The results are reported relative to the V-PDB standard and have a precision of better than  $\pm 0.02\text{‰}$  for both  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$ . (Chivas et al. 2002).

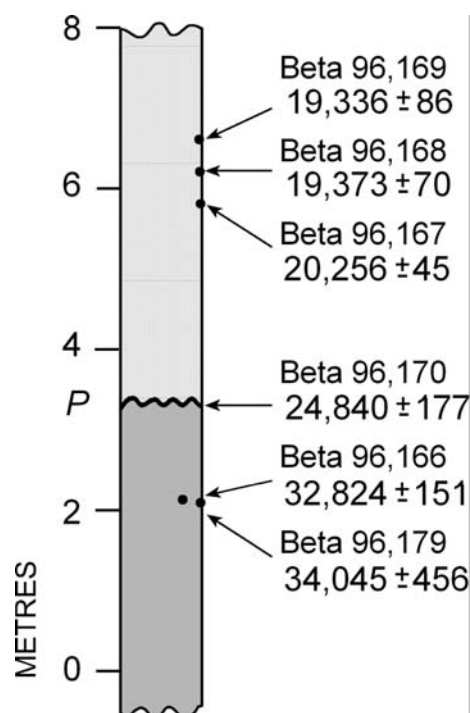


Figure 3. Section 1 of late Pleistocene sediments at the Slippery Dip locality (composite section after Williams et al., 2001). Dates shown are calibrated  $^{14}\text{C}$  AMS ages.

Table 2. Changes in the diversity and frequency of ostracods and mollusca with depth in Section 1 at the Slippery Dip locality in Brachina Gorge, central Flinders Ranges. The numbers represent the counted frequency of shells, mollusca and charophyte oogonia.

Original Sample Name	Av. Sample Height above Base (cm)	Ostracod Fragments	New Genus	Gomphocythere sp.	Cypretta sp.	Gomphodella maia	Candanoecypis novaezealandiae(adult)	Candanoecypis novaezealandiae(juv)	Ilyodromus viridulus	Mesocypus	Darwinula sp.	Lymnocythere mowbrayensis	Candonids	TOTAL OSTRACOD FRAGMENTS	Charophyte oogonia	Austropyrgus sp. (Hydrobiidae)	Unknown sp.	(Hydrobiidae) Juvenile stages mixed.	Charopidae sp.	Mollusc Fragments	TOTAL MOLLUSC FRAGMENTS
BG15	593	400		2		4	8	85	2	3	70			574			10			400	410
BG 14	520.5		2		1	1	2				1	1		8							0
BG 13	452.5	100	2		8	21	20	3			10	34		198							0
BG 12	413	100		5				80			60	1		246			3			100	103
BG 11	387	400					15	300			105			820				12		5	17
BG 1	359.5	5					4				1			10							0
BG 2	336	40						4			35	6	2	87		8		9	1	20	38
BG 3	302	3						2				6	1	12		2		5	1	3	11
BG 4	271.5	6	3		1		2	3				3	2	20		3		6	1	2	12
BG 5	232	3	1	2		3	1						4	14		5		14		5	24
BG 6	202	150	22	27	14	30	9	59	5		8	30	2	356		12		25	2		39
BG 7	137	70	30	40	17	17		27			2	11	17	231		1		8	2	20	31
BG 8	99	200	12	30	42	21	30	60			34	8	23	460				30		20	50
BG 9	62	20	10	9	10	23	1	13			2	2		90	1	2		8	3	30	43
BG 10	3.5	100	3	1		7	5	16			2	7	5	146				2		40	42

## Results

### Microfossils

The quantitative yields of ostracods and molluscs (fragments and intact shells) recovered from outcrop samples of the Slippery Dip section are presented in Table 2 and Figure 4 (overleaf). (Photomicrographs of representative fauna are shown in Plates 1 (ostracods) and 2 (molluscs), available online at: [www.aqua.org.au](http://www.aqua.org.au))

Throughout the lower 202 cm of the section there is an abundance and diversity of microfossils, both ostracods and molluscs, although there does seem to be a slight increase in diversity of mollusca between 202 and 338 cm above its base (*Austropyrgus* sp. adults become more numerous). This diversification coincides with a marked drop-off in ostracod species diversity. Nine species of ostracods are identified here, including one that is apparently new.

The mollusca in the lower unit belong mainly to the gastropod family Hydrobiidae. In addition, there are rare specimens of the land snail family Charopidae. The zone of least diversity is just below the palaeosol. Above this level, there is a gradual increase in microfossil abundance. Fossils in the thinly bedded upper unit above the palaeosol are less well preserved and more fragmented than those below.

### Ostracods

(Plate 1: see [www.aqua.org.au](http://www.aqua.org.au))

Candonids (possibly *Candonopsis* sp. or *Candonopsis tenuis*). *Candonopsis tenuis*: is only known as a freshwater form (De Deckker, 1982a).

*Candonocypris novaezelandiae*: a freshwater, benthic species common in farm dams and eutrophic water bodies; often found grazing on decaying vegetable debris and black organic-rich mud; adults have not been observed to swim, in contrast to juveniles, which are good swimmers (De Deckker, 1981a, 1982c).

*Cypretta* sp.: good swimmer in freshwater, including slowly flowing river; uncommon in temporary pools (De Deckker, 1982a).

*Darwinula* sp.: found mostly in freshwater, but are also fairly tolerant of a wide range of conditions; their eggs cannot tolerate desiccation such that their presence indicates a permanent water body (De Deckker, 1982a; Yilmaz and Külköylüo lu., 2006). The *Darwinula* of this locality are similar to the type described by De Deckker (1982a) from Tasmania.

*Gomphocythere* sp.: potentially a new ostracod genus or species (P. De Deckker, pers. com.). Park and Martens (2001) have described a similar extant form from Lake Tanganyika. The new endemic species there has been

named *Gomphocythere woutersi* and was collected from a water depth of 18 m on a sandy substrate. It is characterised by the pitted tubercle ornamentation on its valves. As no species like it, either extant or extinct, has been described in Australia, its value as a paleo-environmental indicator is uncertain. It is interesting to note, however, that its occurrence along the section parallels that of *Gomphocythere* sp.

*Gomphodella maia*: presence generally indicates permanent water conditions, although it is possible that they burrow in sediment during times of desiccation; they require permanent water to reproduce. De Deckker (1980, 1981c, 1982a,b).

*Ilyodromus viridulus*: considered a freshwater species and has never been found in brackish waters (De Deckker, 1982c). Most *Ilyodromus* species in Australia are freshwater forms that favour organic-rich sediments as substrates (De Deckker, 1982b).

*Lymnocythere mowbrayensis*: a benthic species still extant in South Australia (De Deckker, 1981b). It cannot swim and is usually found crawling among filamentous algae in permanent fresh water, but can tolerate waters of up to 6% salinity in ephemeral locations (De Deckker, 1981b, 1982b).

*Mesocypris* sp.: taxonomy of this form is uncertain but this genus is found in slow flowing fresh waters and swampy areas (De Deckker, 1982a).

### Mollusca

(Plate 2: see [www.aqua.org.au](http://www.aqua.org.au))

The main molluscs identified in this section belong to two families of gastropods, the Hydrobiidae and the Charopidae.

*Austropyrgus* sp. seems to be the most prominent species of Hydrobiidae, with both adult and juvenile forms present. Extant examples live mainly in streams and springs, including those of the Flinders Ranges. It needs permanent water.

A second new genus or species of gastropod also seems to be present in the section. It looks like a living phreatic species from the Flinders Ranges, presently being described by Dr Winston Ponder at the Australian Museum, Sydney. What it indicates about the environment is still unknown.

A few unassigned examples of the Charopidae were identified. These are native land snails associated with damp vegetation (W.F. Ponder, pers. comm.).

Bulk sample	Interval from Base	Sub sample ID	Mean height from base	Ostracod		Mollusc		Mean		n	Genus	Description
BG-	cm	PGI-	cm	del13C	del18O	del13C	del18O	del13C	del18O			
15	587-599	15F	593	-8.9	-2.2			-8.9	-2.2	1	Candanocypris	5 small & 5 large valves, 10 fragments
12	409-417	12F	413	-4.8	-1.6			-6.5	-2.6	4	Candanocypris	16 juvenile valves
		12Dia	413			-9.5	-3.5					1 fragment
		12Dib	413			-7.3	-3.2					2 fragments
		12Dic	413			-8.4	-2.0					1 fragment
11	382-292	11F	387	-8.3	-2.9			-7.9	-2.8	3	Candanocypris	8 adult valves
		11Di	387			-7.7	-2.7					3 fragments
		11G	387	-7.7	-2.9						Darwinula	25 valves
	352-367	palaeosol	360									
2	327-345	2Di	336			-9.0	-3.2	-8.7	-3.3	3	Angrobia	1 fragment
		2Dii	336			-8.5	-3.0					4 shells, dirty inside
		2G	336	-8.6	-3.4						Darwinula	18 valves
3	296-308	3Di	302			-6.1	-3.2	-6.6	-3.1	2		2 shells, dirty
		3Dii	302			-7.1	-3.0					4 shells
4	267-276	4Di	271.5			-8.1	-1.4	-7.6	-2.3	2		2 fragments
		4Dii	271.5			-7.1	-3.1					5 shells
5	227-237	5Di	232			-11.3	-3.0	-8.9	-3.3	3		2 fragments
		5Dii	232			-8.3	-2.7					1 large & 2 small shells, dirty inside
		5F	232	-7.0	-4.1						Candanocypris	1 adult valve
6	197-207	6Fi	202	-7.7	-2.2			-8.3	-2.7	10	Candanocypris	2 adult valves
		6Fii	202	-8.6	-3.0						Candanocypris	1 adult valve
		6Fiii	202	-8.3	-2.2						Candanocypris	4 juvenile valves
		6Fiv	202	-7.5	-2.0						Candanocypris	5 juvenile valves
		6H	202	-10.4	-3.5						Lymnocythere	15 valves
		6Dia	202			-8.6	-1.4					1 medium shell
		6Dib	202			-8.2	-2.7					1 medium shell
		6Dic	202			-8.3	-2.6					1 medium shell
		6DIIa	202			-8.5	-3.2					1 small shell with sediment inside
		6DiiB	202			-7.7	-3.9					1 small shell with sediment inside
		6Diic	202			-7.0	-2.7					1 small shell with sediment inside
7		7Di	137			-8.7	-3.1	-8.0	-3.5	2		2 fragments of large shell
		7Dii	137			-7.2	-3.8					7 small shells
8		8F	99	-8.9	-2.4			-8.0	-2.8	4	Candanocypris	2 valves
		8I	99	-6.9	-3.3							7 valves
		8Di	99			-8.5	-3.0					1 fragment
		8Dii	99			-7.7	-2.6					7 small shells
9		9Dia	62			-8.1	-4.3	-7.6	-4.0	4		1 fragment
		9Dic	62			-7.4	-4.4					1 fragment
		9Dii	62			-7.3	-3.9					4 fragments
		9F	62	-7.6	-3.4							13 juveniles & fragments
10		10Dia	3.5			-7.6	-4.3	-7.5	-2.9	4		1 fragment
		10Dib	3.5			-6.3	0.8					1 fragment
		10Dic	3.5			-8.4	-4.4					1 fragment
		10F	3.5	-7.7	-3.7							5 adult fragments & 11 juveniles

Table 3. Stable isotopic composition of ostracod valves and mollusc shells in Section 1 at the Slippery Dip locality in Brachina Gorge, central Flinders Ranges.

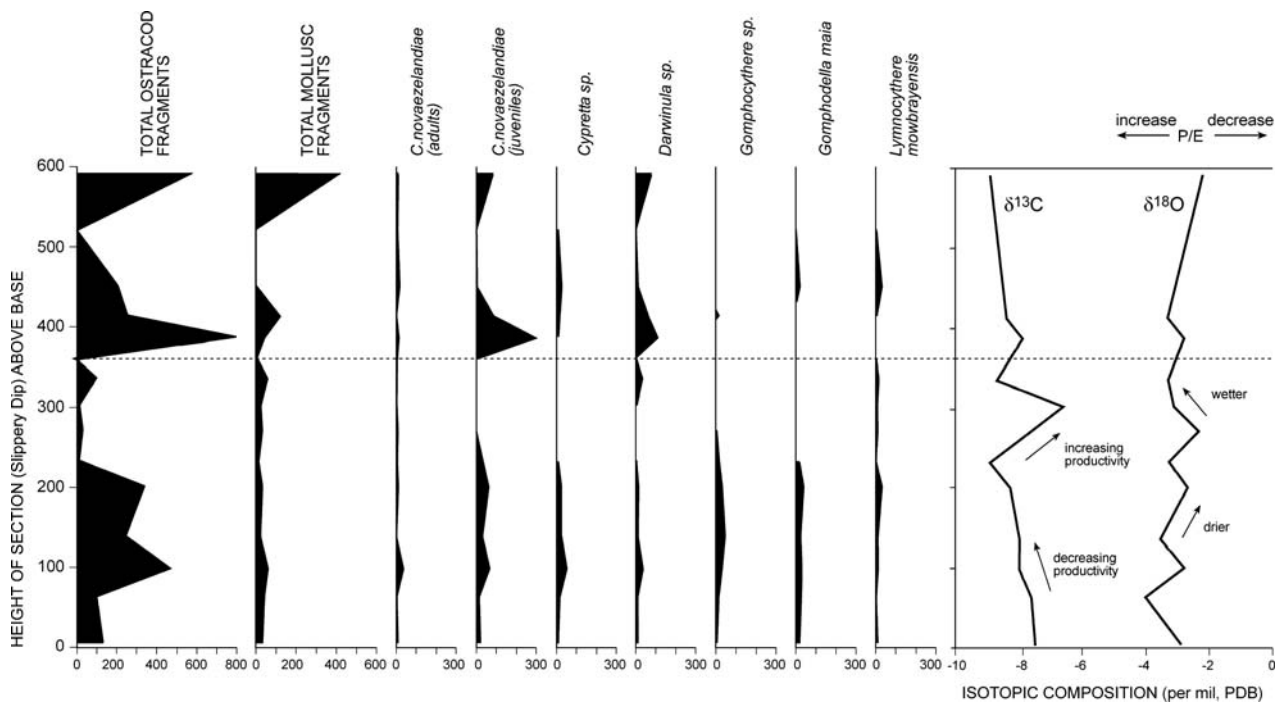


Figure 4. Ostracod, mollusc and stable isotope profiles of Section 1 at the Slippy Dip locality, Brachina Gorge, central Flinders Ranges. Dotted line marks position of palaeosol.

## Carbon and oxygen isotopic signatures

The results of the stable isotopic analysis of ostracod valves and mollusc shells recovered from Section 1 at the Slippy Dip locality are presented in Table 3 and plotted in Figures 4 and 5.

The two microfossil populations have broadly similar carbon and oxygen isotopic signatures (Figure 5), which in turn are typical of freshwater limestones (Hudson, 1977). In samples from which multiple specimens of ostracods and/or molluscs were analysed, each phylum for the most part is both isotopically uniform and indistinguishable from the other. This phenomenon of isotopic congruence is best illustrated by the eleven sub-samples from 207–197 cm height in the section (Table 3). The mean values for their two populations are as follows: ostracod  $\delta^{13}\text{C} = -8.5 \pm 1.2\text{‰}$ ,  $\delta^{18}\text{O} = -2.6 \pm 0.6\text{‰}$  ( $n = 5$ ); and mollusc  $\delta^{13}\text{C} = -8.1 \pm 0.6\text{‰}$ ,  $\delta^{18}\text{O} = -2.8 \pm 0.8\text{‰}$  ( $n = 6$ ). There is one notable instance where this isotopic uniformity does not prevail. The ostracod sub-sample from 417–409 cm comprises solely juvenile *Candonocypris novaezealandiae*, which are markedly heavier ( $\delta^{13}\text{C} = -4.8\text{‰}$ ,  $\delta^{18}\text{O} = -1.6\text{‰}$ ) than the shell fragments in the mollusc sub-samples ( $n = 3$ ) from the same interval ( $\delta^{13}\text{C} = -8.4 \pm 1.1\text{‰}$ ,  $\delta^{18}\text{O} = -3.3 \pm 0.8\text{‰}$ ). Accordingly, data on the aforementioned ostracod sample were omitted when calculating the average isotopic values of this sample interval.

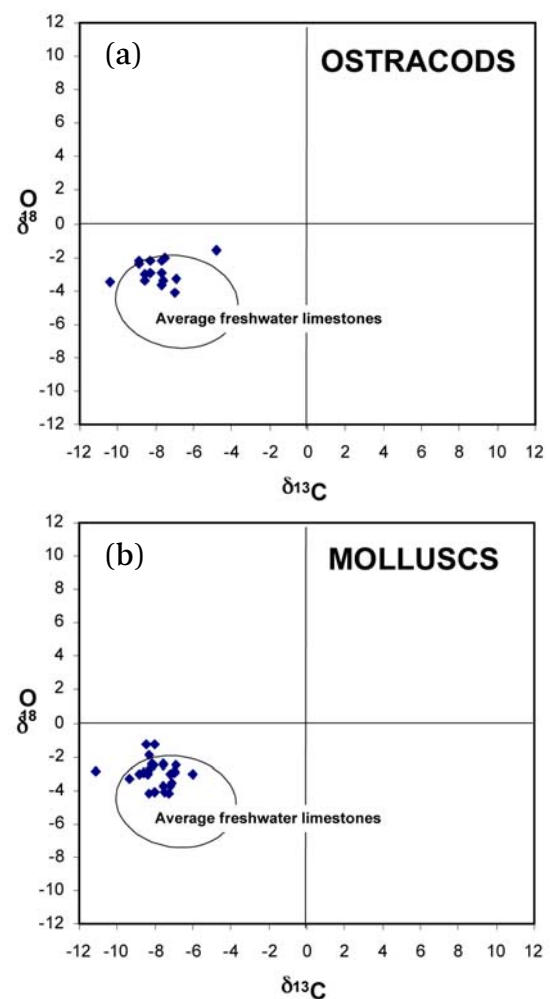


Figure 5. Plot of  $\delta^{18}\text{O}$  against  $\delta^{13}\text{C}$  for calcareous microfossils (a: ostracods; b: molluscs) from Section 1 at the Slippy Dip locality, Brachina Gorge, central Flinders Ranges. Field for average freshwater limestones is taken from Hudson (1975).

The carbon and oxygen isotopic profiles of Section 1 (Figures 4 and 5) are based on the average values of each sample interval. These profiles show that overall  $\delta^{13}\text{C}$  decreases upwards through the section from  $-7.5\text{‰}$  at the base to  $-9\text{‰}$  at the top, although there is a prominent but short-lived ( $\sim 1$  ka) positive excursion within the upper half of the lower unit. In contrast,  $\delta^{18}\text{O}$  oscillates between  $-4$  and  $-2\text{‰}$  through the lower unit before climbing from  $-3$  to  $-2\text{‰}$  through the upper unit. The apparent regular oscillation of the oxygen isotope data may well be an artefact of the sample interval and should be treated with caution until more high resolution sampling can be done. The profiles highlight a weak inverse relationship between the two parameters. The difference in overall slope of the profiles, and their contrasting fine structure, suggest subtle changes in the freshwater setting in which these sediments accumulated. Secular changes in the ratio of precipitation to evaporation (P/E) will be reflected in  $\delta^{18}\text{O}$ , whereas the  $\delta^{13}\text{C}$  values are more likely to have been influenced by variations in productivity, as demonstrated by, for example, the record of Late Quaternary environmental change in Lake Pamvotis, Greece (Frogley *et al.*, 2001). The significance of the trends and patterns evident in Figure 4, particularly when coupled with the microfaunal data, are discussed below.

### Palaeoenvironmental Implications

The lower unit, from about 60 cm to 230 cm above the base, contains diverse and abundant microfauna. The ostracods include free swimmers such as *Cypretta* sp. and benthic species that normally do not swim but crawl on the substrate or on vegetation growing beneath the water (*Candonocypris novaezelandiae*, *Gomphodella maia*, *Lymnocythere mowbrayensis*). All these taxa live in freshwater environments, although some can tolerate slight levels of salinity (*L. mowbrayensis*). Some of them require permanent water for breeding (*Darwinula* sp., *L. mowbrayensis*). *Gomphadella maia* is thought to inhabit permanent pools but De Deckker (1982b) suggests that it may burrow into sediment when the ponds dry out. Also present in the deposits are freshwater phreatic gastropods from the Family Hydrobiidae that are found in streams and springs, as well as land gastropods, from the Family Charopidae, which frequent damp vegetation. This indicates a stable, humid regime with a diversity of wetland habitats including streams, ponds and swamps. The stable isotope data (Figures 4 and 5) suggest a somewhat different setting at Brachina Gorge prior to the LGM. Rather than the climate being uniformly humid, the oxygen isotope profile indicates a regular oscillation between wetter and drier conditions. The amplitude of this apparent fluctuation in P/E ratio is relatively constant throughout the interval in question, although its periodicity shortens up the section (see calibrated ages in Figure 3). The carbon

isotope profile shows that this change of climate was accompanied by a steady decline in productivity of the wetland. This preliminary interpretation awaits confirmation by higher resolution sampling and analysis.

The upper part of the lower unit, from about 230 cm to 360 cm above the base, shows a general decline in microfossil diversity and abundance. *Darwinula* sp., a fairly cosmopolitan species but requiring permanent water, disappears while small numbers of *Lymnocythere mowbrayensis* persist along with *Candonocypris novaezelandiae*. Both these species are benthic and indicate that the wetland was possibly contracting into small ephemeral pools that partially dry out and are fed by seepages from ground water. The free-swimming conditions favoured by *Cypretta* sp. seems to no longer have been available. A drying trend is certainly evident in the oxygen isotope profile between 230 cm and 275 cm, although a return to wetter conditions is indicated through the remainder of the upper unit (Figure 4). These changes overlap the short-lived positive excursion in  $\delta^{13}\text{C}$  that, in lacustrine settings, would normally be attributed to enhanced primary productivity of aquatic algae.

In this same interval there is an increase in the numbers of *Austropyrgus* that is not as well represented in the lower part of the section, while other Hydrobiid gastropods (including juveniles), which are not yet specifically identified, are more abundant. More will need to be found out about this gastropod group to understand the meaning of this difference. The regional taxonomy and ecology of this group is currently being studied (Clark *et al.*, 2003).

A sharp change in the physical character of the deposits occurs at the palaeosol horizon (Williams *et al.*, 2001) (Figures 2 and 3). The microfossil population changes across this boundary in three ways. First, the total number of ostracod and mollusc fragments increases dramatically (Figure 4). Second, the diversity of the ostracods drops to about three varieties (juvenile *Candonopsid* varieties, which are difficult to identify, and *Darwinula* sp.). Interestingly, the juvenile forms of *C. novaezelandiae*, unlike the adult forms, are good swimmers. This is an indication that more permanent water was available again. *Lymnocythere* numbers drop at this stage and those of *Darwinula* sp. increase. Between 450 cm and 520 cm above base of the section there is a drop in *Darwinula* sp. numbers and an increase in the numbers of both *Gomphadella maia* and *Lymnocythere mowbrayensis* (Figure 4). Both these latter species have been reported in slightly saline conditions, as discussed above, and this may indicate that there was an increase in salinity in the waters at this time. Third, the large increase in total ostracod remains is made up of non-identifiable fragments, suggesting that

high-energy events such as floods prevailed during which fragile shells were broken up.

Following this increase in ostracod abundance, there is a gradual decline to almost zero at 520 cm above the base of the section (Figure 4), indicating a period of apparent desiccation. Both the ostracod and mollusc faunas then recover towards the top of the section.

Although constrained by data from just three stratigraphic levels, the microfossil profile of the upper unit suggests a slight increase in the wetland's salinity following the LGM, and a continuation of the slow decline in its organic productivity. Interpretation of the results (both isotopic and micropalaeontological) is in part limited by the use of bulk samples. There are about 30 discrete laminae between the palaeosol horizon at 360–370 cm, and the top of the section at ~580 cm above the base of the exposed section. Only six samples were taken over this interval, which is hardly adequate to document the apparently increasing frequency of turnover between wetter and drier periods. Again higher-resolution sampling of the section is required to confirm this turnover.

## Conclusions

This study has shown that there were two main phases of late Pleistocene wetland sedimentation at the Slippery Dip locality in the Brachina valley of the central Flinders Ranges. The first, from about 34,000 yr BP to the LGM, occurred during a time of generally high precipitation such that freshwater microfossils, including both free-swimming and benthic ostracods, were preserved in relatively large numbers. The carbon and oxygen isotopic signatures of the ostracods and coeval molluscs provide an additional perspective, indicating that the prevailing moist conditions were punctuated by drier periods. The palaeosol, about 370 cm above the base of the section, marks the end of the initial stage of deposition. This horizon is relatively free of microfossils and coincides with a drying phase.

Following the hiatus, around the time of the LGM, the second phase of sedimentation probably records a prolonged series of high-energy events (possibly floods), given the fragmented nature of the shells. A decline in microfossil diversity suggests a slight increase in salinity. The limited isotopic data on this interval are consistent with the overall drying out and decline in productivity of the wetland.

This preliminary investigation highlights the need for higher-resolution sampling of the sediments above the palaeosol, with a view to better documenting changes in their microfossil diversity and stable isotopic composition. Additional ages will also be necessary to establish the nature and frequency of the events leading to the prominent lamination of this part of the Slippery Dip

section. Such information will comprise a local signature of global events that occurred between the LGM and the dawn of the Holocene.

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# Carbon isotope discrimination by C<sub>3</sub> pasture grasses along a rainfall gradient in South Australia: Implications for palaeoecological studies

F. Donald Pate, Evelyn Krull

F. Donald Pate (corresponding author) Email: [donald.pate@flinders.edu.au](mailto:donald.pate@flinders.edu.au)

Department of Archaeology, Flinders University, Adelaide, SA 5001, Australia

Evelyn Krull, CSIRO Land and Water, Private Bag No. 2, Glen Osmond, SA 5064, Australia

## Abstract

Samples of C<sub>3</sub> pasture grasses (Barley grass, *Hordeum leporinum*) were collected at five field sites in south-eastern South Australia with varying mean annual rainfall in order to address variability in grass tissue stable carbon isotope composition in open, arid-land habitats. Mean annual rainfall at the collection sites ranges from 1045 mm at Bridgewater in the southern Adelaide Hills to 238 mm at Morgan in the arid north. Stable carbon isotope values of C<sub>3</sub> grasses become less negative with decreasing mean annual rainfall. Mean  $\delta^{13}\text{C}$  values vary from -31.5‰ at Bridgewater to -27.7‰ at Morgan, a 3.8‰ difference correlated with a change of mean annual rainfall of 807 mm. The greatest magnitude of grass tissue  $\delta^{13}\text{C}$  change (2.5‰) occurs between the semi-arid (345 mm rainfall) and arid (238 mm rainfall) zones. Although the least negative C<sub>3</sub> grass  $\delta^{13}\text{C}$  values occur in the arid zone, effects on the stable carbon isotope composition of bone collagen in grazers will be minimal because C<sub>4</sub> grasses dominate the arid landscape. In a majority of the temperate and semi-arid habitats occupied by grazers, mean  $\delta^{13}\text{C}$  values in C<sub>3</sub> grasses differ by only 0.3 to 1.0‰. The quantification of variability in  $\delta^{13}\text{C}$  values within C<sub>3</sub> and C<sub>4</sub> plants associated with environmental variables such as soil moisture stress, aridity, and high light levels is essential to a range of ecological and palaeoecological studies employing stable isotope analyses of tissues from plants, herbivores and human consumers.

## Introduction

Stable isotopic analyses are employed regularly in ecological studies to address environmental and dietary variability in a range of modern and past ecosystems. Isotopic analyses of soils and tissues from humans, animals, and plants have been employed to address dietary composition, trophic level, photosynthetic pathway, habitat use, water stress, nutritional stress, humidity, and climate in marine and terrestrial ecosystems (Peterson and Fry, 1987; Rundel et al., 1989; MacFadden and Bryant, 1994; Pate, 1994, 1997; Bocherens et al., 1999; Witt, 2002).

Past research addressing dietary variability in terrestrial mammals via stable carbon isotope analysis focused on isotopic signatures in plant foods associated with various habitats and environmental conditions. These isotopic differences in plants are passed on to the tissues of herbivore consumers (Schwarcz and Schoeninger, 1991; Pate, 1994). Due to slow biochemical turnover rates, bone stable isotope values are related to long-term patterns of food consumption and habitat use. In most vertebrates, stable carbon isotopes provide information about lifetime dietary averages (Libby et al., 1964; Stenhouse and Baxter, 1979).

Initial studies focused on the bimodal distribution of  $\delta^{13}\text{C}$  values in plants as determined by various photosynthetic mechanisms (Park and Epstein, 1961; Smith and Epstein, 1971; Downton, 1975; Raghavendra and Das, 1978; O'Leary, 1988). Stable carbon isotope analysis of animal bones permitted the identification of browsing and grazing fauna in many regions of the world in both modern and fossil systems (Ambrose & DeNiro 1986, van der Merwe 1986, 1989, Cormie and Schwarcz, 1994; Quade and Cerling, 1995; Grocke, 1997; Cerling et al., 1999; Pate and Schoeninger, in review). Because the carbon isotopic composition of soils and plants shows spatial variations within regional food webs, herbivore bone has the potential to provide an average isotopic signal for particular environments (Tieszen et al., 1979; Teeri et al., 1980; Cavagnaro, 1988; Korner et al., 1988; van der Merwe et al., 1988; Cormie and Schwarcz, 1994). Hattersley (1983) reports the geographic distribution of C<sub>3</sub> and C<sub>4</sub> grasses in Australia in relation to climatic zones. The southern temperate regions of South Australia are dominated by C<sub>3</sub> grasses; C<sub>4</sub> grasses become dominant in the arid northern areas. Thus, there is a distinct geographic distribution of C<sub>3</sub> and C<sub>4</sub> grasses in Australia that may be employed to address variations in climate and associated herbivore dietary variability.

Bone collagen stable carbon isotope values in marsupial and eutherian herbivores collected at five field sites along a 1275 km south-north transect from temperate coastal to arid interior South Australia become less negative toward the arid north in relation to increasing quantities of  $C_4$  grasses (Pate and Noble, 2000). There is a strong linear relationship between percentage of  $C_4$  grasses at the collection sites and kangaroo bone collagen  $\delta^{13}C$  values ( $r^2 = 0.98$ ). Mean annual rainfall along the transect ranges from 775 mm at coastal Mount Gambier (23%  $C_4$  grasses) to 168 mm at Cordillo Downs (78%  $C_4$  grasses) in the northeast corner of the state. Because stable carbon isotope ratios in herbivore bone collagen reflect the  $\delta^{13}C$  composition of ingested grasses, stable isotope analysis provides a method to address dietary selection and dietary variability in Australian herbivores and carnivores.

More recent studies have focused on observations that plants employing  $C_3$  photosynthesis show a large range of mean  $\delta^{13}C$  C tissue values (grand mean =  $-27.1 \pm 2.0\text{‰}$ ; range of  $-35\text{‰}$  to  $-20\text{‰}$ ; see Deines, 1980; O'Leary, 1988). Plants growing in tropical closed-canopy forests have  $\delta^{13}C$  values at the more negative end of the range, while plants of the same species growing in open, arid-land habitats have less negative  $\delta^{13}C$  values. The more negative values result from  $\delta^{13}C$  enrichment of local atmospheric  $CO_2$  from biomass degradation (van der Merwe and Medina, 1989; Broadmeadow et al., 1992) and depressed rates of photosynthesis under low light conditions (Yakir and Israeli, 1995).

Plants growing in savannas and other open arid-land ecosystems show less negative  $\delta^{13}C$  tissue values because photosynthesis occurs during periods of stomatal closure and photosynthesis is stimulated by high light levels (Hubick et al., 1986; Ehleringer and Cooper, 1988; Ehleringer, 1989; Farquhar et al., 1987, 1989; Pate and Arthur, 1998). This photosynthetic mechanism preserves moisture in plants growing in arid-land ecosystems and in the process reduces discrimination against the heavier  $\delta^{13}C$  isotope. In addition, in open habitats local atmospheric  $CO_2$  is isotopically similar to the global atmosphere due to the lack of canopy effect (cf. Ambrose and DeNiro, 1986; van der Merwe and Medina 1989; Schoeninger et al., 1997). Ehleringer and Cooper (1988) report a 1–2.5‰ intraspecific increase in the leaf  $\delta^{13}C$  values of desert perennials along a decreasing soil moisture cline from wash to slope microhabitats.

Similar variations in leaf and wood  $\delta^{13}C$  values have been reported for pines and eucalypts growing along rainfall gradients in open-forest environments (Pate and Arthur, 1998). During the growing season, wood  $\delta^{13}C$  C values from pines (*Pinus radiata*) in Australia and New Zealand increase by 2–3‰ in direct association with increases in mean annual rainfall from

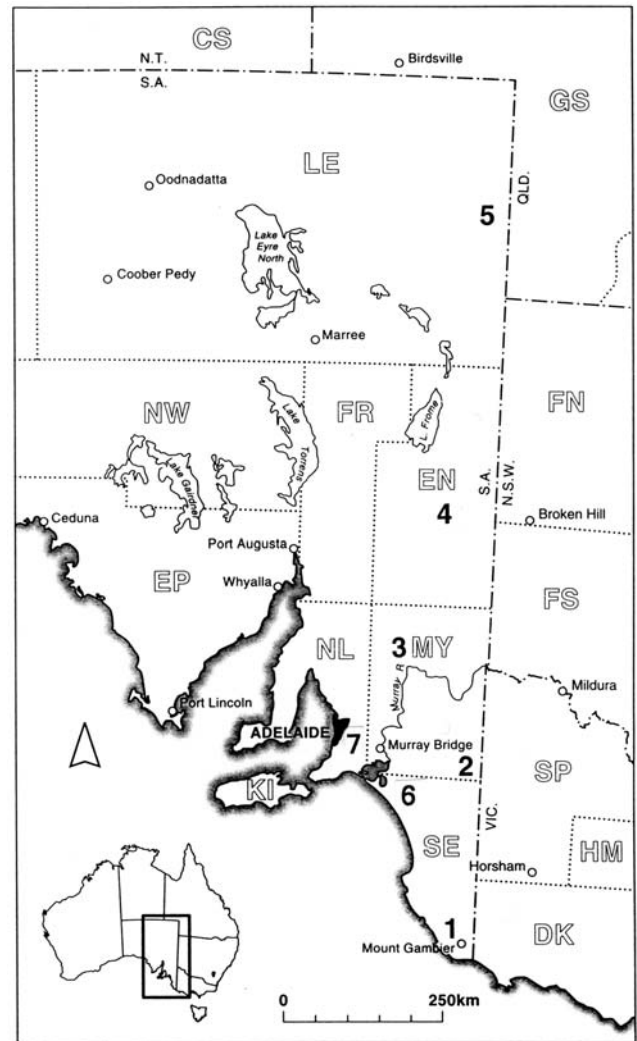


Figure 1. Map showing location of the South Australian collection sites for grasses and kangaroo bones: (1) Mount Gambier, (2) Karte and Pinnaroo, (3) Morgan, (4) Plumbago, (5) Innamincka, (6) Coonalpyn, and (7) Bridgewater and Mount Barker with associated geographic subdivisions indicating abundance of  $C_3$  and  $C_4$  grasses in relation to climate (after Hattersley 1983). Geographic subdivisions: SE = South-eastern, MY = Murray, NL = Northern Lofty, EN = Eastern, LE = Lake Eyre (adapted from Pate and Noble, 2000).

650 mm to 1500 mm (Walcroft et al., 1997; Korol et al., 1999). Leaf  $\delta^{13}C$  values in 12 populations of shallow-rooted *Eucalyptus* are also positively correlated with mean annual rainfall ( $r = 0.75$ ) and negatively correlated with predicted evaporation during the summer months in southeastern Australia (Anderson et al. 1996). Wood  $\delta^{13}C$  are more variable than leaf values because wood records an average of tissues synthesized over a longer period of time (Miller et al., 2001).

This paper addresses  $\delta^{13}C$  variability in  $C_3$  pasture grasses at five field sites along a rainfall gradient from temperate coastal to arid interior South Australia in order to assess the impact of soil moisture stress, aridity, and high light levels on plant stable carbon

isotope tissue values. Differences in C<sub>3</sub> grass  $\delta^{13}\text{C}$  tissue values will be passed on to herbivores. Thus, in addition to differences in the distribution and abundance of C<sub>3</sub> versus C<sub>4</sub> grasses across various habitats, stable carbon isotope variability within C<sub>3</sub> grasses introduces an additional mechanism that will affect herbivore bone collagen  $\delta^{13}\text{C}$  composition.

## Materials and Methods

Samples of C<sub>3</sub> pasture grasses (Barley grass, *Hordeum leporinum*) were collected at five field sites in south-eastern South Australia with mean annual rainfall values ranging from 1045 mm to 238 mm. The collection sites included Bridgewater, Mount Barker, Coonalpyn, Pinnaroo, and Morgan (Figure 1). Bridgewater and Mount Barker are located within the Adelaide Hills region to the southeast of the city of Adelaide. Five samples of grass were collected at each site from a 25 m<sup>2</sup> area of flat pasture ground in areas that were not irrigated. Grass blades were cut near the top of the plant to avoid contamination from the underlying soil. Samples were submitted to the CSIRO Land and Water laboratory, Adelaide for stable carbon isotope analysis. Samples were oven dried at 50°C, ground, and analysed by mass spectrometer using an automated Europa Scientific ANCA-SL system with on-line separation. Analytical precision was better than  $\pm 0.1\text{‰}$ .

## Results

Stable carbon isotope values of C<sub>3</sub> grasses become less negative with decreasing mean annual rainfall. Mean  $\delta^{13}\text{C}$  values vary from  $-31.5\text{‰}$  at Bridgewater (1045 mm rainfall) to  $-27.7\text{‰}$  at Morgan (238 mm rainfall), a  $3.8\text{‰}$  difference correlated with a change of mean annual rainfall of 807 mm (Table 1). The greatest magnitude of grass tissue  $\delta^{13}\text{C}$  change ( $2.5\text{‰}$ ) occurs between the semi-arid (Pinnaroo, 345 mm rainfall) and arid (Morgan, 238 mm rainfall) zones, whereas there is no significant difference ( $0.3\text{‰}$ ) between mean values at the Pinnaroo and Coonalpyn (453 mm rainfall) collection sites.

Differences in  $\delta^{13}\text{C}$  values for grasses between temperate coastal and arid interior habitats are reflected in the bone collagen  $\delta^{13}\text{C}$  values of herbivore consumers (Table 2; Figure 1). For example, the difference in mean  $\delta^{13}\text{C}$  values for grasses at Mount Barker (767 mm rainfall) versus Morgan (238 mm rainfall) is  $3.2\text{‰}$ , while the difference between grey kangaroo (*Macropus fuliginosus*) bone collagen values at Mount Gambier (775 mm rainfall) versus Morgan is  $3.4\text{‰}$  (Pate and Noble, 2000; Pate and Schoeninger, in review). Mean  $\delta^{13}\text{C}$  values in C<sub>3</sub> grasses from a majority of the temperate and semi-arid regions in South Australia that are occupied by kangaroos differ by only  $0.3$  to  $1.0\text{‰}$ .

Table 1.

Collection Site	Location	Mean Annual Rainfall (mm)	Mean Grass $\delta^{13}\text{C}$ (‰) $\pm$ SD	Range	n	
Bridgewater	35 00' S, 138 45' E	1045	$-31.5 \pm 1.1$	-33.4, -30.5	5	Stable carbon isotope variability in C <sub>3</sub> grasses (Barley grass, <i>Hordeum leporinum</i> ) at five South Australian collection sites along a rainfall gradient from temperate coastal to arid interior.
Mount Barker	35 04' S, 138 52' E	767	$-30.9 \pm 1.0$	-32.2, -29.6	5	
Coonalpyn	35 42' S, 139 50' E	453	$-29.9 \pm 1.2$	-31.5, -28.7	5	
Pinnaroo	35 16' S, 140 54' E	345	$-30.2 \pm 0.7$	-31.3, -29.4	5	
Morgan	34 01' S, 139 39' E	238	$-27.7 \pm 0.7$	-28.4, -26.6	5	

Table 2.

Collection Site	Location	Mean Annual Rainfall (mm)	Percentage <sup>a</sup> C <sub>4</sub> Grasses	Kangaroo <sup>b</sup> $\delta^{13}\text{C}$ (‰)	n	
Mount Gambier	37 56' S, 140 47' E	775	23	-24.8	6	Mean bone collagen stable carbon isotope results for South Australian kangaroos collected along a south-north transect from temperate coast to arid interior (after Pate and Noble, 2000; Pate, unpublished data for Morgan site).
Karte	35 04' S, 140 42' E	350	47	-21.6	7	
Morgan	34 01' S, 139 39' E	238	47	-21.4	6	
Plumbago	32 04' S, 139 53' E	200	69	-17.6	13	
Innaminka	27 56' S, 140 47' E	176	78	-15.4	12	

a: After Hattersley (1983)

b: Grey kangaroos (*Macropus fuliginosus*) for Mount Gambier, Karte, and Morgan;

Red kangaroos (*Macropus rufus*) for Innamincka; Red and grey kangaroos for Plumbago

## Discussion

Most of the observed variation in kangaroo bone collagen  $\delta^{13}\text{C}$  values in the temperate coastal and semi-arid interior regions of South Australia appears to be related to the consumption of varying quantities of  $\text{C}_3$  and  $\text{C}_4$  grasses. For example, mean grey kangaroo  $\delta^{13}\text{C}$  values at Mount Gambier (775 mm rainfall, 77%  $\text{C}_3$  grasses) versus Karte (350 mm rainfall, 53%  $\text{C}_3$  grasses) differ by 3.2‰, but mean  $\text{C}_3$  grass  $\delta^{13}\text{C}$  values at sites with similar rainfall values, e.g. Mount Barker (767 mm rainfall) versus Pinnaroo (345 mm rainfall), differ by only 0.7‰.

In contrast, in arid-land habitats with mean annual rainfall values less than 250 mm, kangaroo bone collagen  $\delta^{13}\text{C}$  values would be influenced by both varying quantities of  $\text{C}_3$  and  $\text{C}_4$  grasses included in diets and the consumption of  $\text{C}_3$  grasses with less negative  $\delta^{13}\text{C}$  values grown under conditions of aridity. Mean kangaroo bone collagen  $\delta^{13}\text{C}$  values at arid, inland Innamincka (176 mm rainfall) are 9.4‰ less negative than those at coastal, temperate Mount Gambier (Pate and Noble, 2000). However, as the most arid habitats are also dominated by  $\text{C}_4$  grasses which have less negative  $\delta^{13}\text{C}$  values, e.g. Innamincka with 78%  $\text{C}_4$ , the impact of  $\delta^{13}\text{C}$  tissue variability within  $\text{C}_3$  grasses on the bone collagen  $\delta^{13}\text{C}$  values of grazers inhabiting arid zones will be minimised.

The important implication arising from the data presented in this study is that overall the effect of  $\text{C}_3$  grass  $\delta^{13}\text{C}$  tissue variability on estimates of relative distributions of  $\text{C}_3$  and  $\text{C}_4$  grasses from stable carbon isotope analyses of bone collagen in South Australian grazers is minimal. Correction factors for various regions can be applied to address the small variations in herbivore bone collagen  $\delta^{13}\text{C}$  values that are related to consumption of  $\text{C}_3$  grasses with less negative  $\delta^{13}\text{C}$  tissue values.

An improved understanding of the effects of various environmental variables on  $\delta^{13}\text{C}$  values in  $\text{C}_3$  and  $\text{C}_4$  plants will assist in the refinement of isotopic methods employed to study modern and past ecological systems.

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# Report on the Symposium 'Land-Ocean correlation of long Quaternary records from the Southern Hemisphere on orbital and sub-orbital timescales (PASH2)'

5th Southern Connection Conference, 21–25 January 2007  
Adelaide University, South Australia

## Peter Kershaw

Centre for Palynology and Palaeoecology  
School of Geography and Environmental Science  
Monash University Fax: 03 9905 2948  
peter.kershaw@arts.monash.edu.au

The PASH2 project developed from a previous Southern Hemisphere initiative of the International Quaternary Association (INQUA) Commission for Palaeoclimatology (PALCOMM) (*Palaeoclimates of the Southern Hemisphere – PASH*), and has been designed to provide a coherent picture of Southern Hemisphere climate change and its drivers. The aim is to provide a more balanced picture of global climates while contributing substantially to the understanding of the development of present landscapes. The project was initiated to address the unique, though under researched, climatic history of the southern continents and oceans. As a result of their association with ENSO and monsoon generation, and their role in the global thermohaline circulation, the southern oceans are critical to an understanding of global climate change. Additional information on the PASH2 project is provided at <http://users.monash.edu.au/~pkershaw/>

The Southern Connections symposium, incorporating 17 presentations on Australia, New Zealand, Southern Africa and South America, was presented in association with an INQUA Palaeoclimate Commission project workshop supported by both INQUA and the ARC Environmental Futures Network. It was introduced by 'keynote' presentations from Jim Bowler and Tim Barrows. These covered, at different resolutions, climate proxy records relating to both land and ocean over almost the whole period of interest with additional background from Bowler on events leading into the Quaternary period (i.e. the last 2.6 or 1.8 million years depending on a pending decision by the International Stratigraphic Commission).

Bowler based his paper on the climatic significance of some 170 coastal strandlines preserved in the landscape from the Murray Basin to the present southern Australian coastline and indicated past sea-level highs related to climate cyclicity over the last 6 million years. In contrast to a previous Late Cenozoic reconstruction (Bowler, 1982), where a major change to aridity (at least during glacial periods) was thought to have occurred in association with the establishment of a westerly wind circulation over

southeastern Australia around the beginning of the Quaternary, the onset of the latest phase of aridity is considered to relate to a Mid Pleistocene transition, around 1.3 million years ago. This change is marked by a change from siliceous shorelines indicating low energy environments to calcarenite shorelines indicative of high energy environments. As this change occurred some 500 ka before the global transition from the 40 ka to 100 ka world of glacial-interglacial cyclicity, Bowler considers that it had a Southern Hemisphere cause, most probably an increase in the latitudinal temperature gradient as a result of an increase in Antarctic ice volume. This change would have led to the development or intensification of the westerly wind system and aridity in Australia as well as possibly triggering the onset of the 100 ka global cycles.

Providing some support for the new Bowler model, Kale Sniderman's detailed and convincingly dated pollen record from an old volcanic crater lake in the Western Highlands of Victoria indicates that a summer rainfall regime was still prevalent in Australia between 1.8 and 1.5 Ma and that the climate was much wetter than that of today. However, dramatic oscillations in representation of rainforest and sclerophyll vegetation are interpreted as indicating 20 ka rather than 40 ka cyclicity. It is proposed that Southern Hemisphere insolation cycles, rather than glacial cycles forced by global ice volume, were the dominant controls over precipitation-induced variation in vegetation. Barbara Wagstaff's equally long, detailed and fission track dated pollen records from volcanic crater lake sediments could provide some refinement of the Bowler model. Conditions were generally drier than today through the period 1.2 Ma to 1 Ma with variation in the predominantly steppe (grass and herbs) and woodland (*Callitris* and *Casuarinaceae*) vegetation showing consistency with precessional forcing. The Mid Pleistocene transition is clearly marked between about 1 Ma and 900 ka, earlier than the global switch to 100 ka cyclicity, with some replacement of *Callitris* by *Eucalyptus*, the beginning of significant representation by forest elements and some plant extinctions. This picture contrasts with the Bowler model in suggesting a later transition, although a Southern Hemisphere influence, and an increase in rainfall cannot be discounted, though this is likely to have been restricted to interglacial periods. Between about 900 ka and 700 ka, there is clear cyclicity consistent with the

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100 ka world and with late Quaternary records from the region.

The extent to which patterns of change in the mid latitudes of the Australian region can be applied to the Southern Hemisphere generally was brought into question by the marine palynological record of Lydie Dupont from off the coast of Namibia in SW Africa (presented in the 'Aridification of the Four Southern Hemisphere Continents' symposium). The record, covering the period 3.4 to 1.8 Ma, suggests that there was an increase in winter rainfall between 3.1 and 2.2 Ma with a northward shift in Polar Front and an increase in the pole-equator thermal gradient, consistent with the onset of the westerly wind system in the original Bowler model. However, increased aridity after this time was partially explained by a southward shift in the Polar Front as indicated in both marine and terrestrial proxies.

An overview of detail within the last glacial-interglacial cycle in the southern Australasian region was provided by four high resolution, multiproxy marine records by Tim Barrows. A common timescale demonstrated synchronicity of records with Northern Hemisphere insolation and ice volume at the orbital scale in calculated sea surface temperatures from foraminifera, alkenones and magnesium/calcium ratios on foraminiferal carbonate. Abrupt temperature changes of up to 6°C occurred within a few centuries. Synchronicity extended to terrestrial sedimentary and pollen signals from the records. A clear Southern Hemisphere signal in the Southern Ocean is demonstrated during the last glacial period, by correspondence with millennial variation recorded in Antarctic ice cores rather than Greenland Dansgaard-Oeschger events and by the lack of a Younger Dryas cooling period.

The orbital picture was echoed in the presentation by Sander van der Kaars on an oxygen isotope dated, 150 ka record from off the southern coast of Western Australia. Preliminary pollen analysis indicates highest rainfall with expansion of woody vegetation during interglacials, with greatest expansion during MIS 5e. Charcoal evidence suggests highest burning levels during MIS 5 with reduced burning, possibly due to a reduction in fuel, after this time. This burning pattern is similar to that from a marine core of northwestern Australia (van der Kaars and De Deckker, 2002) suggesting it could be a broad regional pattern. One feature of interest to those involved in the 'Megafaunal Extinction' symposium was the notable decline in *Sporomelle* spores, a fungus considered to indicate faunal biomass, in the middle of MIS 3. Merna McKenzie provided a comparative land record of the last glacial cycle from a very detailed record from the high altitude site of Caledonia Fen in eastern Victoria. Age control is provided by radiocarbon and OSL dates through the last 70 ka. Temperature appears to provide the major control over vegetation that is dominated by alpine herbaceous vegetation except during the Holocene and, unexpectedly, at the beginning of MIS 3 where forest

expands. There is no clear fire signal but within the latter part of MIS 3 a number of ancient, fire-sensitive taxa disappear from the record. The last glacial period is characterised by a number of abrupt 'amelioration' events. However, dating is too imprecise to relate to either Northern or Southern Hemisphere sub-millennial patterns.

Five papers, addressing Southern Hemisphere low latitudes, demonstrate a great deal of variation in patterns and forcing of climate over the last 50 to 500 ka. Patrick Moss presented an extension of the pollen record from ODP Site 820 in the Coral Sea that reinforces orbital-scale Northern Hemisphere forcing. However, it also shows regional features. The most marked of these is a series of step-wise changes between 180 and 40 ka to more open vegetation and drier or more variable climates that are probably a response to a sustained increase in sea surface temperature within marine proxies between about 350 ka and 250 ka. Although the cause is unknown, it probably relates to an expansion in the Indo-Pacific Warm Pool and an increase in intensity of ENSO. The regional significance of this 'Mid-Brunhes' event was illustrated by Scott Hocknull (in the 'Aridification' symposium) from a fossil vertebrate record in northeastern Australia. The record reveals a major faunal turnover event from rainforest to an open vegetation taxon dominance with reduced precipitation sometime between 280 and 170 ka.

Peter Kershaw compared the ODP record with other long palynological records from northern Australia and the low southern latitudes of Southwest Africa and South America, all of which have been suggested to be under the influence of monsoon climates. Records from northwestern Australia and southern Africa appear to show domination by the Southern Hemisphere precession, at least over the last 200 to 300 ka, and may be explained by the response of monsoon rainfall to Indian Ocean sea surface temperatures. Conversely, records from the north of Australia are dominated by the Northern Hemisphere obliquity signal indicating forcing by the Asian winter monsoon. Although summer insolation, acting through the South Atlantic monsoon, is considered to be the major influence on the Southern Hemisphere tropics of South America (Fritz et al., 2004), a trend towards increasing moisture availability over the last 170 ka, inverse to that in northeastern Australia, may suggest that increasing Pacific El Niño activity was a major forcing influence.

On a shorter timescale, Sue Rule presented results of her very high resolution pollen and charcoal record from Lynch's Crater, covering the last 50 ka within 9m of sediment from contiguous 2cm samples. Sub-millennial scale variability that has been correlated with that in the Greenland ice cores (Turney et al., 2004), shows up in places as extremely abrupt events. It is hoped that interesting differences in charcoal derived from micro-fossil and macrofossil analysis will reveal the sources

of burning that reflect much of the pollen variation and, in particular, contribute to an understanding of the cause of the major increase in burning recorded about 45 ka. Using a similar time period, Andrew Marshall presented results from the Fast Ocean Atmosphere model applied to an understanding of monsoon rainfall patterns over northern Australia. The model results generally conformed with available palaeodata and suggested that sea level and solar insolation changes had dominated rainfall intensity over the period with little influence from vegetation and greenhouse gases.

There are few records of Quaternary climate change from the subtropics of coastal eastern Australia but Lynda Petherick helped fill this gap with a pollen and aeolian dust record from North Stradbroke Island in southern Queensland. The fact that it is continuous through the last 40 ka suggests that glacial/interglacial rainfall variability may not have been as great as in more temperate and tropical areas where continuous coastal sequences of this duration are generally absent. However, the aeolian component of the sediments does suggest notable changes in rainfall with representation of events such as the Last Glacial Maximum (LGM) and Antarctic Cold Reversal. The analysis of a long distance dust component allows identification of a number of different sources, indicating systematic changes in atmospheric circulation over the period.

Other contributions focused the last 30 ka – the domain of INQUA Palaeoclimate Commission project 'Australasian INTIMATE (Integration of Ice, Marine and Terrestrial Records of the Last Glacial Maximum and Termination)'. Most intensive research on this period has been undertaken in New Zealand and high resolution records of pollen and other proxies from terrestrial records were presented from the South Island by Marcus Vandergoes and from the North Island by Donna D'Costa. The representation of tephras provides an excellent basis for dating and correlation within New Zealand and examination of the degree of synchronicity of events with other parts of the world. Five key events have been identified in New Zealand within the LGM and Last Termination that extended from about 29 ka, earlier than the global onset in the Northern Hemisphere and marine records, to 9 ka. An examination of terrestrial proxies in marine records provided the basis for assessment of climate change and atmospheric circulation in south-west Africa and south-west South America through and since the LGM. Both the high resolution pollen records of Lydie Dupont from off Namibia and Angola and the records of aeolian dust and fluvial mud of Jan-Berend Stuut off the coast of Chile convincingly demonstrate that the Southern Westerlies extended substantially northwards during the LGM resulting in higher rainfall in these locations. It is expected that a similar movement of the westerlies should be recorded in southern Australasia but the evidence, to date, is equivocal (Shulmeister et al., 2004). It is hoped that the data compilation of high

quality records from the Southern Hemisphere, being compiled and analysed by Martin Williams, will allow a comprehensive picture of patterns and causes of climate change over the whole region for the last 30 ka.

The number of proxies developed for refinement and testing of climatic estimates is increasing. A number of relatively new proxies, including alkenones and chironomids that can be applied to quantification of temperature estimates of sea surface and aquatic temperatures respectively, have been applied in some of the studies presented. One method that has been neglected in Southern Hemisphere studies, is the systematic application of plant macrofossils to refinement of vegetation and climate reconstructions generated by pollen analysis. Here, Tara Lewis demonstrated the value of the method within records from the Western Plains of Victoria. She is developing a seed data base to help develop the general application of the method within the region.

The symposium has highlighted a greater degree of variation in climate change in the Southern Hemisphere than is generally apparent in the Northern Hemisphere. It appears that there has been a dilution of the Northern Hemisphere signal, most obvious on land rather than in the ocean, relative to regional insolation acting through monsoon-type processes, ENSO and Antarctic ice. The situation is clearly complex and there is need for a great deal more research, in the form of data generation and analysis involving existing and new proxies as well as modelling, to understand underlying forcing of climate on a range of spatial and temporal scales. However, the wealth of information presented in the symposium provides some basis for identification of promising areas for future research and of gaps that need to be filled.

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# Australia and New Zealand Geomorphology Group Workshop

New Frontiers in River Research, Canberra and Kioloa  
6 – 8 February 2007

Kathryn Amos, Rachel Nanson

Kathryn Amos: School of Physical, Environmental and Mathematical Sciences

The University of New South Wales at the Australian Defence Force Academy, Canberra ACT 2600 Email: k.amos@adfa.edu.au

Rachel Nanson: Department of Archaeology and Natural History, Research School of Pacific and Asian Studies

Australian National University Canberra ACT 0200 Email: rachel.nanson@anu.edu.au



Figure 1. Workshop participants at Tuross Head, with the beach and estuary barrier in the background. Photo taken by Jim Brophy.

From the 6th – 8th February 2007, the fluvially-inclined members of the Australian and New Zealand Geomorphology Group (ANZGG) gathered for a workshop to explore new frontiers in river research. 2007 is a ‘gap year’ between the bi-annual ANZGG conferences and the workshop was intended to maintain the momentum of communication between fluvial geomorphologists within the region. It also provided a forum for researchers and students to share ideas, present new work and discuss techniques, ideas and problems in an informal environment. The 55-plus participants included students, early-career researchers, academics and agency-based scientists. Thirty oral presentations covered a range of topics, from the arid zone to the tropics, gully erosion to river rehabilitation, and LIDAR to new advances in radioisotope and luminescence dating techniques.

The meeting began in Canberra, at CSIRO Land and Water, where invited speakers presented on a range of topics targeted at providing the audience with rapid insights into current approaches to fluvial research and rehabilitation. John Gallant (CSIRO) provided an overview of the application of LIDAR to fluvial environments and

Andrew Brooks (Griffith University) presented an assessment of the practicalities of Large Woody Debris (LWD) re-emplacement in south-eastern Australian river systems. Tim Pietsch (CSIRO) and Ed Rhodes (Australian National University [ANU]) each described the theory of Optically Stimulated Luminescence (OSL) single and multiple aliquot dating techniques, and highlighted their applicability, potential problems, and ideal sample collection methodologies.

Late on Day 1 the meeting adjourned to the New South Wales (NSW) South Coast. Participants drove across the middle reaches of the Shoalhaven catchment before descending 800m down Clyde Mountain to the Clyde River. A short drive north up the narrow coastal plains brought them to the lovely ANU coastal campus at Kioloa, where master chef Jim Brophy (CSIRO) prepared a traditional Aussie BBQ.

Day 2 comprised a field trip, led by Paul Rustomji (CSIRO), to the lower Tuross River (Figure 1) in south-eastern NSW, to observe some of the fascinating flood-plain morphologies that occur within this system and to discuss the drivers for Holocene valley aggradation.



Figure 2. Geomorphologists trigger estuary mouth opening? Three days after the ANZGG workshop fieldtrip to the Tuross River on the New South Wales south coast, 150 mm of rain fell over the weekend, resulting in the opening of the estuary mouth in fairly spectacular fashion. A. Before breach (photo taken by Jeff Shellberg). B. After breach (photo taken by James Woodford). C. At the breach (photo taken by James Woodford).

The Tuross River drains a catchment of c. 2180 km<sup>2</sup> and is a confined, sand-bedded meandering river (Ferguson and Brierley, 1999) with an intermittent/ephemeral discharge regime. The steep forested headwaters of the Tuross River reach an elevation greater than 1000 m asl, and are underlain by Devonian granites. On the coastal side of the Great Dividing Range escarpment, the catchment is underlain by Ordovician metasediments. In the lowermost 60 km of channel, slope decreases from 0.0011 to 0.0007 m m<sup>-1</sup> and bed material fines downstream from cobbles to sand, with mixed sand and mud in the infilling estuary lake which is impounded by a coastal sand barrier (Rustomji et al., 2006).

The field trip started at Tuross Head, which overlooks the mouth of the wave-dominated estuary of the Tuross River. At the time of our field trip, the estuary was completely blocked by a large sand barrier (Figure 2a), a common feature of the many wave-dominated estuaries of Australia's south-east coast. Paul Rustomji has estimated that there has been sufficient inflow to the Tuross estuary for it to be flushed and the barrier breached between 10 and 50 times per decade over the past 100 years. By way of demonstrating geomorphology in action, a few days after our visit to the area, over 150 mm of rain fell over the catchment. This triggered a spectacular breach of the barrier (Figure 2c).

The field trip then moved upstream to our second stop, overlooking the meandering lower reaches of the Tuross River. Here, Holocene progradation of the river mouth resulted in floodplain aggradation over estuarine sediments. Alec Costin pointed out the low-lying flood basin depressions along the bedrock margins and palaeochannels that have been submerged during periods of high discharge.

As we travelled further upstream, dominant alluvial features became apparent, including a prominent high-level alluvial (levee/floodplain) surface that is typically 10–14 m above the thalweg, and substantial benches that are typically 6–8 m above the thalweg and less than 50 m wide (Ferguson and Brierley, 1999; Rustomji et al., 2006). For those participants used to working on near-flat floodplains that are many kilometres wide, the narrow valleys and distinct topography of alluvial features were a luxury, although some participants from New Zealand remarked on the lack of “real rivers” in this part of the world!

At our lunch stop a debate arose over the mechanism by which Holocene valley aggradation occurs. Paul Rustomji proposed a model by which aggradation is driven by river mouth progradation, with a constant rate of aggradation occurring at all locations along the lower Tuross extending tens of kilometres upstream. This model was vigorously challenged by Tim Cohen, who proposed that the rate of floodplain and bed aggradation must diminish in an upstream direction, and should only extend as far as

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the backwater effects. The conflict of opinion was enjoyed by all, including the most involved and opinion-ated participants to the debate.

Discussion was also sparked over what defines an “active” floodplain. It was suggested that an inundation frequency of 5 years or less is appropriate for the definition of a contemporary floodplain surface along this river, but a number of participants emphatically stated that such a definition is not necessarily applicable in environments with ephemeral or highly variable discharge. OSL dating of floodplain deposits in the lower Tuross have shown that there has been a marked decrease in accretion rates of the high level surface over the past 2500 years, and this ‘high-level accretion surface’ has been described as an abandoned floodplain (Rustomji et al., 2006). This was queried by some who argued that in a system with an intermittent discharge regime, a floodplain surface that is regularly inundated (last recorded ~20 years ago) is not abandoned and should be described as an active floodplain.

After an evening of further vigorous discussion, the final day consisted of a full day of talks, followed by a return drive to Canberra. Students and NRM agency representatives were well represented on this final day and their talks demonstrated the range of tropical, arid and temperate zone river research currently being undertaken in the Australian and New Zealand region. The workshop was a fantastic opportunity for the Australia and New Zealand fluvial geomorphology community to get together, discuss our research techniques and latest results and communicate these to students, early career researchers and NRM practitioners. We are grateful to CSIRO Land and Water, and Land and Water Australia, who provided a \$3500 conference grant to ensure the success of our first biannual fluvial group meeting.

Further information about the ANZGG and their regular bi-annual meetings, including the upcoming meeting which will be held in Tasmania in February 2008 (Ancient and Modern: late Cainozoic modification of Australasia’s relict landscapes) can be found at: <http://www.anzgg.org>.

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# The 2nd International Young Scientists' Global Change Conference, AND The 2nd Earth System Science Partnership's Open Science Conference

Global Environmental Change: Regional Challenges  
November 2006 Beijing China

**Joëlle Gergis**

School of Creative Media, RMIT University, Melbourne Victoria 3001  
Email: jgergis@gmail.com

In November 2006, I had the privilege of representing Australian palaeoclimatology at two international meetings on global change research held in Beijing, China. They profoundly challenged my views on the threat posed by global warming. Climate change is very real, happening now, and the rate of change is accelerating. I was struck by the urgency for direct and immediate action needed - at every level, in every nation.

The first conference I attended was the International Young Scientists' Global Change Conference (YSC) (Figure 1). The YSC took place November 5–8, 2006 the China Meteorological Administration campus in Beijing, China. The conference was sponsored by the Earth System Science Partnership (ESSP) and was organised by the global change SysTEM for Analysis, Research and Training (START) and the China Meteorological Administration. START is a capacity building initiative for global change researchers funded by the ESSP program (detailed below). It targets developing countries and collaborations that conduct research on regional environmental change, the assessment of impacts and vulnerabilities to such changes, and information to policy-makers.

It brought together 100 young scientists from 35 countries to discuss some of the key challenges facing our scientific discipline, and the implications they hold for the future of global sustainability. Four people attended the meeting from our region, including three Australians (Ben Preston (CSIRO), Anna Richards (University of Queensland) and myself) and one New Zealander (Olivia Warrick (Victoria University)). I was the only Australian (and palaeoclimatologist) to address the congress.

The conference was an excellent platform for young scientists to present their research findings to both peers and leading scientists in the environmental change field. Keynote speakers included distinguished climatologist and numerical modeller Prof. Congbin Fu (China) and Prof. Paul Crutzen (USA), who received the Nobel Prize in 1995 for his research on atmospheric ozone. The meeting was organised into six themes:

- Earth system variability and modelling
- Ocean, freshwater and coastal systems
- Land ecosystem and biodiversity
- Biogeochemical cycles; cryospheric studies
- Human vulnerability and risk management
- Global change and agricultural systems

My talk addressed uncertainties surrounding late 20th century El Niño-Southern Oscillation (ENSO) extremes (Gergis and Fowler, 2005). This involved reconstructing the long-term history of ENSO using high-resolution palaeoarchives including tree-rings, corals, ice-cores and documentary records (Gergis et al., 2006). Previous ENSO reconstructions have been geographically biased toward East Pacific teleconnection regions, with little representation of sites influenced by the Western Pacific warm pool. I presented the first large-scale Southern Hemisphere effort to reconstruct ENSO using an expanded network of recently developed Western Pacific palaeoarchives.

Of the total number of extreme El Niño/La Niña event years reconstructed since A.D. 1525, 43% occur in the 20th century. Strikingly, 30% of all reconstructed ENSO event years occur post-1940 alone, suggesting that recent ENSO variability appears anomalous in the context of the past five centuries (Gergis and Fowler, 2005). These results suggest it is likely that ENSO operates differently under natural (pre-industrial) and human-influenced background states. Given the large-scale socio-economic impacts of ENSO events, investigations into how continued global warming will influence future ENSO behaviour are vital.

Over the course of the conference, we were encouraged to informally discuss the question "What are the big questions in global change science?" This led to some very interesting conversations, as it is not often you get physical and social scientists from 35 countries in the same room! Collectively, we identified three main areas:

- Detection and attribution of physical climate cycles and their forcing mechanisms;
- Improved inter-disciplinary communication of science within and beyond the scientific communities;



Figure 1. Participants of the 2nd International Young Scientists' Conference on Global Change, 5–8 November 2006, Beijing, China. Photograph courtesy Sandra Stowe, International START Secretariat.

- Adaptation and mitigation strategies to minimise socio-economic impacts.

The key concern was how we can effectively apply our science to confront environmental challenges and create a sustainable future. Scientists from developing nations were quick to comment that basic development issues identified by the 2005 *Millennium Ecosystem Assessment*, such as public health, food production, habitat fragmentation, coastal management and urbanisation, should not be dealt with in isolation. Vulnerability to climate-related impacts on society are compounded by factors unrelated to climate change, such as rapid population growth, unsustainable patterns of development and socio-economic inequity. Adaptation policy must aim to make societies more robust to developmental issues including, but not confined to, the issue of climate change.

Improved dialogue between science and policy-makers was also identified as another key priority area. As scientists, we need to be attuned to the interests of policy makers and need to improve on communicating our work to non-specialists. The group agreed that there is an important and practical need to continue interdisciplinary meetings, such as this one, to cultivate an understanding of the complexity of global environmental change research and its practical application.

After negotiating the tangle of inner-city Beijing for a field trip to the awe-inspiring Forbidden City, all YSC participants then took part in the Earth System Science Partnership's Open Science Conference, "Global Environmental Change: Regional Challenges", at the Beijing International Conference Center. The ESSP is a collaboration between the four major international global

change research programmes:

**DIVERSITAS:** an International programme of biodiversity science

**IGBP:** the International Geosphere-Biosphere Programme

**IHDP:** the International Human Dimensions Programme on Global Environmental Change

**WCRP:** the World Climate Research Programme

The meeting was attended by more than 1,000 global environmental change scientists, policy makers, members of the private sector and journalists. Issues discussed ranged from state-of-the-art advances in climate science, global food security, human health, sustainable development and biodiversity loss. The concept of a new form of "Earth System Science" was proposed as a cross-disciplinary integration of environmental and developmental sustainability in the natural and social sciences.

The term *Anthropocene*, first suggested by Paul Crutzen in 2000, is now being used to describe the most recent period in the Earth's history. The period begins during the 18th century when the activities of humans first began to have a significant impact on the Earth's climate and ecosystems. Crutzen explained how the influence of humankind on the Earth in recent centuries as so significant as to constitute a new geological era.

In a radical attempt to sequester atmospheric carbon, he discussed a controversial "geoengineering solution" currently being investigated by NASA (Crutzen, 2006). It is proposed that one million tonnes/year of sulphate aerosols are injected 16km into the upper atmosphere to increase the albedo of the earth's atmosphere, reducing global warming. This essentially simulates the radiative

effect of a large volcanic eruption, with models predicting a substantial warming of winter temperatures in the Northern Hemisphere. There is also lot of uncertainty about acid rain fallout and the impact on precipitation and temperatures in the stratosphere. This seems a desperate attempt to initiate a 3°C cooling to offset 2°C of global warming. Having sat through days of talks describing practical adaptation and mitigation solutions to a shifting climate, I found the whole concept a little hard to swallow.

But drastic times call for drastic measures. We learned that the planet is currently in a “non-analogue” state when the environmental conditions experienced today have no historical counterpart any time in our geologic past. According to evidence from ice-core records drilled from Dome Concordia (Dome C) in Antarctica, the closest we get to finding global temperatures somewhat similar to present is close to 800,000 years ago (EPICA, 2004). During that period, there were nowhere near the 6.6 billion people with the technology to alter the ecological systems the Earth houses today.

CSIRO’s Michael Raupauch, from the Global Carbon Project, explained that global growth in carbon dioxide emissions from fossil fuels was four times greater in the 2000–2005 period than in the preceding ten years. Despite efforts to reduce carbon emissions, the global growth rate in CO<sub>2</sub> was 3.2% in the five years to 2005 compared to 0.8% in the 1990 to 1999 period. Recent efforts to reduce emissions have had virtually no impact on emissions growth and effective caps are urgently needed. Raupauch stated that on our current path, we will find it extremely difficult to rein in carbon emissions sufficiently to stabilise the atmospheric CO<sub>2</sub> concentration at 450 ppm; even 550 ppm will be a challenge.

Currently, we are on track for the Intergovernmental Panel on Climate Change (IPCC) A1B “worst case” scenario trajectory. As outlined in the recently released *Climate Change 2007: The Physical Science Basis: Summary for Policy Makers*, this is likely to be shaped by an increasingly frequent series of extreme climate episodes in a rapidly unstable and unpredictable climate system. Due to environmental inertia, even when anthropogenic emissions do begin to decrease, atmospheric CO<sub>2</sub> will continue to rise for up to a century.

This concept is often referred to as our “commitment” to climate change. During this period, global temperatures will continue to increase, locking the world into continuous feedbacks of unforeseen climatic change. Effective management of the Earth system under such conditions will depend on early and consistent actions. Action is needed now, not in some vague, distant future. This had me (and many others) squirming in my seat: what to do?

At the close of the meeting, Conference Co-Chair Gordon McBean (Canada) presented the *Statement of the Beijing Conference on Global Environmental Change*, formulated

as an urgent call by the scientists to society and policy makers to collaborate in the face of an ever faster changing environment. They noted: *In this era of human activities modifying the planet on a global scale, we are concerned for the continuing adverse affects on the global environment and the resulting serious threats to sustainable development of human society.*

The urgent need for improving communication between scientists with the broader public was identified, stating it was our role to: *Take responsibility to mobilise knowledge for action, and provide society with the scientific information to better meet present and future needs within the context of sustainable development.*

This left me with mixed feelings. I was concerned at the distinct lack of Australian and New Zealand scientists at these meetings. More importantly, I was concerned about the lack of research opportunities available in global change in Australasia. On a positive note, it gave me the final motivation to begin engaging in science communication work.

I strongly encourage young scientists to keep an eye out for these inter-disciplinary conferences. They provide an outstanding opportunity to expand knowledge of global change, to educate others about your field and learn how your work fits into the “bigger picture”.

We have a responsibility as scientists to get involved in communicating to the broader community and across disciplines if the breakthroughs needed to face climate change are to be realised. Global environmental change is an immense social and technological call-to-action that will require collaboration on every scale. As is clear from the latest IPCC report, it is one we cannot afford not to heed.

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# Plant Macrofossil Workshop

University of Adelaide 15–19 January 2007

## John Tibby

Geographical and Environmental Studies  
University of Adelaide South Australia 5005  
Email: john.tibby@adelaide.edu.au

With support from the ARC funded Environmental Futures Network, John Tibby and Jennie Fluin organised a plant macrofossil workshop at the University of Adelaide. The course was delivered primarily by Drs Carl Sayer and Tom Davidson of the Environmental Change Research Centre, University College London, and attended by participants from University of Adelaide, ANU, University of Canberra, Flinders, Macquarie and Monash Universities, University of Tasmania and the Environment Protection Authority, Victoria. The workshop was biased towards applied issues and examined how plant seeds, leaves and other assorted “bits” can document changes in aquatic plant composition and abundance. Workshop topics included:

- determining restoration targets using plant remains,
- the ecological structuring role of plants in shallow lakes,
- production, dispersal and preservation of plant remains.

Examples of Australian work were presented by Tara Lewis (Monash), Michael Reid (Canberra), Susan Rule (Monash) and John Tibby (Adelaide). Tara Lewis and Sue Rule focussed on using the plant record for reconstructing climate change in, respectively, Western Victoria (focussed on Lake Surprise) and NE Queensland (Lynch’s Crater). Michael Reid’s talk highlighted the utility of plant-associated animals for understanding European impacts on plant cover (particularly in the absence of plant remains themselves). John discussed European impacts on plants from the coastal lakes, Lake Ainsworth (NSW) and The Coorong (SA), the latter representing the work of Honours student Jenny Dick. Both Tara Lewis and John Tibby’s presentations noted recent localised extinctions of plants from study sites, while Sue Rule’s research showed how the macrofossil data has helped her to identify unknown pollen types which then provided a longer record of the plant’s presence in the landscape.

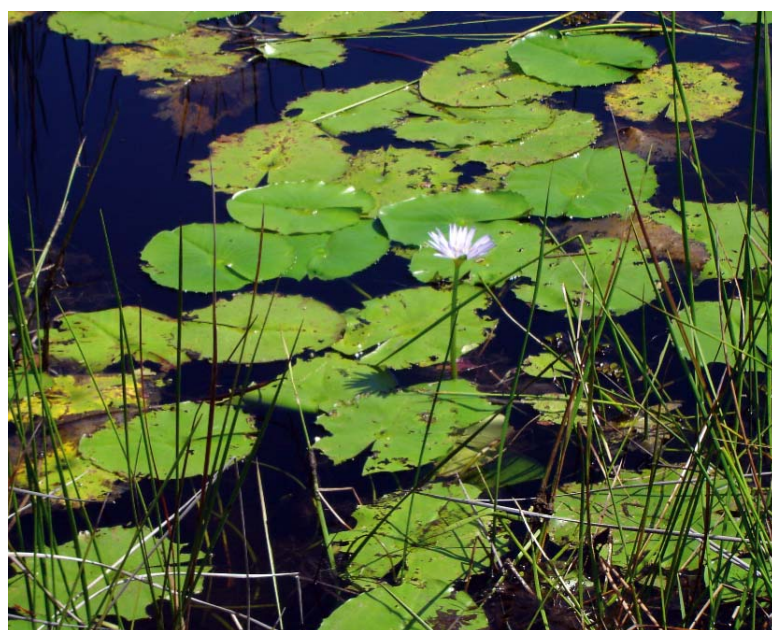
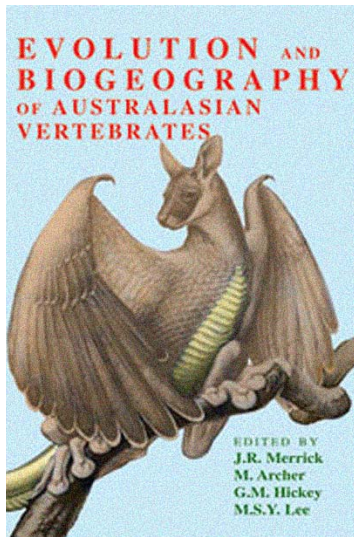


Figure 1. *Nymphaea* sp., 18 Mile Swamp, Stradbroke Island, Queensland, a taxon which leaves identifiable remains including seeds.

The workshop was a great success, tremendous fun (including many references to the recent Ashes campaign and poetry delivered by presenters and participants alike) and illustrates that we are at the tip of a large and interesting iceberg in terms of our understanding of pre-contact plant communities in Australia.

### For further information see

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***Evolution and Biogeography of Australian Vertebrates***

Edited by J.R. Merrick, M. Archer, G.M. Hickey and M.S.Y. Lee  
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**Summary of features**

This large reference volume (Reduced A4: 275 x 210 mm, 942 pp.) provides a comprehensive overview of the knowledge of vertebrate diversity within Australasia, together with discussion of the factors that influenced the evolution and distributions of the faunas we see today. By considering the major forces shaping the extant vertebrate assemblages, using new techniques and strategies, we can formulate ideas about how to best conserve and manage these dynamic vertebrate groups as well as the ecosystem complexes on which they depend.

The 38 chapters are divided into 7 major sections. The first group of chapters covers the general topics of classification and evolution, together with geologic and climatic processes influencing environments and biogeography of parts of Australasia. Then follow 5 sections that each concentrate on a major vertebrate grouping, from primitive jawless fishes to specialized marine mammals and humans. The final section focuses on the future, describing some of the latest techniques and systems used for assessing biodiversity and assisting in conservation management.

Each chapter is fully sourced and illustrated with line diagrams, as well as other figures next to the relevant text. Attempts have been made to maintain a clear, informal style for readers without specialized knowledge and a humorous or irreverent essence when appropriate. The 136 colour plates are distributed throughout the book as close to the related chapters as possible. A general combined Index is at the back.

Over 50 leading researchers, from all parts of Australasia and elsewhere, have combined as authors and co-authors to make this a ground-breaking volume of international significance. This resource book follows in the tradition of Vertebrate Zoogeography & Evolution in Australasia (edited by Archer and Clayton) released in 1984. This new title is a natural development providing a balanced updated coverage of the field. It is hoped this book will:

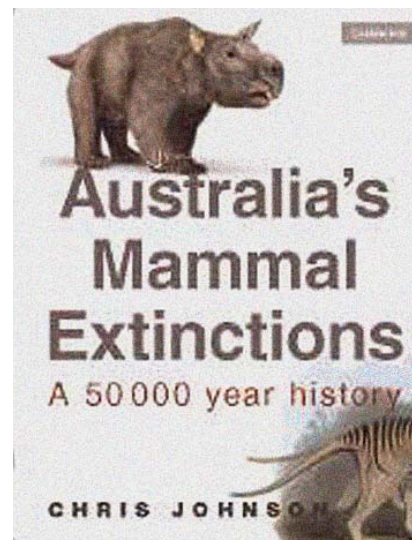
- increase awareness of the unique Australasian vertebrate faunas;
- emphasise the importance of Australasian environments and the associated biodiversity
- provide background for decisions that limit biodiversity loss in the region – against the trend in the current world-wide extinction crisis.

• • • • •

***Australia's Mammal Extinctions: A 50,000 Year History***

Chris Johnson  
 Cambridge University Press 2006  
 ISBN/EAN: 0521686601/9780521686600  
 Paperback: AU\$49.95

Mega fauna extinctions in Australia and the Americas have attracted the attention of scholars with diverse approaches to the expanding databases from geology, biology, archaeology and the dating that constrains them. James Cook University ecologist Chris Johnson scrutinises an impressive array of records relevant to Australia's mammal extinctions, using numerical modelling and modern ecological research to inform debate on the much-discussed Late Quaternary megamammal extinction as well as the smaller mammals lost since 1778. Well-written natural histories of Australian mammals are set against a background of evolutionary trends and Quaternary climatic and environmental change, with exquisite colour paintings of recently-extinct marsupials and rodents, and colour photos of extant marsupials and



remnant vegetation, illustrating what has been lost and the much-reduced endangered fauna we still have.

In evaluating the probable cause(s) of the Australian extinctions, Johnson methodically tests multiple working hypotheses (Chamberlin 1890), using the strong inference procedure at the heart of the scientific method, which leads to the logical exclusion of one or more alternatives. And as Platt (1964) reminded us, progress is seriously slowed when a logical conflict of ideas degenerates into the kind of personal attack that currently plagues extinction debates on both sides of the Pacific Ocean. Johnson's analysis excludes climate change and hyperdisease, because the available data does not fit critical predictions of either hypothesis, and no doubt some will dispute his conclusion that predation is the most likely candidate: the first human colonists caused large mammal extinctions *ca.* 45,000 years ago, then a rapid human population increase in the Late Holocene (and introduction of the dingo) primed a depleted fauna for the European extinction of small-medium sized mammals since 1788, particularly by the introduction of foxes and cats.

Addressing and updating issues raised in Tim Flannery's 1994 book *The Future Eaters*, Johnson wryly notes: *At the risk of oversimplification, the prehistory of Australia can be divided into two distinct ecological periods: before and after 6 kyr ago.*

Where Flannery speculated that 'fire-stick farming' was important soon after the Late Quaternary extinctions took out all the largest herbivores, Johnson considers that the evidence, for example from charcoal particle counts in lake and marine cores,

does not convincingly demonstrate widespread anthropogenic burning. However, increasing charcoal peaks through the Holocene probably do document the mosaic burning practices of a rapidly increasing human population, which the Jones (1969) thought experiment teleported back to megafauna extinction time. And where some have proposed rewilding experiments involving large herbivores, Johnson suggests that an increased dingo population (to suppress predation by foxes and cats) would better serve our remaining endemic mammals. It is not hard to imagine, despite the author's persuasive argument, many necks reddening at such a prospect.

*Australia's Mammal Extinctions* is handsomely produced, a very good read, and highly recommended for both academic and non-specialist audiences.

– Reviewed by Richard Gillespie

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## ANZGG CONFERENCE 2008

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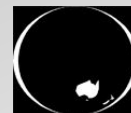
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**Ian Houshold**, Dept Primary Industries and Water,  
Tasmania, Australia Email [Ian.Houshold@dpiw.tas.gov.au](mailto:Ian.Houshold@dpiw.tas.gov.au)  
T (03) 6233 3868 F (03) 6233 3477 M 0419 744 500

**Dr Tim Cohen**, Research Fellow  
School of Earth and Environmental Sciences  
University of Wollongong NSW, Australia, 2522.  
Email [tcohen@uow.edu.au](mailto:tcohen@uow.edu.au)  
T (02) 4221 5318 F (02) 4221 4250



Cradle Mountain, western Tasmania. Photo by Tim Barrows.



**A Late Quaternary palaeoenvironmental investigation of the fire, climate, human and vegetation nexus from the Sydney Basin, Australia**

MANU P. BLACK (PhD)  
University of New South Wales

It is widely believed that Australian Aborigines utilised fire to manage various landscapes however to what extent this use of fire impacted on Australia's ecosystems remains uncertain. The late Pleistocene/Holocene fire history from three sites within the Sydney Basin, Gooches Swamp, Lake Baraba and Kings Waterhole, were compared with archaeological and palaeoclimatic data using a novel method of quantifying macroscopic charcoal, which is presented in this study. The palynology of the three sites was also investigated. The Gooches Swamp fire record appeared to be most influenced by climate and there was an abrupt increase in fire activity from the mid-Holocene perhaps associated with the onset of modern El Niño dominated conditions. The Kings Waterhole site also displayed an abrupt increase in charcoal at this time however there was a marked decrease in charcoal from ~3 ka. Similarly Lake Baraba displayed low levels of charcoal in the late Holocene. At both Kings Waterhole and Lake Baraba archaeological evidence suggests intensified human activity in the late Holocene during this period of lower and less variable charcoal. It is hence possible that Aboriginal people dominated fire activity in the late Holocene perhaps in response to the increased risk of large intense fires under an ENSO-dominated climate became more prevalent. The fire history of the Sydney Basin varies temporally and spatially and therefore it is not possible to use a single type of fire regime as a management objective. There were no major changes in the composition of the flora at all sites throughout late Pleistocene/Holocene although there were some changes in the relative abundance of different taxa. It is suggested that the Sydney Sandstone flora, which surrounds the sites, is relatively resistant to environmental changes. Casuarinaceae was present at Lake Baraba during the Last Glacial Maximum and therefore the site may have acted as a potential refugium for more mesic communities. There was a notable decline in Casuarinaceae during the Holocene at Lake Baraba and Kings Waterhole, a trend that has been found at a number of sites from southeastern Australia.

**Late Quaternary Environments and Climate History at Lakes Bolac and Turangmoro, Western Victoria, Australia**

ELLYN J. COOK (PhD)  
Monash University

A palaeoecological record produced from Lakes Bolac and Turangmoro details the changing nature of vegetation patterns, lake levels and climate in the drier part of the Victorian Western Plains over approximately the last 90,000 years. In addition to the routine palynological proxies of pollen, spores and charcoal, a range of non-pollen palynomorphs was analysed and their usefulness as palaeoecological indicators in Australia was evaluated. A range of transfer functions was also developed to relate modern (pre-European) pollen distributions to climatic parameters in mainland southeastern Australia. The functions that reconstruct summer, annual and winter rainfall and temperatures were found to be the most robust while temperature of warmest and coolest periods, and moisture indexes are also strong. Application of the functions to the fossil data from Lakes Bolac and Turangmoro produced estimates which are corroborated by trends seen in other lines of evidence, confirming this new approach as an additional reliable technique for quantification of the past climates of mainland southeastern Australia.

During marine isotope stage (MIS) 5.1 and mid MIS 3 the palaeoecological record indicates regional vegetation composed of open woodland dominated by *Allocasuarina luehmannii* type with low numbers of *Banksia*, *Eucalyptus* and other Myrtaceae under which a diverse understorey developed. During these times Lake Turangmoro held fresh water of varying depths. Estimates derived from pollen data show these periods received annual precipitation higher than today which was more equally distributed between summer and winter. Strong contrast in seasonal temperature extremes during MIS 5.1 appears to relate to corresponding peaks and troughs in insolation received at the site. The degree of representation of MIS 4 and MIS 3 in the record is uncertain owing to discontinuities resulting from the lake having periodically dried. Luminescence dating indicates a change to open grassland-steppe occurred shortly after 47,000 years BP and lake levels fluctuated considerably before the lake became shallow and saline. Open

grassland-steppe continued through MIS 2 with almost no presence of trees while the aquatic flora reflected further lake level declines and increasing salinity. Driest conditions, indicated by deflation of lake sediments during lunette building, are dated to between ~18000 and ~11000 years BP. Open woodland in the early Holocene was dominated by *Allocasuarina verticillata* type until partial replacement by *Eucalyptus* around 7–8000 years ago when the vegetation cover present at European arrival was established. Increased contrast between summer and winter precipitation and much reduced contrast in temperature parameters marked the establishment of present day climatic patterns for this part of Western Victoria. Considerable evidence for mean annual temperatures higher than today in the early Holocene, increased regional precipitation during the mid Holocene and late Holocene drying suggested by other studies from the region was discernable in the palaeoecological record, lake level history and the quantitative climatic estimates from Lakes Bolac and Turangmoro.

Comparison of the palaeoecological record with those from Lakes Wangoom and Terang on the wetter part of the western plains shows good correspondence in the upper parts of the sequences but, beyond this, a lack of reliable chronologies for the latter records prevents the establishment of absolute correlations. However, changes in vegetation and climate patterns were sufficiently distinct to allow exploration of climate forcing and representation in all three sequences was found to follow changes in the southern hemisphere mid-latitude westerly circulation. This finding suggests that patterns of vegetation change recorded in pollen records from southeastern Australia are strongly influenced by local insolation in addition to northern hemisphere forcing.

**Environmental Boundaries in the Sydney Basin during the Holocene**

ROSALIND JAMES (PhD)  
School of Human and Environmental Studies,  
University of New England

This thesis tests selected environmental indicators against a chronological record derived from estuarine sediments in order to assess the possibilities of disentangling human from natural impacts on the environment in the Sydney region during the mid to late Holocene. Results show that

environmental conditions in south east Australia during the mid to late Holocene, if the indicators from the Sydney Basin are representative, were anything but stable, albeit within a smaller range than the greater perturbations of the Glacial Cycle. Although there are well known problems associated with the use of saline estuarine deposits, the lack of the desiccation and degradation of the sediment record which mars most inland Australian wetland sedimentary sites more than makes up for these disadvantages. Estuarine muds and sands give a continuous and relatively stable record, once the singular geochemistry of sulphate soils is understood and controlled for in the analysis. An achievement of this work was to blend the age profiles of Lead-210 and Carbon 14 isotopes, and to some extent bridge the troublesome gap of the last 500 to 1000 years, so that for the first time European impact can be compared directly with the period immediately preceding it. This work shows that there is a wealth of evidence available in the sediment sinks of the Sydney estuaries, and that that evidence, even within the limits of the analyses used, plainly shows periods of sharp change. The changes were overwhelmingly driven by larger scale climatic changes, with two turning points: one around 2800–3000 cal years BP, and another around 500 years BP. These turning points showed up over several sites and wide areas of the Sydney Basin. Human land use practices such as burning may well have taken advantage of climate shifts, but were very much secondary to the effects of the larger meteorological changes. Even the much greater impact of European settlement is sometimes negated by environmental shifts: Aboriginal land use impact may have been even less able to prevail against climatic shifts which are ultimately of extra-terrestrial origin. The results of this study casts doubt on the efficacy of charcoal counts on their own as an adequate measure of fire history, and strongly suggests that charcoal in the sediment record is sometimes more useful as an erosion marker than an account of actual fire history, whether human or natural. However, in some cases, charcoal used in conjunction with other analyses, particularly magnetic susceptibility and geochemistry, can pinpoint extreme fire events. The most valuable environmental indicator proved to be phytoliths, although these only gained their full usefulness in parallel with the other,

more arduous and less spectacular methods, such as stratigraphic logging, magnetic susceptibility and geochemistry, within the limits of the geochronology. The work lays a useful base for interpreting the Holocene in the Sydney basin on which more sophisticated and expensive methods can be applied to get a more exact picture. However, the hard and necessary work of correctly identifying and coring representative sites will always be the precursor of more complicated methods. This thesis presents the hard-won results of such work.

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### **From Midden to Sieve: The Impact of Differential Recovery and Quantification Techniques on Interpretations of Shellfish Remains in Australian Coastal Archaeology**

ROBYN A. JENKINS (Honours)  
School of Social Science, University of  
Queensland rajenko@bigpond.net.au

Experimental mechanical sieving methods are applied to samples of shellfish remains from three sites in southeast Queensland, Seven Mile Creek Mound, Sandstone Point and One-Tree, to test the efficacy of various recovery and quantification procedures commonly applied to shellfish assemblages in Australia. There has been considerable debate regarding the most appropriate sieve sizes and quantification methods that should be applied in the recovery of vertebrate faunal remains. Few studies, however, have addressed the impact of recovery and quantification methods on the interpretation of invertebrates, specifically shellfish remains.

In this study, five shellfish taxa representing four bivalves (*Anadara trapezia*, *Trichomya hirsutus*, *Saccostrea glomerata*, *D. deltoidea*) and one gastropod (*Pyrasmus ebeninus*) common in eastern Australian midden assemblages are sieved through 10mm, 6.3mm and 3.15mm mesh. Results are quantified using MNI, NISP and weight. Analyses indicate that different structural properties and pre- and post-depositional factors affect recovery rates. Fragile taxa (*T. hirsutus*) or those with foliated structure (*S. glomerata*) tend to be overrepresented by NISP measures in smaller sieve fractions, while more robust taxa (*A. trapezia* and *P. ebeninus*) tend to be overrepresented by weight measures. Results demonstrate that for all quantification methods tested a 3mm

sieve should be used on all sites to allow for regional comparability and to effectively collect all available information about the shellfish remains.

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### **A Method for Reconstructing the Quaternary Climates of Australia Using Fossil Beetles**

NICK PORCH (PhD)  
School of Geography and Environmental Science,  
Monash University  
Current Address: Archaeology and Natural History,  
RSPAS, The Australian National University,  
Canberra, ACT 0200 nicholas.porch@anu.edu.au

This thesis presents a method for reconstructing Australian Quaternary climates using the modern climatic requirements of beetle taxa. The method of climatic reconstruction utilised is the coexistence (overlap) of the climatic ranges of taxa in the assemblages. In order to test the performance of the method and to examine the utility of various climatic parameters, bioclimatic profiles for 735 taxa of Australian beetles were constructed. This involved the accumulation of distributional data from a wide range of published and unpublished sources, geocoding of the localities (>5900), and analysis using the computer program BIOCLIM to produce climatic summaries for each taxon. Using this dataset, the ability to predict modern values (on the basis of modern assemblages), using the range of BIOCLIM temperature and precipitation parameters, was tested by comparing beetle-predicted with actual climate at a range of sites from across Australia.

The results of these analyses suggested the best performing BIOCLIM temperature parameters were *Annual Mean Temperature*, the 'summer' or warm season temperature parameters *Temperature of the Warmest Quarter* and *Maximum Temperature of the Warmest Month*, and the winter parameters *Temperature of the Coldest Quarter* and *Minimum Temperature of the Warmest Month*. Contrary to the Northern Hemisphere, where the Mutual Climatic Range method uses a measure of seasonality (Trange), the *Annual Temperature Range* was found to perform poorly in the observed *versus* predicted experiments. In terms of precipitation the most useful parameters were found to be *Mean Annual Precipitation*, and *Precipitation of the Warmest* and *Precipitation of the Coldest Quarters*. Critical consideration of these temperature and precipitation parameters suggests

that, although they perform well under the present climate space, complications may arise under alternative climate space conditions that almost certainly existed during the Quaternary. For this reason winter temperature parameters and subsequently annual temperature reconstructions need to be regarded with caution; the absence of cold continental climates today in Australia limits the potential for reconstruction of such climates in the past.

Summer temperatures (which are less likely to be influenced by climate space limitations, except at the extreme edges of climate space), were routinely estimated to within 1°C of the actual value at modern test sites – the precision increasing with increasingly large assemblages. For precipitation parameters the relationships are more complex. Although coexistence methods yielded acceptable results there are reasons to treat the actual-*versus*-predicted results with caution. The principal reason is related to the distribution of high precipitation environments in Australian climate space; relative to drier areas, they are infrequent and therefore less commonly represented in the bioclimatic profiles of taxa. It was subsequently determined that, although the maximum of the predicted range for a precipitation parameter is likely to be artefactual, the minimum is reliable. With these results and considerations in mind, the methods were applied to a series of five Quaternary assemblages.

Results from Stony Creek Basin, an Early Pleistocene lake record in central Victoria, indicates that the climate, during periods represented by sclerophyll dominated pollen assemblages, was warmer and much wetter than it is today, especially in summer. The beetle assemblage lacks modern analogues and consists of wet sclerophyll forest/rainforest microthermic taxa characteristic of the foothills and uplands of southern Australia, occurring with taxa of wet sclerophyll forest/rainforest that are generally associated with the eastern Australian escarpment. There is the probability of a range of extinct taxa in the assemblages, although it is possible these may be extant, but uncollected. The existence of summer rainfall climates in southern Australia in the Early Pleistocene, indicates that the switch to the modern climate system (winter dominated rainfall) occurred later than previously suspected.

The assemblage from the site of Yarra Creek, on King Island between the Australian mainland and Tasmania, dates from marine isotope stage (MIS) 5, although its exact age (MIS substage) is impossible to ascertain with current chronological data. The beetle assemblage is associated with a cool temperate rainforest micro- and macro-flora and, unsurprisingly, contains a range of wet sclerophyll forest and rainforest inhabiting beetle taxa. Climate estimates suggest a summer temperature regime very similar to the present with more summer rainfall and similar, or more, annual precipitation. The reconstruction of winter temperatures and annual range suggest a more continental climate than present, although this may be an artefact of the lack of modern distribution data from extremely maritime climates, like that of King Island today.

Spring Creek is a megafauna-containing site that was initially believed to be last glacial maximum in age but has been demonstrated to be significantly older; AMS radiocarbon determinations on plant and insect macrofossils collected during this project showed the site to be older than 40,000 radiocarbon years BP. The insect assemblage is associated with a pollen assemblage characterised by the absence of trees, which would be considered 'glacial' by comparison with pollen assemblages from other sites in southeastern Australia. Climatic reconstructions based on the beetle assemblages suggest a more continental climate (warmer summers, colder winters, increased range), with rainfall similar to the present day. Limited data from the plant macrofossil record indicates a lowland flora. The caddisfly fauna is also of a characteristically lowland type.

A small assemblage from the site of Pipe Clay Lagoon, in lowland eastern Tasmania, is dated to the MIS 3/2 transition. The record is dominated by aquatic and hygrophilic taxa but includes several species that are today restricted to humid forests of southeastern Australia and Tasmania. Climatic reconstructions suggest summer temperature were similar to the present, possibly slightly warmer, and winter temperatures slightly colder. Somewhat surprisingly, several taxa suggest wetter summer and annual climates, which contrasts with the general view that last glacial, especially the latter part of MIS 3 and MIS 2, were colder and drier than the present. The Pipe Clay Lagoon reconstruction suggests this may be a simplistic view of this period.

Finally, a late Holocene assemblage from Lake Keilambete is examined to test the potential for Holocene climate reconstruction, in Australia, using beetle assemblages. The assemblage, recovered from the edge of the receding lake, was found immediately below the lowermost of two distinctive isochronous hardpans that outcrop around the lake. It contains a mixed assemblage of aquatic and terrestrial taxa, the terrestrial component indicating the presence of grassland and/or grassy woodland. Climate reconstructions suggest temperature regimes almost identical to the modern regime, but several taxa suggest slightly more summer rainfall than presently falls.

Application of the beetle-based methods to Quaternary assemblages proved the utility of the methods developed for both temperature and precipitation reconstruction. The combined reconstructions of seasonal, especially summer, temperature and precipitation regimes meant key questions regarding the nature of Quaternary climates were answered. The indications, from Spring Creek and Pipe Clay Lagoon, that glacial climates may at least partly be characterised by summer climates similar to those of the present is particularly significant. Unfortunately, the potential influence of altered climate space across the region on the nature of winter and therefore annual climates means that the significance of winter climates in determining the nature of glacial environments, especially vegetation, is unknown and potentially unknowable.

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### **Modern fluvial process and prior landscape history in an arid-zone river: Fowlers Creek, New South Wales, Australia**

GRESLEY A. WAKELIN-KING (PhD)  
Department of Earth Science  
La Trobe University

Fowlers Creek is a small arid-zone ephemeral river. It has five fluvial styles, spread over three geomorphic subregions: the Uplands (the source of the creek's water and sediment), the Trunk (the central reaches, constrained by outcrop), and the Terminal Floodout (where it diminishes and disappears).

Fowlers Creek is dominated by fine sediments, including a high proportion of mud aggregates which directly influence the fluvial style.

In the proximal Uplands, the creek is a discontinuous ephemeral stream, showing a sequence of channel types (gully-arroyo-

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## Thesis Abstracts CONTINUED

intermediate floodout). The fluvial processes fluctuate around the threshold between valley-floor strength and channel incision. The sediments are dominated by floodplain muds and flat-lying sheetflow deposits. The intermediate floodouts are pinned at tributary confluences, reflecting formation during large floods; they are drought refugia, and are key components of the ecological landscape. In the mid-Uplands, the creek forms a mobile-channel, unstable-floodplain assemblage. The fluvial processes are chaotic and threshold-driven, characterised by catastrophic reach-scale channel relocation. Sediments are a patchwork of fine floodplain deposits around shoestring sands.

In the Trunk, Fowlers Creek shows coexisting anabranching and pool-and-riffle morphologies. Fluvial characteristics (e.g. channel number, type, and capacity, channel and floodplain roughness, hydraulic radius) are highly variable, indicating very complex flow dynamics.

In the Terminal Floodout, the channel is meandering, and fluvial deposits include point bars and overbanks. In the proximal and central Floodout fan-head autocyclic and/or underlying tectonic influences promote channel incision as well as meandering.

Although it has been postulated that the rivers of western NSW have undergone a complete change of style as a result of

widespread post-European erosion, the present study shows that the modern fluvial styles are not different from those of the past. Instead, severe but localised erosion along linear landscape disturbances has increased erosion in some parts of an already-unstable system.



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PH: +61 (0) 2 6125 2059 FAX: +61 (0) 2 6125 5544  
Editor@aqua.org.au

**Public Officer** Dr Matt Cupper  
School of Earth Sciences The University of Melbourne  
Melbourne, Victoria 3010 Australia  
PH: +61 (0) 3 8344 6521 FAX: +61 (0) 3 8344 7761  
cupper@unimelb.edu.au

