# Late Pleistocene Glaciation of the Kosciuszko Massif, Snowy Mountains, Australia.

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The Kosciuszko Massif in the Snowy Mountains represents the only area of irrefutable Pleistocene glaciation on the Australian mainland. However, considerable controversy dates back to the 19th century as to the timing and extent of the glaciation. To review the evidence, we remapped glacial landforms on the Massif and found that the maximum extent of glaciation was within the 'probable' limits drawn by Galloway (1963). There is evidence for at least 2 glaciations, the first consisting of at least one advance and the second consisting of at least three advances. To place numerical ages on the glaciations we exposure-dated 24 boulders from the moraines sequences at Blue Lake and Lake Cootapatamba, making them some of the best dated sequences in the Southern Hemisphere. Exposure dating is based on measuring the accumulation of cosmogenic isotopes in minerals from rock surfaces, in this case $^{10}Be$ in quartz. The dates indicate that the first glaciation (the Early Kosciuszko) which was also the most extensive, occurred ~55-65,000 years ago. The last glaciation, the Late Kosciuszko, consisted of three advances which were progressively less extensive and occurred between ~15,000 and ~35,000 years ago.

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# WHAT IS THE NATURE OF THE RELATIONSHIP BETWEEN THE AUSTRALIAN VEGETATION AND THE CLIMATE?

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Past climates have been inferred from vegetation structure derived from pollen studies by assuming analogous relationships between past and present vegetation and climate. This approach is flawed as the vegetation structure will also be affected by changes in the partial pressure of $CO_2$ in the atmosphere, irrespective of any change in climate. During the Last Glacial Maximum the partial pressure of $CO_2$ was about half of its present value (Barnola, 1987).

The vegetation structure can be conveniently summarised by fPAR, the fraction of photosynthetically active radiation absorbed by the land surface. FPAR is a continuous variable that can be estimated from satellite spectral data. The present fPAR can be shown to be correlated with the structure of the natural vegetation, and with the availability of soil moisture.

I have developed a model that predicts the effect that this change in the partial pressure of $CO_2$ would have on fPAR. I am also developing a model that allows prediction of fPAR from pollen data. Any differences between the fPAR determined from LGM pollen studies and fPAR predicted for present climate and LGM $CO_2$can mostly be attributed to a change in soil moisture. However, it may not be possible to unravel changes in precipitation and temperature from soil moisture changes.

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## Pluvial Aspects of the LGM: evidence from SE Australia

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Conditions of the last glacial maximum (LGM) centred on 20ka were dramatically different from those of today. While evidence of widespread dune building and lake floor deflation contributes to evidence of aridity, such evidence varies depending on the location from which it is derived.

Throughout the Murray Basin in southeastern Australia, conditions during this interval were greatly influenced by a system of groundwater-surface water interaction substantially different from that in the same area today. Groundwater levels were regionally high following a period of positive (wet) hydrologic conditions in which components of both local and regional recharge combined to maintain regionally high water tables. Such conditions persisted well into the period of the LGM even though local rainfall may have been much reduced.

Lake basins marginal to upland catchments provide evidence of a relative abundance of water during this interval, with levels often exceeding those in the same systems today. These conditions contrast with records from basins more remote from catchment sources where lake floor deflation and pelletal clay or gypseous dune building dominated over surface water controls. While Lakes Tyrrell, Frome, Eyre and the those of the Willandra system were subject to basin deflation at this time, Lake Urana (Murrumbidgee catchment) and lakes adjacent to the Grampians in western Victoria retain evidence of shoreline dune building under high water-level conditions.

The apparent contradiction between arid conditions in systems far removed from effective catchments and those marginal to catchment sources is a function of improved catchment efficiency during this period of greatly reduced temperature regimes. Major changes in catchment coefficients, associated with increased run-off from slopes often affected by periglacial environments, were sufficient to maintain at least ephemerally high magnitude events in streams feeding adjacent basins. Additionally, depressed evaporation regimes meant that relatively little annual discharge was necessary to maintain local lake levels.

By contrast, in areas distal from catchments of increased efficiency, surface recharge was insufficient to replace evaporative loss. These lakes fell, many becoming groundwater discharge systems with consequent production of saline deflation products compared to the clean quartz sand beaches and dunes derived simultaneously from catchment margin basins, a feature of special relevance to groundwater hydrology. The contrast in surface water budgets coincides with zonal changes from groundwater recharge to discharge systems across the plains

In this system hygrologic gradients from catchments to plains were greatly increased. The existence of pluvial systems near the foothills contrasting with high groundwater, arid conditions on the plains provides a salutary warning to those of us who seek simple climatic solutions. The dilemma of simultaneous existence of environments both wetter and drier than today is thus more apparent than real. Both co-existed, but in substantially different hydrologic settings.

# SEA LEVEL EVENTS IN THE LAST GLACIAL CYCLE - THE UMPTEENTH WORD FROM HUON PENINSULA,

# PAPUA NEW GUINEA

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Oxygen isotope data from deep sea cores and stratigraphic data from coral terraces in Papua New Guinea indicate significant sea level fluctuations that cannot be related to orbital forcing of climate. Four events with amplitudes of 10-25 m occurred between 30 and 63 ka. Earlier events are recognised at about 72, 90 and 115 ka, and an apparently very large event has been reported at 130 ka, during the Penultimate deglaciation. TIMS U-series dates from the coral terraces suggest that sea level rises between 30 and 63 ka correlate with isotopic interstadials 8, 12, 14 and 18 in Greenland but the amplitudes, rates, and peak timing of these events cannot be determined from dating alone.

A computer model of reef growth was used to search for the sea level curve that generates the best match to topographic, stratigraphic and age data from Huon Peninsula. Starting from a user-defined initial surface, the model generates successive reef profiles at 200-year time steps in response to given sea level changes and tectonic movements. Coral growth rate is assumed to be constant (G) from sea level to a critical depth Zc and decreases linearly below that to zero at a cut-off depth. Input data include user-defined rates for G, tectonic uplift (U) and coastal cliff retreat (E). Uplift can be uniform or intermittent. Model sequences were compared with dated, closely surveyed sections at Bobongara and Kanzarua for 30-75 ka period; for the period 75-140 ka, the Kwambu and Kwangam sections were used.

The search for a sea level curve commenced with the HP2 curve of Chappell and Shackleton (1986). Key parameters were varied, including timing, maximum, minimum and shape of each sea level oscillation. Oscillations also were deleted or inserted. Best-fit simulations are those that match the topographic profiles, facies structure and age measurements from observed terrace sequences. No simulations match all data perfectly but good-fit models are generated by sea level curves that define a narrow envelope with prominent peaks at 36, 44, 52 and 60 ka, and lesser peaks at 32.5, 49, 72, 90 and 115 ka. It proved difficult to match observations with simulations that included a large excursion at 130 ka. Peaks at 36 and 44 ka coincide Heinrich events H4 and H5; the peak at 60 ka and H6 may also coincide. Good-fit simulations indicate that sea level was rising relatively slowly (1-3 $m.ka^{-1}$) for several thousand years before these events, suggesting that H-events may be triggered when rising sea level destabilises the ice sheets.

# LATE HOLOCENE DIVERSION AND EXTINCTION OF 3 LARGE TIDAL RIVERS IN NORTHERN AUSTRALIA: A SINGULAR CLIMATIC EVENT?

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Large mangrove swamps that formed in north Australia estuaries during the last stage of Post-glacial sea level rise were replaced by prograded coastal plains, estuarine wetlands and macrotidal rivers, after sea level stabilised 6000 years ago. Geomorphologic evidence shows that three large macrotidal rivers - the Adelaide, Mary and Blyth Rivers - were diverted or blocked while their coastal plains were prograding; the Adelaide avulsed and reoccupied an ancient channel through a bedrock passage, many km to the west; the Blyth was displaced eastwards, and the Mary became blocked so that the fluvial river afterwards dissipated in lowland swamps. Drilling and dating show that these events occurred between 3500 and 2000 years ago. However, blocking did not occur on smaller macrotidal rivers nearby (e.g. the Wildman and West Alligator), which, with their smaller catchments, should have been more susceptible.

There are no traces of beach ridges across the extinct estuaries of the Mary and Adelaide, ruling out damming during cyclonic storms. No sea level changes large enough to promote sediment infill between 3500 and 2000 years ago have been detected. A climatic explanation is possible: seaward flushing of sediment by wet season floods could have weakened during an unusually dry period, leading to blockage by sediment pumped tidally upstream by dry season tidal action. In support, a dry period between about 3500 and 2000 B.P. is recorded in a billabong sediment core from the South Alligator area. However, as the relatively small Wildman and West Alligator Rivers apparently did not become blocked, the threshold is sensitive. The key may be the presence of alternative channels, which existed for the Mary and Adelaide and may have existed for the Blyth; the fork is potentially a site for damming by sediment carried tidally upstream: a period of reduced wet season flooding would promote this.

The evidence does not permit any estimation of the intensity or duration of this hypothetical dry episode, and the chronologic constraints are loose: all three events occurred sometime after about 3600 B.P. and before 2000 B.P. (before 2600 in the case of the Blyth). Indeed, this is a case where independent palaeoclimatic information is needed, to understand certain dramatic palaenvironmental events.

# THE LATE QUATERNARY HISTORY OF THE GULF OF CARPENTARIA


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The Gulf of Carpentaria is an epicontinental sea (maximum depth 70m) between Australia and New Guinea, bordered to the east by Torres Strait (currently 12m deep) and to the west by the Arafura Sill (53m below current sea level). Throughout the Quaternary, during times of low sea-level, the Gulf has been separated from the open waters of the Indian and Pacific Oceans, forming Lake Carpentaria, perched above contemporaneous sea-level with outlet channels to the Arafura Sea.

A 4444-km ship-borne seismic survey of the Gulf of Carpentaria was performed by the U.S. Geological Survey in 1994. At least ten, and possibly up to 17, basin-wide transgressive/regressive cycles and episodes of subaerial exposure and erosion have been identified. In 1997, a coring expedition used a giant piston-corer deployed from the *Marion Dufresne*, in a joint Australian/French/USA operation, largely funded by the Australian Research Council and as part of the IMAGES program. Six sediment cores were collected to depths of between 4.2 and 14.9m below sea floor.

The recovered material suggests two or three marine/lacustrine cycles, with the uppermost transition dated to around 10ka. Iron-mottled horizons and calcrete nodules indicate episodes of subaerial exposure at basin margins, whilst in the deepest part of the Gulf, the marine/lacustrine transitions are commonly defined by facies changes. Detailed work, some still in progress, including physical data such as magnetic susceptibility, density and p-wave velocity of the enclosing sediments, sedimentary and grain-size analysis, microfaunal assemblages and geochemical studies, pollen, nannofossil and diatom identification and carbon-isotope measurements on bulk organic matter will better define the nature of these transitions.

Two cores (MD972128 and 29) in the north-west part of the Gulf, show the change from yellowish clays (below) to greenish grey marine muds (above) at 25 and 65cm depth. The microfossils in the lower section are indicative of a mixed environment with shallow water (*Ammonia* sp., *Elphidium* spp.). The palynology indicates a surrounding open swampy area. In the other cores, further to the south-east, nearer the depocentre of the Gulf, the transition occurs at 60-70cm depth, from dark grey crumbly clays (below) to marine sediments at the top. In the lower section, the microfossils indicate a fresh to saline palaeolake with *Ammonia* sp.,*Cyprideis* sp., *Ilyocypris* sp., *Cyprinotus* sp., *Ilyodromus* sp. and *Chara* sp. The pollen indicate an open swampy area with a few trees. The marine sediments at the top are similar in all cores and show a higher diversity of Foraminifera and Ostracoda, while pollen indicate an increase in woodland and mangrove vegetation type with New Guinean taxa.

# PALAEOENVIRONMENTAL RECORDS FROM GROUNDWATER DISCHARGE BASINS IN SOUTHWESTERN NEW SOUTH WALES

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Palaeoecological, geomorphological and sedimentary records are being studied at groundwater discharge complexes in southwestern New South Wales. These basins preserve a record of Late Quaternary lacustrine and aeolian processes, associated with either moist climatic phases with high groundwater and surface water levels, or drier deflationary periods. Susceptibility of these systems to quite minor changes in their hydrological budgets means that they may preserve a record of small magnitude climatic fluctuations, such as ENSO-type cycles, in addition to glacial and inter-glacial climate change. This research project involves stratigraphic and sedimentological analyses of the salt lake basin and arcuate dune sediments at a number of these complexes located in the semi-arid dune country to the west of the Darling River. Pollen and carbonized particle records from the lacustrine sequences will be used to determine past vegetation patterns and fire regimes. Optically Stimulated Luminescence (OSL) and AMS radiocarbon dating will be used to establish the timing of landscape changes and correlate geomorphic and ecological events. A palaeoenvironmental history for the last glacial cycle will be inferred using the proxy records.

# Palaeoenvironmental change on land and at sea in the vicinity of Cape Range of Western Australia: A 50,000 years record unravelled using numerous proxies on a deep-sea core.

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The upper 2.5m of a gravity core Fr10/95-GC17, taken offshore Cape Range in northwestern Australia, has been studied in great detail and, on average, samples were taken at 2 cm intervals. This core was taken at a water depth of 1,093 m and its location is 22°07.74'S 113°30.11'E. Above the site, salinity in December 1995 was 34.92 ‰, typical of the poleward-flowing Leeuwin Current water. Below that shallow watermass, obvious Indian Central Water [ICW] occurs with a maximum salinity of 35.65, and from 560 m water depth down to the sea floor, Antarctic Intermediate Water [AAIW] prevails with an average salinity of 34.45. Sea-surface temperature at the time of core collection was 25.7°C.

This core was chosen for an extensive study among a selection of 51 other cores taken during 2 oceanic cruises using the national facility *RV Franklin* along 2 transects between Perth, Java and Darwin. It was chosen because it is conveniently located today at the southwestern margin of the Warm Pool in the Indian Ocean, because it is situated below the Leeuwin Current which is characteristically of low density [ as a result of low salinity and high temperature]. The site also occurs close to the coast and receives airborne pollen and dust from mainland Australia.

Monospecific samples of planktic foraminifers from sixteen horizons from Core Fr10/95-GC17 were radiocarbon-dated by AMS [by Fifield, Santos, Yokoyama and Lawson together with members of ANSTO], thus providing a good chronology for changes recorded in the core spanning the last 45,000 years. In addition, OSL dates have successfully been obtained on individual aeolian quartz grains recover from specific intervals of the core deposited during the period spanning the Last Glacial Maximum. This is the first time OSL dates have been obtained from deep-sea cores, and which permit comparison with radiocarbon dates from deep marine sediments.

The following studies were carried out on the core: faunal counts of planktic foraminifers [by Martinez; see ref.1] and calculation of sea-surface temperature based on those counts [by Barrows; see ref. 2, and in prep.], floral counts of calcareous nannoplankton and estimates of broad temperature signals [by Takahashi; see ref. 3], presence of pteropods [by Martinez], pollen counts [by van der Kaars; MS in prep.], d13C and d18O on planktic foraminifers [see ref.1], total carbon, inorganic and organic carbon [by M. Sloan], XRD analyses [by M. Pryzbylak and D. Isaacs]. Interpretation of data from the core also rely on a calibration against 52 core tops obtained during the 2 *Franklin* cruises and also some 300 water samples for which stable isotope measurements have been made.

The following results will be presented at the talk:

1. For the last 40,000 years, there have been two climatic and oceanic modes affecting the southwestern margin of the Warm Pool. One, during the glacial period, saw much reduced precipitation [by down to 30-40% from the present- ref.4], enhanced sea-surface salinities [=SSS] and moderately reduced sea-surface temperatures [=SST]. At the time, the extent of the Warm Pool was reduced. The other, which commenced at the onstart of the Holocene, registered broad SSS fluctuations due to an increase in precipitation over the Warm Pool and the throughflow of the Leeuwin Current. Cyclonic activity, which contributes to over 40% of the rainfall over Cape Range today, also did commence at the onstart of the Holocene. This is recognised also by a dramatic switch of the supply of terrigenous material to the coring site. The Holocene sequence is characterised by dark brown sediments compared to the previous sequence which is much richer in carbonates and pale grey in colour.

Those 2 different modes of atmospheric circulation, reflected in the nature of the surface of the ocean of the Warm Pool has already been developed [ ref. 4, 5] and is further substantiated by the work of van der Kaars et al. [ref. 6] from a core from the Banda Sea.

2. Sea-surface temperature conditions for core site GC17 have already been compared against a dozen other sites along a north-south transect between Java and Perth [ref. 1]. Additional levels for the Holocene were examined for the present study to obtain a higher resolution, and we now can provide a good chronology to support the SST reconstructions .With confidence, we can claim that mean SST were in the vicinity of 22°C between 33,000 and 20,000 cal yearsBP. Lowest temperatures were registered around 31,000 and also from 23 to 21,000 cal yearsBP. After that mean SST rose slowly at first up to 16,000 [23°C], followed by a slight drop until 14,000 cal yearsBP by which time SST rose more dramatically until 7,000 cal yearsBP where it reached ~ 26.5°C. This was followed by a temperature drop lasting one millennium, and at 5,500 cal yearsBP it climbed to reach 27.5°C at 4,000 cal yearsBP. After that, SST dropped progressively with minor fluctuations. Of note is that seasonality in SST were at their lowest during the highest temperature reconstructions centred around 4,000 cal yearsBP.

3. The vegetation reconstruction by van der Kaars on core GC17 further confirms the 2 climatic modes. At the Last Glacial Maximum [=LGM], *Callitris* levels were highest for the last 45,000 years; *Eucalyptus* percentages were at their lowest. The 'deglaciation' [=transition between LGM and Holocene with sea level rapidly rising] was characterised by an increase in eucalypts, the low-shrub *Gyrostemon* and chenopods. The Holocene vegetation spectra, on the other hand, differ; it could be called the 'Poaceae period', to the detriment of chenopods. In addition, eucalypts increase but do fluctuate much, but were never as high in percentages as during the period predating the LGM. Of note also is the predominance of mangrove pollen peaking around 8,400 cal yBP; this is earlier than at other sites in northern Australia, but is consistent with a similar observation from the Banda Sea region [ref. 6]. For the Holocene, characterised by much SST fluctuations, there is no apparent parallelism with vegetational changes. This may be the consequence of the sampling intervals as fewer levels were examined for pollen compared to the levels for planktic forams and d18O.

4. The calcareous nannoflora in core GC17 has been compared against that of two other cores [ref. 3], one located in the Java Upwelling System, and the other further south offshore Carnarvon. In core GC17, the Holocene is characterised by warmer taxa [as a greater abundance of *Gephyrocapsa* taxa] than during the LGM and the entire marine isotope stage 2 [-MIS], but differences are subtle compared to the core offshore Carnarvon. Lower SSTs, prior to the middle of MIS2, point out to the diminishing [or absence] of the Leeuwin Current. It is postulated that many of the nannoplankton taxa could have been immersed into a cold ICW watermass during the glacial period. For the Holocene especially, the increase in warm-water indicators [*Gephyrocapsa* taxa] coincide with the peaks in SST obtained from the foraminifer faunal counts; these independent observations based on different organisms give additional support to the validity of SST reconstructions obtained from the foraminifer faunal assemblages by Barrows [AUSMAT-2, unpubl.].

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# Yallalie — Cycles of aridity, extinct rainforest types, burning and other preliminary findings from a new significant Pliocene site near Perth, Western Australia

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The Pliocene Epoch (1.78-5 Myr) was the last time when global average temperatures were warmer than the present (Crowley 1996). The period often is categorised as transitional between the mostly temperate climates of the Tertiary and more arid and large magnitude climate cycles of the Quaternary. A more realistic assessment is that the Pliocene, like the Quaternary, encompasses episodes of climatic variability imposed on the global cooling trend initiated some 40 Myr earlier in the Early Eocene. The nature of Pliocene floras, vegetation and climates in Australia has been difficult to determine because of minimal sediment accumulation onshore. Many sections are deeply weathered and any fossils are poorly preserved or have been destroyed (Kershaw *et al*., 1994; Macphail, 1997).

This situation changed dramatically when Drs. John Backhouse and Mike Macphail were alerted to the occurrence of a thick sequence of lake sediments in a 1990 hydrocarbon exploration well drilled by Ampol Exploration Ltd at Yallalie, on the southern boundary of the Watheroo National Park about 200 km north of Perth. This small (< 15 km diameter) basin, informally named the Yallalie Basin, appears to be the result of a meteor impact in the Dandaragan Trough during the Early Cretaceous (Dentith *et al*., 1992). Over 3 km of sediments have accumulated since that time and a preliminary pollen analysis (Macphail, 1994) confirmed that the lacustrine section was probably Pliocene (age range Late Miocene to Pliocene).

ARC funds permitted the lacustrine section, between 67-177 m depth, to be continuously cored in 1998. There was virtually 100% core recovery and the sediment features and plant fossils including diatoms, spores, pollen and charcoal are spectacularly well-preserved. The core has been described, dated via palaeomagnetism, and analysed for a selection of chemical properties as well as examined for the first stages of an analysis of diatoms, spores and pollen. This paper presents an overview of the sequence and preliminary results on the fossil analyses from the upper 30 m.

Key findings are: (1) The palaeomagnetic record shows a good match with the Gaussian Chron and includes the Kaena and Mammoth Subcrons, allowing the construction of an age-depth model for the lake sequence. (2) Two major lithostratigraphic units are present — an upper unit which accumulated between ~2.5-3.51 Myr (mid Pliocene) and which is characterised by fine organic laminae, and a lower relatively massive unit where sedimentary features are less well preserved. (3) Climates were generally wetter than at present but were interrupted by short intervals of semi-arid conditions between ~2.53-2.58 Myr. Other cycles may exist elsewhere in the record. (4) Conditions were particularly variable, and possibly seasonal between 2.87-3.0 Myr and 3.22-3.06 Myr.

Chemical analyses indicate that water depth was variable and that salinity levels and diatom abundance reflect climate rather than nutrient flux. During the wetter phases, the dryland vegetation was dominated by a mixture of sclerophyll and rainforest trees and shrubs, in particular Myrtaceae and *Araucaria*. This community superficially resembles dry rainforest, now confined to coastal Queensland and northern NSW. In fact it is a vanished vegetation type since less common elements are endemic to eastern Australia, Tasmania and/or islands in the South West Pacific, e.g. *Agathis*, *Dacrycarpus*, *Phyllocladus* and *Nothofagus* (*Brassospora*), or are wholly extinct. A possible relative of the recently discovered NSW Wollemi Pine (*Wollemia*) coexisted with a eucalypt (*Eucalytus spathulata*) now confined to semi-arid southwestern WA. Essentially the same rainforest type is found in other Pliocene sites along the southern margin, e.g. at Grange Burn, southwest Victoria (Macphail 1996).

During semi-arid episodes, chenopod (salt-bush) shrubland developed around the lake. Charcoal is abundant throughout the late Pliocene — evidence that natural wildfires were a perennial feature of the environment in southwestern Australia 3 Myr before humans arrived. In spite of fire, there is no pollen evidence for extensive grassland but pollen representing many of the herbs and sclerophyll shrubs that make the southwestern Australian flora the most diverse in Australia are preserved. Proteaceae examples are *Banksia*, *Conospermum*, *Dryandra*, *Isopogon*,Musgravieae, *Stirlingia* and *Xylomelum*. In some instances, more than one species are represented, e.g. *Acacia* and *Banksia*/*Dryanda*. There is a great richness in the Myrtaceae which dominates the uppermost pollen assemblage. There are several distinctive fossil pollen types that cannot be matched to living genera and there are many ferns that no longer occur in the region, e.g. *Calochlaena*/*Culcita*, *Cyathea*and *Pteris*.

The Yallalie record offers the best opportunity found so far to use fossils to study the development of high biodiversity of a region which contains half the number of flowering plant species of Australia. Yallalie is located within the midst of one of the richer areas in the Southwest. Much additional work is required to flesh-out this and other evidence preserved at Yallalie and to assess local climatic events against the regional and global record. For example, the interval of semi-arid conditions between ~2.53-2.58 Myr coincides with the development of large continental glaciers at ~2.54 Myr in the Northern Hemisphere. Adding to the challenge, and international significance of Yallallie, is that it should contribute to debates centred upon closure of the Indonesian Seaway in the early Pliocene (Srinivasan & Sinhas 1998, Wei 1998), events in the Southern Ocean including possible instability of the East Antarctic Ice Sheet during the mid Pliocene (Hodell *et al.* 1991, Burkle *et al*., 1996, Gersonde *et al*., 1997), and non-linear (124 Kyr) and orbital-scale (41 Kyr, 32-19 Kyr) climatic forcing recorded in the parallel (~3-2.6 Myr) high resolution continental record at Pula Maar in Hungary during the late Pliocene (Willis *et al*., 1999).

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# QUATERNARY WATERS, SALTS AND MINERALS: LAKE LEWIS, CENTRAL AUSTRALIA

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Lake Lewis is a 250 $km^2$ salt lake, or playa, in central Australia (Figure 1). The lake is fed by groundwater discharge and a centripetal array of ephemerally active creeks that rise in major mountain ranges in the north and south (Figure 2). The basin is hydrologically closed. The area today receives almost 300 mm average annual rainfall and has an average annual potential evaporation rate of 3065 mm. With an evaporation-precipitation ratio of >10, the area is classified as arid. Rainfall is derived from the Australian summer monsoon system and tropical cyclones that originate in coastal regions to the north.

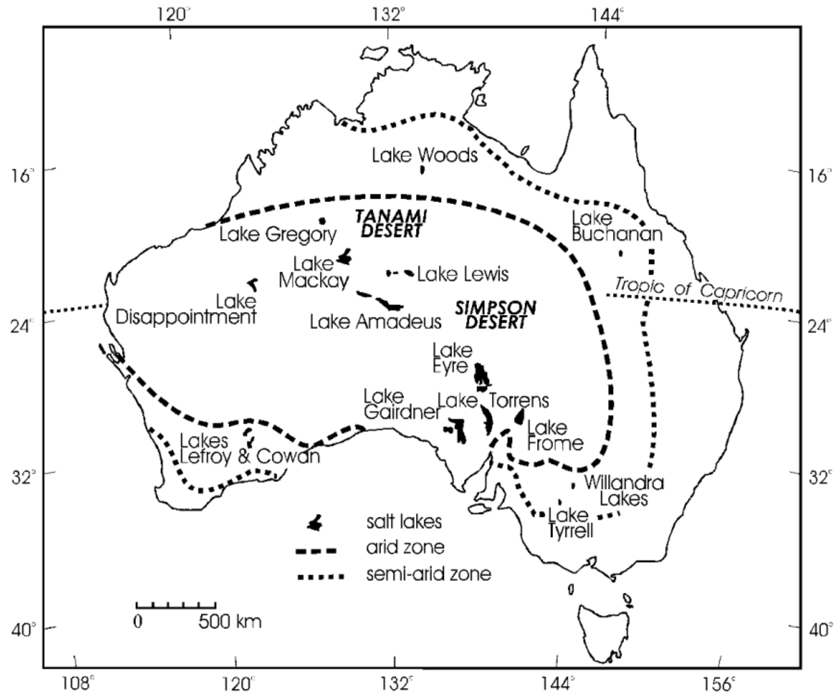


Figure 1. Distribution of major salt lakes in Australia. Lake Lewis basin is located on the Tropic of Capricorn and is the most inland of the salt lakes. At 550 m (AHD) elevation, Lake Lewis is the highest salt lake in Australia.

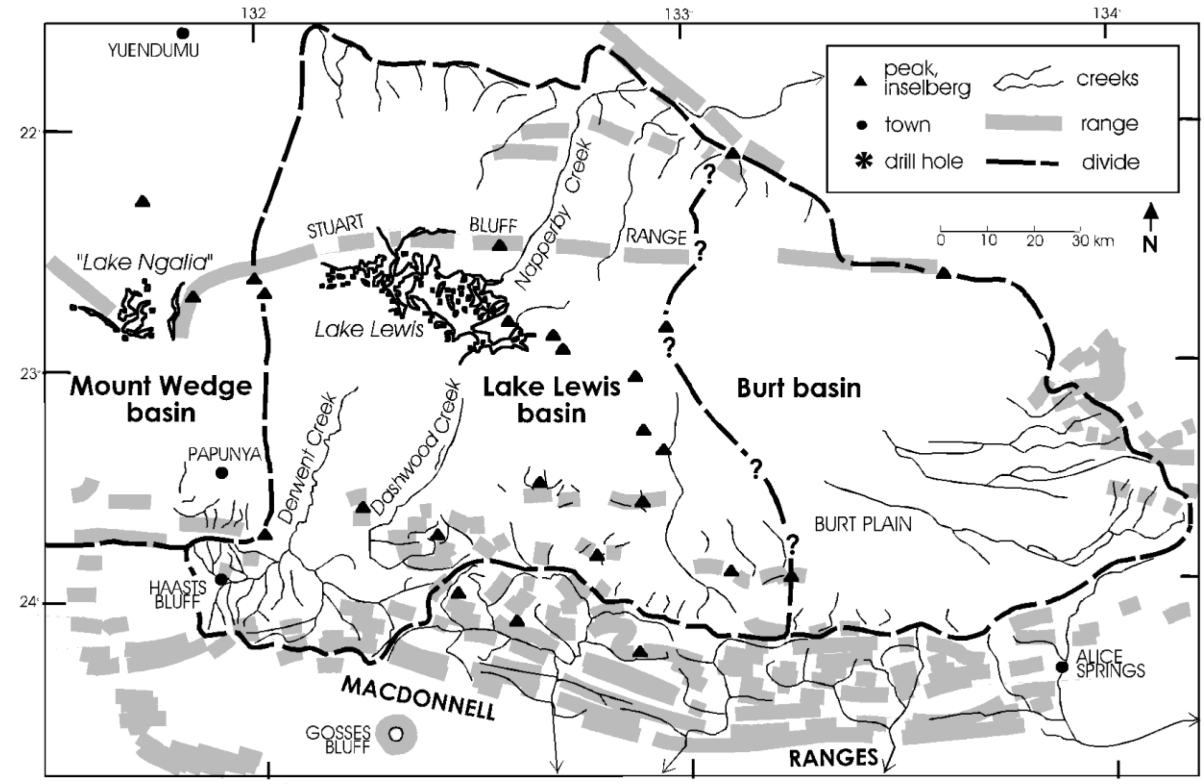


Figure 2. Lake Lewis basin and adjacent Cainozoic basins north of the Macdonnell Ranges. Burt, Lake Lewis and Mount Wedge basins are separated by basement highs of crystalline bedrock and are hydrologically separate. The basins are part of a Cainozoic basin-and-range province. The East Lewis drill site is shown with an asterisk.

The landscape of Lake Lewis basin is composed of steep mountains of granite, gneiss and quartzite; widespread alluvial fans; a lacustrine plain; dunefields and playas. Up to 80 m of Cainozoic lacustrine sediment, Anmatyerre Clay, underlies Lake Lewis playa, infilling a pre-existing mountainous topography of crystalline basement rocks. The detrital clastics of Anmatyerre Clay reflect the composition of the granites and amphibolites that dominate the catchment lithologies. Imprints of expanded perennial lacustrine conditions of the Pleistocene are expressed in the geomorphology and stratigraphy of the basin. In particular, the landscape bears palimpsest evidence of a high lake stand at the 560 m contour; this palaeolake represents a water body several metres deep and 1375 $km^2$ in area, i.e. 5.5 times the size of the present playa. The continuity of Anmatyerre Clay suggests perennial lacustrine conditions through the Middle Pleistocene, culminating with the 560 m megalake phase and contractional stages thereof. The "Anmatyerre lakebed" subsequently dried up and was scoured before a new, distinctive regime overtook basinal processes after the last interglacial. The gypseous Tilmouth Beds, along with gypsum-rich aeolian deposits and relatively recent episodic flood alluvium, represent approximately the last 100 000 years of sedimentation at Lake Lewis.

The evolution of Lake Lewis from a large perennial lake to a shrunken dry playa has been accompanied by major changes in the groundwater system of the basin. With reduced rainfall and associated diminished runoff and attenuated recharge since the last interglacial, groundwater flow in Lake Lewis basin became sluggish and residence times in aquifers became more prolonged. Acquisition of solutes by stagnant or slow-moving groundwaters, coupled with increased evaporation rates, resulted in the waters becoming progressively more solute-rich in the closed hydrologic system. A >5 km wide halo of phreatic calcrete ($CaCO_3$) precipitated around the contracting lake, nucleating on surface and near-surface sediments in the lakebed of the former 560 m megalake. With continued and intensified aridity, the waters evolved to gypsum ($CaSO_4$) saturation, in response to evaporative concentration. The Tilmouth Beds of intercalated grey-olive clay and sedentary gypsum are a legacy of perhaps the earliest manifestation of high levels of salinity in the basin.

The evolution of contemporary groundwaters in shallow aquifers of Lake Lewis basin follows the calcium carbonate to calcium sulphate path that has prevailed since the last interglacial. The groundwater flow rate is of the order of a few thousand years over the 60 km distance from the ranges to the playa. In response to intense evaporative concentration, fresh waters sourced from the mountains and floodplains evolve to $CaCO_3$ saturation levels as they approach the playa. With depletion of carbonate-bicarbonate, the remaining Ca is coupled with sulphate to precipitate gypsum at the discharge zone. Displacive (intrasedimentary) gypsum precipitates from interstitial brine in both the Anmatyerre Clay and the overlying flood alluvium. Because the playa surface is within the capillary fringe of the high water table, efflorescent crusts of gypsum and minor halite (NaCl) precipitate as the brine evaporates. Calcium availability seems to be the limiting factor to the volume of gypsum being precipitated. The salinity gradient over a few kilometres, from $CaCO_3$ saturation to residual brine that is enriched in Na-Cl-$SO_4$, is steep, because of the high intensity of evaporation at the playa.

Additional to accumulation of carbonates, sulphates and chlorides in the closed hydrologic system, silica concentrations also increase along the groundwater flow path. Aqueous silica ($H_4SiO_4$), derived from weathering of feldspar, mica and kaolinite in bedrock and alluvium, are at supersaturation levels with respect to quartz in groundwaters approaching the centre of the basin. Opaline and chalcedonic silica and cryptocrystalline quartz precipitate in calcrete in the playa margins, largely in response to intense evaporation. Consequent depletion of $SiO_2$ lakeward from the playa margin, in the brine pool beneath the playa, results in aqueous compositions that are undersaturated with respect to quartz. This depletion of available $SiO_2$ in the brine pool, coupled with decreased $H^+$ activity due to consumption of $H^+$ during weathering of aluminosilicate clays, and increased aqueous $Na^+$ due to evaporative concentration of this very soluble ion, result in the $SiO_2$-deficient zeolite mineral, analcime, attaining equilibrium in the system. Analcime, $Na(AlSi_2)O_6{\cdot}H_2O$, precipitates below the water table in Anmatyerre Clay as an authigenic mineral, crystallising from amorphous aluminosilicate clays or gels whilst accessing $Na^+$ ions and water molecules from interstitial brine. This is a distinctive Late Pleistocene diagenetic development that is an outcome of high levels of salinity at the playa, coupled with chemical compositions of lacustrine clays and brine that are optimum for zeolite formation. The abundance of authigenic analcime at Lake Lewis is likely to increase with the duration of hydrologic closure of the basin under prevailing arid climatic conditions.

# Timing and duration of the Last Interglacial from Western Australian corals

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The Western Australian coast line, from Perth to Ningaloo is intermittently ringed by fossil coral platforms. At places these are substantial structures, 3 m to 5 m above present sea-level, densely packed by *favide* species corals and also by large (>0.5 m) *porites* heads. At Ningaloo, the fossil platforms were once part of a barrier reef and lagoon structure very similar to what exists there currently. Behind the fossil platforms, in the old lagoon, are there are mounds of coral colonies and also groups of very large (>2 m) *porites* heads standing in growth position. All of these structures date back to the Last Interglacial period about 125,000 years ago.

We have dated corals from eight of the Last Interglacial fossil reefs using mass spectrometric U-series techniques. The corals were selected in growth position from localities that are characterized by apparently low levels of diagenesis and relative tectonic stability so that the fossil reefs provide critical information on Last Interglacial sea levels without requiring models of tectonic movements. In addition, we have improved the constraint on the timing of onset of reef growth by recovering drill core coral from the base of the reefs. Uranium and thorium isotopes were measured with high levels of precision, leading to improvements in age resolution and allowing samples which have undergone diagenetic exchange of uranium and thorium to be more easily identified and discarded. With more than seventy mass spectrometric U-series ages, constraints could be placed on the timing, duration and character of the Last Interglacial sea level highstand. Reliable ages show that reef growth started contemporaneously at 128 ± 1 ka along the entire Western Australian coastline, based on a sharply defined boundary in the data, while relative sea levels were at least 3 m above the present level. Because Western Australia is located far from the former Penultimate Glacial Maximum ice sheets and are not significantly effected by glacial unloading, these data constrain the timing of onset of the Last Interglacial period to shortly (<1 ky) before 128 ± 1 ka. A unique regressive reef sequence at Mangrove Bay constrains the timing of termination of the Last Interglacial period to 116 ± 1 ka. The major episode of reef building, however, both globally and locally along the Western Australian coast, is restricted to a very narrow interval occurring from ~128 ka and ~121 ka, suggesting that global ocean surface temperatures were warm enough and/or sea-levels were stable enough for prolific reef growth only during the earlier part of the Last Interglacial.

# TEMPORAL PATTERNS OF ABORIGINAL OCCUPATION IN NORTHWESTERN NEW SOUTH WALES, AUSTRALIA, DURING THE LATE HOLOCENE: A REFLECTION OF ENVIRONMENTAL OR SOCIO-POLITICAL CHANGE?

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A mid- to late-Holocene increase in the frequency of Aboriginal stone artefacts associated with heat-retainer hearths has been reported in arid Australia (1). While explanations for these phenomena vary significantly (2-6), there is wide agreement that these developments represent a continent wide change, the Australian equivalent of the broad-spectrum revolution that heralded the arrival of agriculture in other parts of the world. Determining whether Australia was on the road to agriculture is crucial since if it was not, Australia becomes the exception that rules out the existence of a single process behind the dramatic Holocene changes in human socio-political and technological organisation that characterise world prehistory (7).

The key to this question is to determine whether changes occurring at one site reflect responses to local contingencies or evidence of continent wide processes. To investigate this, we report on a program of systematic dating of heat retainer hearths from Stud Creek, a small area of Sturt National Park in arid north-west New South Wales, Australia (Figure 1), where concentrations of artefacts and hearths have been clearly identified (8, 9). They are highly visible because of accelerated erosion that has occurred across the region since the introduction of sheep grazing by Europeans in the mid-nineteenth century (10). If the late Holocene <u>was</u> characterised by reduced human mobility reflecting increased population levels and more complex socio-political organisation, we would expect evidence of near-continuous hearth construction and use. Instead, the pattern of radiocarbon determinations from Stud Creek (Table 1) suggests two phases of activity over the last 1700 radiocarbon years (220□ 55 - 820□ 50 and 1170□ 130 - 1630□ 50 radiocarbon years BP), separated by a hiatus in which no heat retainer hearths were constructed. Both the existence and duration of this gap have been statistically confirmed using sample based Bayesian inference (11). The computed hiatus duration at 95% confidence levels is 211-485 calendar years. Thus at least 211, and perhaps up to 485, calendar years separates each phase of hearth construction at Stud Creek.

In a continent-wide model of change in the late Holocene in which mobility levels are believed to have decreased (2), such a hiatus in hearth construction is unexpected. Possible explanations for the existence of the hiatus are examined in this paper, in particular the evidence for paleoenvironmental change during the Late Holocene which may have affected resource availability in, and hence patterns of occupation of, specific areas of what is now the Australian arid zone.

The hiatus may indicate people reacting to environmental variation on either a continental or local scale. At the continental scale, the Late Holocene paleoclimate record in Australia shows increased desiccation between 3000 and 1500 BP followed by a return to relatively moist conditions (e.g. 12). This may explain the lack of hearths older than 1700 years, but currently available paleoenvironmental records do not show a continent-wide event that coincides with the hiatus in hearth construction at Stud Creek. Very few published studies have the fine resolution required to understand environmental change on time scales of a few hundred years, yet it is these time scales which will contribute the most to our understanding of human interaction with the environment, particularly of the last 1500 years.

On a local scale, the pattern may represent short-term abandonment following either microenvironmental change (e.g. drought) or over utilisation of resources (e.g. food resources and/or water). However, three hundred years is likely to be longer than the period needed for resource regeneration (e.g. 13). Thus, the question to be addressed may not be why Aboriginal people <u>ceased</u> hearth construction in places like Stud Creek in the short term, but why it took so long (at least six generations and possibly longer) for such places to be used in this way again.

Clearly, large numbers of hearth dates are needed from many regions to consolidate and further explain the pattern we have discovered. However, the results obtained so far are sufficient to question the scale at which theories for change in late Holocene Aboriginal Australia should be pitched. Stud Creek may appear anomalous within the Australian archaeological record because it has been studied so intensively. Comparing a few widely scattered records across the continent will tend to support large-scale explanations, while relatively large samples from small regions such as Stud Creek reveal a pattern that hints at a complex, contingent Aboriginal prehistory, where regional variation outweighs continental processes. Before the broad-spectrum revolution equivalent (7) can be demonstrated for Australia, more attention needs to be given to small scale, regional processes.

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Table 1. Radiocarbon determinations for charcoal samples from 28 heat retainer hearths from the valley floor of Stud Creek in northwestern NSW, Australia. Two phases of hearth construction are suggested by Bayesian analysis of the results. The dates are independent of spatial location (see Fig 1) and sample weight.

| Phase $\theta$ | Sample | Laboratory | $\delta^{13}C$ | % Modern | Result (BP) | Weight (gm) |
|---|---|---|---|---|---|---|
| 1 | H98-75 | WK 6632 | -23.1 ± 0.2 | 97.3 ± 0.6 | 220 ± 55 | 3.20 |
| 1 | H98-16 | WK 6621 | -23.6 ± 0.2 | 95.4 ± 0.6 | 380 ± 50 | 10.40 |
| 1 | H98-46 | WK 6625 | -23.2 ± 0.2 | 94.5 ± 1.4 | 450 ± 120 | 2.15 |
| 1 | H98-13 | WK 5332 | -23.3 ± 0.2 | 94.3 ± 0.6 | 470 ± 50 | 15.15 |
| 1 | H98-12 | WK 5127 | -22.0 ± 0.2 | 93.1 ± 0.6 | 580 ± 60 | 5.82 |
| 1 | H98-59 | WK 6627 | -24.1 ± 0.2 | 92.5 ± 1.4 | 630 ± 130 | 1.51 |
| 1 | H98-11 | WK 5125 | -22.6 ± 0.2 | 92.2 ± 0.5 | 660 ± 50 | 15.06 |
| 1 | H98-71 | WK 6631 | -23.4 ± 0.2 | 92.1 ± 0.6 | 660 ± 50 | 3.38 |
| 1 | H98-21 | WK 5330 | -23.6 ± 0.2 | 91.8 ± 0.5 | 690 ± 50 | 10.10 |
| 1 | H98-32 | WK 6624 | -24.0 ± 0.2 | 91.4 ± 0.6 | 720 ± 55 | 3.15 |
| 1 | H98-4 | WK 6038 | -23.0 ± 0.2 | 93.1 ± 4.9 | 790 ± 50 | 7.00 |
| 1 | H98-60 | WK 6628 | -23.3 ± 0.2 | 90.7 ± 0.8 | 790 ± 75 | 2.10 |
| 1 | H98-15 | WK 5329 | -22.0 ± 0.2 | 90.3 ± 0.5 | 820 ± 50 | 15.04 |
| 2 | H98-65 | WK 6629 | -23.3 ± 0.2 | 86.4 ± 1.4 | 1170 ± 130 | 1.95 |
| 2 | H98-28 | WK 5124 | -22.8 ± 0.2 | 86.0 ± 0.5 | 1210 ± 50 | 10.11 |
| 2 | H98-22 | WK 5122 | -22.5 ± 0.2 | 85.5 ± 0.4 | 1260 ± 40 | 15.08 |
| 2 | H98-25 | WK 5126 | -23.2 ± 0.2 | 85.5 ± 0.6 | 1260 ± 60 | 8.89 |
| 2 | H98-19 | WK 6622 | -22.7 ± 0.2 | 85.2 ± 0.6 | 1280 ± 60 | 4.85 |
| 2 | H98-10 | WK 6036 | -23.2 ± 0.2 | 85.2 ± 0.4 | 1290 ± 50 | 10.70 |
| 2 | H98-20 | WK 5331 | -23.2 ± 0.2 | 85.1 ± 0.5 | 1300 ± 50 | 15.10 |
| 2 | H98-30 | WK 6037 | -23.4 ± 0.2 | 84.9 ± 0.5 | 1310 ± 60 | 5.90 |
| 2 | H98-54 | WK 6626 | -23.0 ± 0.2 | 84.8 ± 1.5 | 1330 ± 150 | 1.42 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2 | H98-23 | WK 6623 | -22.6 ± 0.2 | 84.5 ± 0.8 | 1350 ± 75 | 2.01 |
| 2 | H98-8 | WK 6620 | -23.6 ± 0.2 | 84.1 ± 0.7 | 1390 ± 70 | 3.50 |
| 2 | H98-27 | WK 5123 | -23.6 ± 0.2 | 83.9 ± 0.5 | 1410 ± 50 | 7.16 |
| 2 | H98-2 | WK 6039 | -22.9 ± 0.2 | 83.6 ± 0.6 | 1440 ± 60 | 5.70 |
| 2 | H98-9 | WK 6035 | -22.5 ± 0.2 | 83.4 ± 0.5 | 1460 ± 50 | 10.30 |
| 2 | H98-66 | WK 6630 | -23.6 ± 0.2 | 81.7 ± 0.5 | 1630 ± 50 | 1.63 |

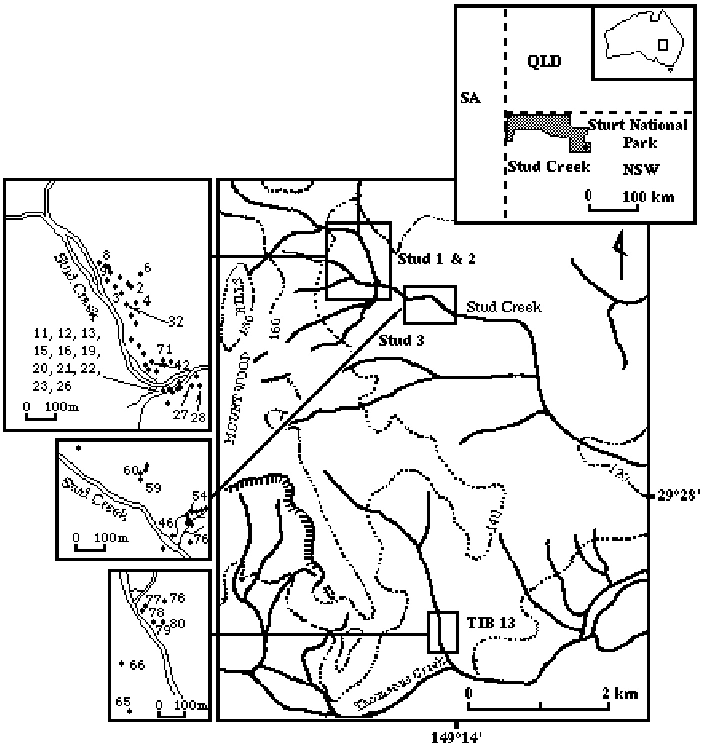


Figure 1. Location of the Stud Creek study site in Sturt National Park, NSW, showing locations of excavated heat-retainer hearths. The numbers correspond to the Hearth ID numbers in Table 1.

# CHRONOLOGIES FROM ACCELERATOR MASS SPECTROMETRY AT ANU

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The extremely high sensitivity of accelerator mass spectrometry (AMS), and its applicability to a range of isotopes, is facilitating the determination of chronologies for many problems in Quaternary studies. At the ANU, the AMS system based on the 15 million-volt 14UD accelerator in the Department of Nuclear Physics is making contributions in the areas listed below. Most of these projects entail collaborations with groups in RSES and/or the Department of Geology, and some will be reported in more detail in other presentations to this meeting. My intention will be to highlight the special capabilities of AMS as well as the symbiosis between physicist and earth scientist that is making these advances possible.

1. Establishing chronologies for marine cores via radiocarbon dating of individual species of foramanifera hand-picked from short sections of core. Typically, less than 1 mg of carbon is available for dating.
2. Determination of atmospheric levels of 14C back to 50 ka before present by comparison of U/Th and radiocarbon dates on corals from the Huon Peninsula, PNG. The small-sample capability of AMS permits both a stringent chemical pretreatment of the samples, and checks on its efficacy, that would not be possible with conventional radiometric methods.
3. Improvement in the age limit of radiocarbon dating. This is resulting in radiocarbon evidence for human occupation of Australia beyond 40 ka B.P., and lends support to other dating techniques, OSL in particular, which have been indicating such earlier occupation for some time.
4. Establishing glacial chronologies on the Kosciusko Massif and in Tasmania via exposure-age dating using the accumulation of 10Be and 36Cl in moraine boulders and glacially-polished bedrock surfaces. These isotopes are produced *in situ* by the action of cosmic rays, and concentrations are so low that only AMS offers the sensitivity to be able to measure them.
5. Recently, in a collaboration with the Institute of Geological and Nuclear Sciences at Lower Hutt in New Zealand, we have shown that it is possible to date ice in temperate-climate glaciers using 32Si, which has a 140 year half-life. This isotope is produced in the atmosphere by cosmic-ray interactions with argon, and falls out in precipitation at the rate of ~103 atoms/cm2/yr. While radiometric methods have been applied to rainwater or snow, where hundreds of litres may be readily obtained, the situation is rather different for glacial ice where typically only a kilogram is available for dating. In this case, only AMS has the requisite sensitivity for determining the extremely low concentrations of the isotope.

# LAND USE AND LAKE SEDIMENTATION DURING THE LATE HOLOCENE AT REDHEAD LAGOON, EAST-CENTRAL NEW SOUTH WALES, AUSTRALIA

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This ongoing study aims to add to our understanding of environmental change and European environmental impact by investigating the Holocene sedimentary record preserved in Redhead Lagoon, located at Dudley, in coastal, east-central NSW. The lake is a small, closed drainage basin. It has therefore acted as an efficient sediment trap preserving a near-continuous depositional record of past environmental conditions.

The catchmnent was originally used as a camping ground for the Awabakal Aborigines (Dyall 1972). Permanent European settlement began in the mid 19$^{th}$ Century, when the early settlers cleared the land for small-scale agricultural activities, such as citrus orchards. In the 1890s, however, Dudley was transformed into a coal mining community and land use in the lake catchment was modified dramatically (Tonks 1987). Mining continued until 1940 and in the 1950s the surface infrastructure was removed and the mine waste dumps transformed into playing fields. Large-scale urbanisation began in 1964, with the largest subdivision taking place in 1968. Two sediment trap dams were installed in the mid 1980s to prevent sediment run off from the landfill.

Caesium-137 and AMS Radiocarbon techniques were used to date the upper and lower parts of the sedimentary sequence respectively. A tentative chronology for the middle part of the sequence has been constructed from the evidence of sediment geochemistry. The simultaneous rises in heavy metal concentrations at a depth of 0.44 m, for example, are interpreted as resulting from the opening of the nearby lead-zinc smelter at Cockle Creek in 1897. The first divergence up-core in the behaviour of Phosphorus and the alkali and alkaline earth elements (Mg, Na, K, Ca) at 0.76 m, is likely to represent initial European contact at ~1860. The Caesium-137 analysis has provided a chronology to ~1955 at a depth of 0.20 m. Two basal dates have been provided by AMS analysis, indicating that the sequence extends back to mid Holocene times.

The most significant and damaging impacts of European settlement occurred during the initial post-contact period as a result of activities such as deforestation and clearance of the land for settlement and orchards, and the early establishment of Dudley Colliery. Site-specific sedimentation rates increased massively during this period to 0.815 kg $m^{-2} a^{-1}$, more than a 60-fold increase from pre-European rates of ~ 0.0132 kg $m^{-2} a^{-1}$. The results indicate that even though the initial impacts of European settlers on the catchment surface were of low intensity, they had an enormous effect on what is likely to have been a sensitive natural system. This may have depleted the available sediment stores, with the result that subsequent, much larger impacts were left with less material to erode because new regolith was unable to reform in the interim.

Sedimentation rates have been steadily declining since 1897. However, there was a brief increase in rates between 1968 and 1976, the 'peak construction' phase of urbanisation in the catchment. A sharp decline in deposition rates during the most recent period, the 'final urban' phase (1976 to 1996) probably reflects the success of recent soil conservation measures (sediment trap dams) and the increased area of impervious urban surfaces.

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# HUMAN IMPACT ON THE NATURAL ENVIRONMENT IN EARLY COLONIAL AUSTRALIA

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Only a fragmentary documentary record exists of the human impact upon the natural environment in early colonial Australia. Amongst the alternative sources of information, perhaps the most useful is that preserved in sediments laid down at the time of initial colonisation. This study exploits this data source, focussing on the depositional record from the New England Tablelands of northern New South Wales, an area conventionally thought to have first been colonised in the 1830s. The pattern of occupation, the history of land use and the sequence of changes in population here are comparable with those experienced throughout much of southeast Australia. The conclusions derived from this work may therefore reflect the picture in other parts of the continent.

The sedimentary evidence reveals that the landscape of the New England Tablelands was transformed by human activity within a few years of the arrival of the first squatter and his sheep. Gullying dissected the land surface, catchments were denuded of soil, water bodies were infilled with sediment and the tree cover was dramatically altered. In particular, there was a selective loss of ?*Casuarina cunninghamiana* as the result of its preferential use and/or clearance by the colonists.

The deposits also provide evidence of intentional efforts to modify the landscape by the planting of exotic trees. Although this may have been done partly for practical purposes, slow-growing deciduous trees can only have been introduced in an attempt to transform the landscape to one more pleasing and more familiar to the settlers. Such trees also provide evidence of a commitment to New England and Australia which is largely missing amongst the very earliest settlers.

Finally, there is evidence of disturbance to the natural environment several decades before the accepted date of arrival of Europeans on the Tablelands. Although this may have been a result of Aboriginal activities, it is more likely to indicate the presence of either Europeans or the shadow of European culture on the New England Tablelands long before the first squatter is thought to have driven his flocks up onto the Tablelands.

**Clashing Cultures in the Willandra**

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Three strands of evidence, geology, archaeology and the dating programs based on this fieldwork, conspire in attempts to place significant events in the Willandra on a logical timescale. After 3 decades of research it seems that the conspiracy has failed, because protagonists from these 3 cultures still cannot agree on some of the important issues. Within each of these cultures there are sub-cultures using different methods and theoretical frameworks, which are as likely to be contrary as complementary in any analysis of a complex site. For most of the dating programs, sample chemistry rather than the physical measurement is central to understanding reported results, this will be illustrated by reference to dates on various materials from selected Willandra sites.

Most pretreatment chemistry employed for radiocarbon dating has been rudimentary and ineffective in removing contaminantion, with the resulting dates often unreliable. More recent work has focussed on component identification and selective separation science to isolate, in ideal cases, a single molecule or chemical class for isotopic measurement. For example, chlorite oxidation allows the isolation of cellulose from wood, permanganate oxidation can isolate oxalate from rock surfaces, and stronger dichromate oxidation can remove all unburnt carbon to isolate elemental burnt carbon. Carbonate dates on bone, shell, otolith and eggshell are sometimes unreliable because carbonate can exchange carbon with groundwater, better results are obtained by isolation of protein or amino acid components which can be purified by chromatography.

Chemistry is also important to U/Th, luminescence and ESR technique salthough the reasoning is different: life processes maintain a constant starting amount of cosmogenic $^{14}C$, but heavy radionuclides like U and Th not normally present in living organisms are aquired at some unknown time after death. This uncertainty in the boundary conditions requires modelling of radionuclide accumulation and loss, which leads to differing age estimations and interpretations. Similarly in the radiation exposure methods, the analytical chemistry of sediments is fundamental to estimating dose rates. Changing lake and groundwater levels, and deposition or erosion of sediments, produce changes in radionuclide chemistry and cosmic dose rates which affect age estimations.

The charcoal/shell problem

In the period 45ka to the present, the radiocarbon record is strong: dates on mussel shells, fish otoliths & emu eggshells agree with each other and with charcoal where available. But there are no acceptable charcoal/shell pairs, in my view because there is almost no charcoal in the shell middens. Middens are just rubbish heaps containing lots of shells, sometimes with bones and other food debris, but the associated ‘black stuff’ is largely unburnt carbon – compost. Conversely, in hearths and fireplaces where there is good charcoal there are no shells. Black sediments usually labelled charcoal may be divided into 3 groups based on solubility: macro charcoal with younger humic acids, micro charcoal with no humic acids, and no charcoal with abundant compost that may be older than the insolubles. So there really is no shell/charcoal problem.

Bowler’s in situ black stump at the Lower Mungo/Upper Mungo Unit contact in the Outer Arumpo lunette has good macro charcoalat 40ka, identical in age with numerous shell & fish dates from stratigraphically equivalent locations, and compost slightly older.

Human burials

The large excavations by Mulvaney and Shawcross near the Mungo 1 burial site have been largely ignored, except for quotation of the charcoal date ANU-1263 at >40,000 BP (which is incorrect due to inadequate measurement on an insufficient amount of a poorly decontaminated sample and should read >18,500 BP). Shawcross considers that sediments from his excavation above the beach gravels at 1.2m are Upper Mungo Unit, whereas Bowler places the same sediments in the Lower Mungo Unit. A fish otolith date from 1.1m of 39.5±1.6ka would appear to support an Upper Mungo interpretation.

This uncertainty in stratigraphic assignment clouds age estimates for the nearby human burials and bones from other Willandra locations, which have $^{14}C$, U/Th and ESR age estimates scattered from Modern to Last Interglacial. Possible reasons for this varibility are similar to those applicable to $^{14}C$ dates on soil carbonates: there is no reliable, all-purpose model for accumulation and loss of the nuclides being measured. It seems likely that the commonly applied EU (early uptake) and LU (late uptake) models for uranium mobility do not place valid boundary conditions on the geochemistry of Willandra samples and some FU (fluctuating uptake) model needs to be developed.

Conclusions

The conspiracy between geological, archaeological and dating programs has not been particularly effective in the Willandra so far, but a few of the many significant events are fairly well defined. When appropriate methods are applied to suitably selected materials, there is generally good agreement between age estimates for Willandra samples, eg. luminescence dates and calibrated radiocarbon dates on the same hearths, or agreement between selective bleach TL, total bleach TL and OSL dates on identical material. By rejecting those age estimates for which considerable doubt exists it is possible to place most of the archaeology into a coherent chronology (Figure 1). General problems in the sequence appear to lie with questions concerning the timing of massive deflation in the Mungo lunette (which exposed the human bones) and of beach gravel deposition events (which shaped the sedimentary sequence).

Figure 1. Summary Willandra chronology based on reliable dates.

| | | Outer Arumpo | Mungo |
|---|---|---|---|
| Youngest middens | Shells & Fish | | 19 ± 2 |
| Last Glacial Maximum | | 20–25 ka | |
| | Shells & fish | 26 ± 2 | |
| Palaeomagnetic site hearths | Charcoal | | 33 ± 3 |
| | Luminescence | | 34 ± 5 |
| Top Hut hearth sites | Charcoal | 33 ± 3 | |
| Oldest middens | Shells & Fish | 40 ± 2 | 40 ± 2 |
| UM /LM Unit contact, Charcoal | | 40 ± 3 ka | |
| | Emu Eggshells | 41 ± 2 | |
| | Luminescence | 42 ± 6 | |
| Beneath Mungo 3 burial | | | 43 ± 6 |

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# A comparison of three Last Interglacial pollen records from eastern Australia

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Lying between 10° S to 44° S, the Australian continent encompasses a range of climates, with dry winters and monsoonal wet summers in the north and wet winters and dry summers in the south. Through comparison of pollen records from terrestrial sites in northeastern and southeastern Australia an attempt has been made to reconstruct Last Interglacial climates across this climatic range. This in turn has allowed the investigation of issues such as synchroneity of climate change, shifts in atmospheric circulation patterns and the degree and nature of regional variation in Last Interglacial climates in comparison with those of the Holocene.

Palaeoclimates have been reconstructed using modern analogue and principle component analysis of pollen assemblages. Chronologies for two of the records have been refined by the use of uranium/thorium dating of peat and lake sediments.

# INTERPRETING THE LINK BETWEEN CLIMATE CHANGE AND SEA LEVEL FLUCTUATIONS IN THE LATE HOLOCENE

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Relic inter-tidal assemblages of sessile organisms which are referred to as fixed biological indicators (FBIs) are shown to be useful proxies for late Holocene climatic and environmental changes as well as direct indicators of short term fluctuations in sea-level. A detailed comparison of change in the inter-tidal assemblages at two comparable latitudinal Southern Hemisphere sites, Port Hacking south-east Australia and the Laguna-Imbituba region of southern Brazil, indicates many marked similarities in the timing and nature of changes. A similar relationship between sea level fluctuations and shifts between temperate and sub-tropical inter-tidal and sub-tidal shellfish species occurs at Rottnest Island, Western Australia. The concurrence is such that it suggests that global forcing factors are swamping regional or local influences, such as isostasy. The value of inter-tidal indicators is developed by identifying the environments associated with the present distribution of the common marker species: tubeworms, barnacles and mussels. Within the relic biostratigraphy at one particular Port Hacking site, two environmental marker species have been discovered which have important implications for late Holocene research. Firstly, the massive form of the coral worm, *Idanthyrsus pennatus*, now found only on the sub-tropical shoreline 400 km to the north, was present at Port Hacking for at least a 900 year period, 4300-3400 years BP. This encrustation covers an earlier formation containing barnacles and bivalves, including a second environmental marker species, the southern mussel, *Brachidontes rostratus*, which now occurs in colder water 240 km to the south of Port Hacking. The $\delta^{18}O$ content of these extant specimens at Port Hacking confirm changes in ocean water temperature and associated sea-level behaviour corresponding to invasion or extinction of species. A similar pattern is repeated, although in a less marked fashion, in the Laguna-Imbituba region of southern Brazil. After 2400 years BP, which date also seems to mark a period of widespread environmental and coastal change, there is a divergence in both regions in marker species distributions and $\delta^{18}O$ content. However, the connection between even relatively small sea level fluctuations and similar small scale climatic shifts seems to be sufficiently pronounced to provide a valuable new proxy to test against terrestrial records of environmental change.

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**Soil production, bedrock erosion, and river incision rates in SE Australia**

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The functional dependency of bedrock conversion to soil on the overlying soil depth (the soil production function) has been widely recognized as essential to understanding landscape evolution, but was quantified only recently. This paper presents soil production, erosion, and river incision rates calculated from $^{26}Al$ and $^{10}Be$ concentrations in granitic bedrock and used to interpret the processes and rates of landform change in two field areas in southeastern Australia. First we show quantification of the soil production function in the context of a retreating escarpment, focusing on the soil-mantled hilly slopes in the upper Bega Valley, NSW. Radionuclide concentrations in bedrock collected at the base of the soil column show that soil production rates decline exponentially with increasing soil depth, defining a function with a maximum soil production rate of 53 m/My under no soil mantle and a minimum of 7 m/My under 100 cm of soil. The form of this function is supported by measurements of soil thickness that show an inverse linear relationship between topographic curvature and soil depth, but also suggest that simple creep does not adequately characterize the hillslope sediment transport processes. Spatial variation of soil depth and therefore soil production rates show a landscape out of dynamic equilibrium, possibly in response to the propagation of the escarpment through the field area within the last few million years. Additionally, a method is introduced to test the assumption of locally constant soil depth and lowering rates using concentrations of $^{10}Be$ and $^{26}Al$ on the surfaces of emergent tors. We find strong support for this assumption by comparing our data to predicted nuclide concentrations.

The second field site is on the southeastern highlands, east of Bredbo, NSW, and is typical of a granitic landscape where chemical weathering has differentiated the bedrock into saprolite and emergent core stones. Soil production inferred for radionuclide analyses from samples of the weathered saprolite may define a much steeper inverse exponential function of soil depth with a maximum production rate of about 140 m/My under zero soil depth. There were no observed soil depths between 20 cm and zero, however, and all exposed bedrock samples were emergent core stones. The maximum soil production rate is therefore about 50 m/Ma and similar to the Bega Valley site. Curvature-depth data from the highland site show a small range of soil depth for a broad range of curvature, which suggests the possibility of nearly constant erosion rates across the site. The catchment average erosion rate is $16 \pm 1$ m/Ma for this site, similar to the average hillslope erosion rate of $15 \pm 1$ m/Ma, with both rates determined from radionuclide analyses of granitic sediments. Bedrock incision rates of the Bredbo River, which sets the base level for the highland site, average 9 m/Ma and suggest that the higher rate of average hillslope erosion may be in response to the propagation of a local knickpoint that is observed in the long-profile of the Bredbo. Nuclide analyses of the outcropping tors yield bedrock erosion rates of about 4 m/Ma, with higher rates for the more weathered tor tops. A profile of nuclide concentrations above the ground on the tor surface is not consistent with the simple model of locally constant soil depth and lowering rates, suggesting that there is a legacy from the of processes dominant during the Pleistocene climates that still may be effecting the highlands. We explore this hypothesis briefly by showing predicted soil depths from a simple landscape evolution model and comparing them to our observed depths.

## Constraining LGM climate change in southern Australia with proxy evidence of aeolian processes and BIOME 4 modelling of vegetation change

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Aeolian processes in the Australian landscape today are very restricted but in the past have formed extensive sand dunes and loess-like mantles and contributed dust to deep-sea sediments. These have all been interpreted as qualitative evidence for greater past aridity. Wasson, using modern climatic data, elegantly described the threshold climatic conditions required for sand dune formation and the stability of the desert dunefields today below the threshold values. The two principle requirements identified to achieve wind erosion are 1) low surface roughness (generally less than 40% to 20% plant cover) and 2) high wind erosivity. Wasson used 'effective vegetation growth potential' based on potential evapotranspiration and precipitation (Ep/P) as a surrogate for plant cover and favoured a combination of stronger winds and drier climates to mobilize the desert dunefields of the last glacial maximum.

Recent analysis of aeolian dust in deep-sea sediments from the Tasman Sea has shown no evidence for stronger LGM westerly winds at the latitudes of southern Australia. The clear implication of this evidence (the most direct available for wind strength conditions) is that to explain enhanced dust load and dune formation during the LGM we must look to changes in plant cover.

Wasson's analysis of aeolian thresholds suggests that without stronger winds, climates would need to be significantly effectively drier to mobilize the desert dunefields. Specifically, the ratio Ep/P would need to increase by 100%. In its most dramatic form, with no change in potential evapotranspiration, this would require a decrease in P of 50%. However, there are many marginal dunefields, dunes or sand sheets in currently more humid areas which would still not reach the threshold condition, as defined by Wasson, even with such a radical reduction in precipitation. Dunes in the upper Blue Mountains, dated to the LGM, were perhaps in a landscape marginal for sand movement when they formed but are now covered by forest and forming deep podzol soils. These dunes would require at least a 500% increase in Ep/P to approach Wasson's threshold, a figure which stretches the extremes of any proposed LGM climate scenarios.

We have used the newly released BIOME 4 vegetation model to consider scenarios which could bring about the vegetative cover conditions necessary to explain the proxy evidence provided by the aeolian record. The model suffers from not having biomes or plant functional types which are tailored to the known Australian flora and the model output therefore requires cautious interpretation. The model allows for variation of climatic factors including average temperature, precipitation and atmospheric carbon dioxide concentration. We have chosen to vary all model grid cells uniformly according to published values of global atmospheric carbon dioxide (180 ppm) and temperature (-9°C) for the LGM in southern Australia. In the absence of more reliable proxy data on temperature variations within the region or seasonally we have chosen to use the single value from Miller et al's studies in the knowledge that it will not be appropriate for coastal areas and tropical Australia. We have run the model for different input values of annual precipitation (again, variations are uniform across Australia) to attempt to identify the magnitude of change required in this unknown to satisfy the proxy data.

## A DETAILED PLEISTOCENE-HOLOCENE VEGETATION RECORD FROM BEGA SWAMP, SOUTHERN NEW SOUTH WALES.

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Bega Swamp, 30 km east of Nimmitabel, NSW, is an elongated valley fill shrub bog at 1080m altitude on the crest of the eastern escarpment on a heavily forested granitic plateau. The restiad-shrub bog is little disturbed and surrounded by tall eucalypt forest. It is the site of intensive research initiated by the late Dr Gurdip Singh into the palaeoecology of the region. (Polach & Singh 1980, Green*et* *al.* 1988). A basal date of 13500 ± 320 years (ANU 1216) is the oldest known in New South Wales for a swamp at this altitude. About 110 Pb 210 and radiocarbon dates have been obtained from several cores taken a few metres from one another. The results from the upper 400mm were interpreted by Green *et al*. (1988) as showing an increase in deposition rate toward the surface, but no mixing of sediments. At greater depth the results from single samples give many minor inversions which do not seem to be consistently related to the fraction dated. Sodium hydroxide soluble fractions, which are often contaminated by young carbon, give some dates which are older than the bulk or fine fractions. Samples between cores (all taken from approximately the same location) also provide some inversions, probably related to coring at different stages of hydration of the bog, which can swell by a possible 400mm after rain.

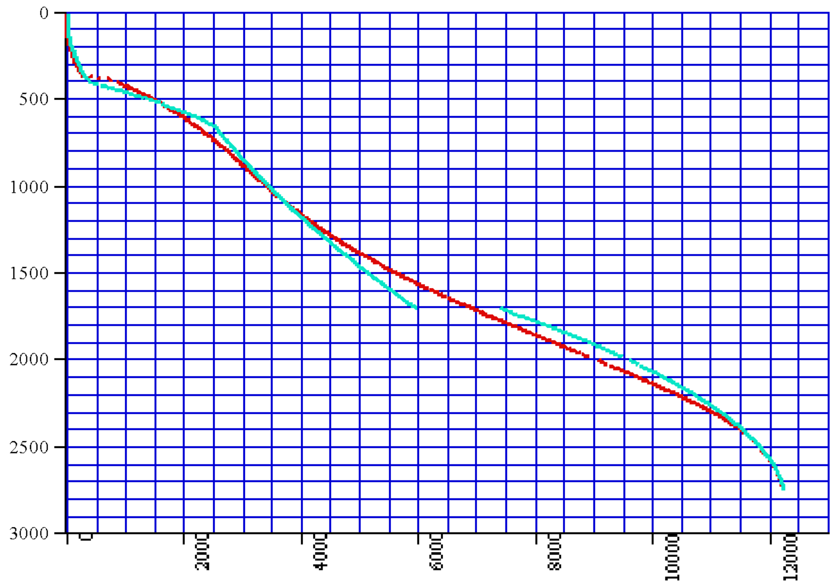


Figure 1. Two chronologies for Bega Swamp based on curve fitting to overlapping segments of radiocarbon data. The continuous chronology is used in the following discussion.

Fitting age depth curves to the data suggests that there may be levels that represent gaps in deposition around 520 and1700mm depth (ie around 450-250 and 6700-6100 years BP). One possible cause may have been fire on the bog. Below 500mm the line of best fit to the 1980 core dates suggests a long term accumulation of the peat at a rate of 20 mm per century, thus providing a second age model in which the dated levels are regarded as trend data rather than better estimates of age than undated levels. This chronology is weak below 2300mm (ca 10,500 yr BP).

The most detailed pollen diagram yet produced in the Southern Hemisphere has been obtained from the 1980 core, a 2742 mm column of slightly fibrous peat above sandy clay. The core was frozen and sliced with a bandsaw to produce 489 2mm slices with an intervening 2-4mm removed by the saw. The resolution below

400mm is thus a sample covering about a decade, the sample interval being 20-30 years between the median depth of each sample. As explained this is a floating chronology, as a level can only be estimated to lie within about ± 200 years. Improvement in the absolute chronology could be achieved as the slices are archived.

Pollen and microscopic charcoal are frequent and diverse, over 240 taxa having been recorded, including 35 myrtaceous types. The bulk of the pollen is probably derived locally and may have been affected by change on the bog surface. In general the bog is stable but it changes from a sedge-daisy-grass-*Epacris* bog to more herb-rich and wetter bog after 11000 BP. *Epacris*, *Myriophyllum*,*Neopaxia*, Apiaceae, including *Hydrocotyle* have long term peaks in the Holocene. Thus the core site has varied from flooded to well drained for various periods suggesting a possible mosaic of growth environments that vary slowly across the bog surface.

The inferred surrounding vegetation shows a transition from shrubby daisy-grass steppe, with a minor input of the alpine podocarp, to a low eucalypt (presumed snowgum) woodland by about 11,800BP, and then a phase of, herbfield development that lasts from 11,500 to 10,800BP. After this there is an abrupt transition to eucalypt forest which increases in diversity, and loses shrubs and possible heath *Casuarina* by 9400BP. The discrimination of Myrtaceae demonstrates that there are abrupt changes in eucalypt dominance about 7000 and 4000 BP which may represent shifts to the *E. fastigata*—*E. dalrympleana* forest of the present day. The highest shared diversity occurs from 6900 to 4300BP. A phase of relatively frequent wet forest elements (chiefly *Pomaderris*, with ferns and *Tasmannia*) lasts from 10,200 to around 2200 BP, but rainforest is never established on the site. This may be due to fire; charcoal frequencies vary but never reach low levels in the record. The highest levels occur from 10,200-7700BP when both*Callitris* and *Casuarina* is relatively well represented. The diverse forest phase after this sees an abrupt reduction in *Casuarina* from 6700-3900BP, suggesting a less open forest.

In climatic terms, Bega Swamp provides information on the Late Pleistocene environment of the coastal scarp edge east of Mt Kosciusko. An open subalpine or alpine environment that includes abundant herbfield elements is established which resembles the summit area of the Main Range today. Compared to the current 912mm and MAT of 9.5°C the moisture was probably slightly reduced, but temperatures may have been 6°C lower. It is hard to judge this; even today scarp summits exposed to strong wind and fog support *Allocasuarina nana* heath. This area probably was moist due to orographic rain and mist but conditions to the west were probably more steppe-like. The disappearance of *Podocarpus* by 11,200BP marks the end of alpine conditions. *Eucalyptus* invades the site well before 10,000BP but the transition to tall eucalypt forest may not be completed until 9000BP. The Holocene dynamics are hard to interpret. While *Pomaderris* has been considered as a "wet element" it really responds to disturbance of the eucalypt forest and this, rather than moisture, may explain why it remained important until 2000BP. The core of a possible "wet phase" is 6000-3300BP. There are no thermal implications.

The pollen record is important in providing the first assessment of the persistence of pollen influx from taxa at decadal resolution. Most pollen data for Australia is at century resolution at best, containing numerous single peaks or troughs of particular taxa which have to be interpreted as "noise". The Bega Swamp record shows very few single sample peaks; in most percentage curves the between sample variance is less than 15% for both dominant and minor elements. Peaks are supported by related increases and decreases in adjacent runs of samples. This is encouraging in endorsing the value of records from the relatively condensed peatland sections available in Australia.

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# THE LATE HOLOCENE AT LAKE VICTORIA


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Lake Victoria, on the Murray River in far southwestern NSW, is one of the main water storages in the Murray-Darling River system. In 1994 reports of up to 16,000 Aboriginal burials disturbed by managed high lake levels became headline news. These estimates have since been shown to be exaggerated, but political momentum led to a retrospective EIS, a s90 consent for Aboriginal relics (but not burials), granted to the MDBC by the NSW NPWS, and the biggest Aboriginal burial protection and monitoring project in Australia. There are unresolved Native Title Claims and applications under federal heritage legislation, and a Conservation Management Plan for the 'Cultural Landscape' of the lake shore is underway.

In many respects Lake Victoria is a typical western NSW Pleistocene lake with a large lunette. However, unlike the Willandra and many other lunette lakes, Lake Victoria continued to fill over the last 10,000 years or so, resulting in the development of extensive Holocene features and sediments within the older Pleistocene Lake basin. These include a classic delta formed by the inlet/outlet channels of Frenchmans Creek and Rufus River, a late Holocene shoreline barrier, and stratified shoreline sediments and palaeosols. For the last 70 years the lake shore has been regularly flooded 4-5m higher than under the pre-regulation natural lake regime. This has led to changes in erosion and sedimentation patterns around the lake shore, exposing Aboriginal burials, shell middens and artefacts in the Holocene sediments. The EIS studies included archaeological, faunal and geomorphological investigation of the sediments (Hudson & Bowler 1998, Hope 1998). As yet no pollen studies have been done, but the organic rich sediments would appear to be suitable.

Holocene C14 dates from Lake Victoria comprise 37 dates from the current study, and another 6 from previous studies (Gill 1973, Bonhomme 1993). Sixty percent of the Holocene dates are less than 2Ky and 40% less than 1Ky.

A summary of the interpreted Holocene sequence is as follows:

- 8-9Ky: Barrier ridges form across inlet channel.
- 7Ky Possible high water phase
- 5.5Ky Lake close to historic level, shoreline barrier initiated.
- 5Ky to historic: Delta extends beyond barrier ridges. Shoreline sediments accumulate, more than one phase of soil formation.
- Ca. 1Ky: soil instability around higher lake shore; red sand covers shoreline palaeosols.

- 600-200y: Dune buildup at southern end of lunette.

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# VOLCANIC ACTIVITY IN THE QUATERNARY OF VICTORIA, AUSTRALIA

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Volcanic landforms and deposits found across Central and Western Victoria, together with related areas in SE South Australia, form the Newer Volcanic Province of SE Australia (Figure 1). Some 400 volcanoes are known, and lava, scoria and ash cover approximately 15,000 sq. km. Absolute dating, supported by some stratigraphic evidence, indicates activity began some 7 Ma ago, and the most recent activity at Mt Gambier in South Australia was about 5,000 years ago. A major part of the activity occurred during the Quaternary, including during occupation of the area by aboriginal people, and future activity cannot be ruled out.

An M.Sc. study of the Geelong area by Jim Bowler, completed in 1963, was mainly concerned with the Tertiary sediments of the area, but also discussed Tertiary and Quaternary sequences, including basaltic lava flows, weathering of sediment and basalt, and the physiography of the Geelong area. The Moorabool Viaduct Sand, a calcareous sand and calcarenite of late-Miocene to Pliocene age, is an important marker for post-Quaternary volcanics. Originally defined in the Geelong area by Bowler (1963) as the sediments between the Fyansford Formation and the overlying Newer Volcanics, its ferruginous weathering and silicification clearly show the influence of late-Tertiary climate. Bowler also recognised evidence for young tectonic activity during and since the time of volcanic activity, evidence of importance in current neotectonic studies in Victoria.

Across Victoria and SE South Australia Quaternary volcanism has left well-preserved cones, craters and crater lakes, scoria with irridescence and stony rise lava flows with ropy and glassy surface textures, and such an obvious youthful appearance overall that the explorer Major Mitchell, the first person to recognise the area as volcanic in 1836, suggested that eruption had been "within the memory of man". However, the thin and widely-separated flow and ash deposits mean volcanic stratigraphic correlation is difficult, and occasional interfingering of these deposits with equally thin and discontinuous Quaternary sediments provides little help with broad correlation across the area.

Further dating, including a new program of Uranium series dating with Ken Collerson and Ph.D. student David Murphy of the University of Queensland, should help clarify the age of activity during the last 0.5 to 1 Ma. Current regolith landform mapping, based largely on radiometric imagery acquired by the GSV in the last few years, and incorporating many detailed student maps of individual volcanoes and deposits, provides a good idea of activity during the last 2 Ma or more (see Joyce 1999). From this work a new estimate of the number, type and distribution of the Quaternary volcanoes and their deposits can now be made, and it is clear they are a major feature of the Quaternary for this part of the Australian continent.

The chronosequence of regolith, landforms and drainage on the Newer Volcanic lava flows of Western Victoria also provides an excellent setting in which to study climate and climatic change, and especially a major change ~2.5 to 3 Ma. Late-Tertiary active weathering and iron movement has produced on lavas deep pallid kaolinitic profiles with ferruginous and mottled upper zones, and these contrast with the slow rate of soil formation since that time which has produced clay soils only 1 to 2 m deep (Figure 2).

Volcanism in Victoria is both an aspect of the Quaternary, and also a key to its further study. It is a major aspect of the landscape, dramatically affecting drainage, groundwater, landforms and soils, and so influencing plants and animals, and aboriginal and later settlers, who have inherited and used a volcanic landscape overprinted with the effects of Quaternary climates. Volcanism is a key to future Quaternary studies which will use volcanic deposits and landforms as age markers, as traps for sediment, fossil pollen and other aeolian deposits, and as sources of archaeological materials for hand axes, and construction such as eel traps and houses. Most recently interest in neotectonics has begun to demonstrate that faulting, warping and doming is a young and probably continuing aspect of the region, affecting the landscape generally but also related to the difficult problem of when volcanism occurred, and why it has occurred in certain areas and not others.

Future work should include studies of the interaction of aeolian and volcanic deposition, particularly in soil formation, and of possible cycles and climaxes in past volcanic activity, and their relevance to predictions of future activity. It is also important to be able to describe the physical effects on the landscape of a scoria cone–lava flow eruption, or a more explosive maar eruption, both to help understand the Quaternary landscape, but also to consider the likely effects of any future activity.

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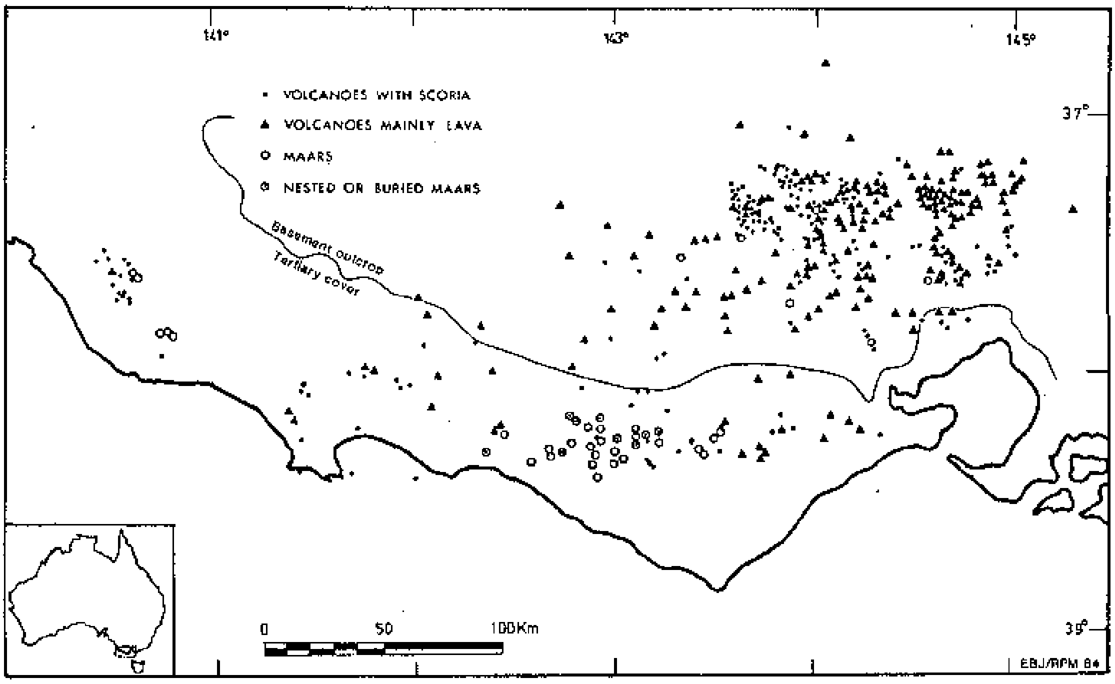


Figure 1: Newer Volcanic Province of southeastern Australia showing distribution by type of eruption points (Joyce 1984).

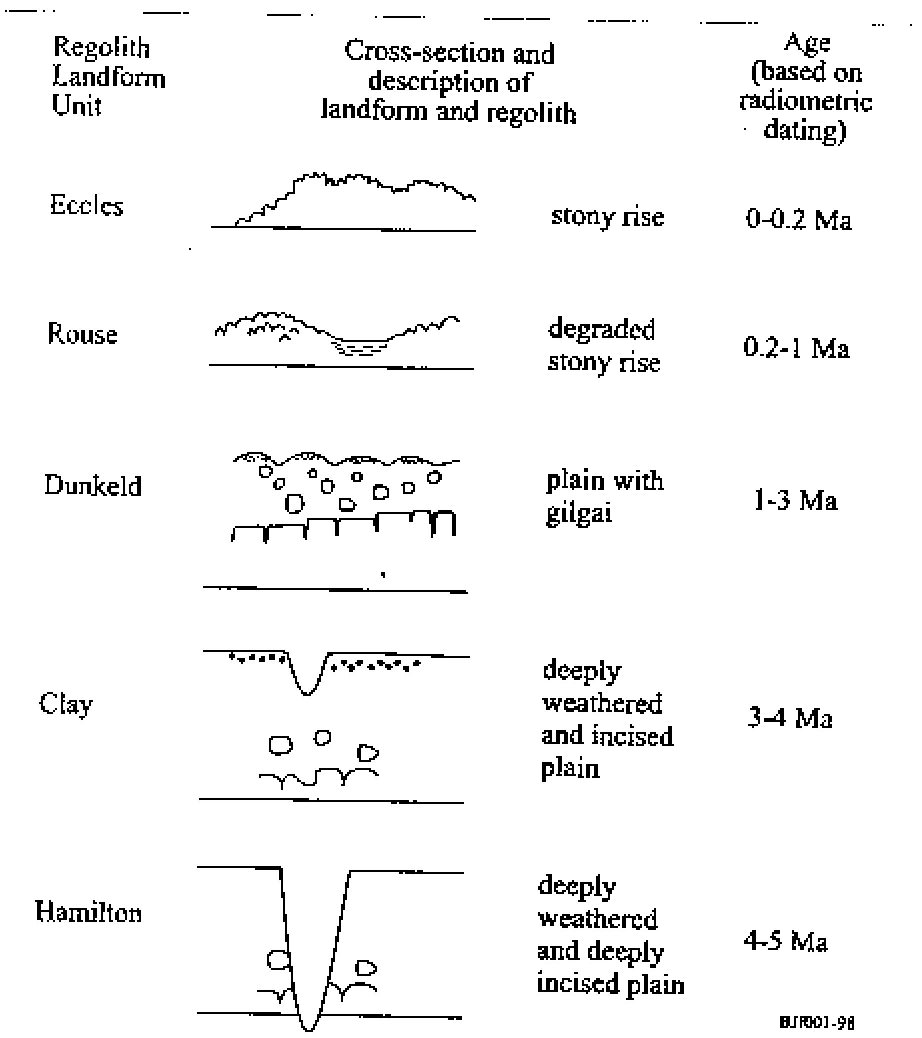


Figure 2: Regolith Landform Units of the basalt plains of the Newer Volcanic Province of southeastern Australia; each profile is approximately 20 m vertically (Joyce 1999).

# Landscape changes during the late Holocene and historical periods, Barmah Forest, Victoria.

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Total Catchment Management and the return of eco-systems to "a natural state" strategies are the current concern of environmental managers. To meet these objectives environmental data at spatial and temporal scales relevant to the landscape are necessary. The Murray River floodplain has a long history of Aboriginal habitation, but only inferred environmental information. European settlement of the region began in the early 1800s when. Settlement was rapid with early reports of the country from explorers and settlers being biased, by necessity, toward the suitability of land for grazing or agriculture. The result is that early historical environmental records are short and incomplete. The aim of this project is to provide extended environmental data on the dynamics of the Barmah Forest floodplain during the late-Holocene and European periods using stratigraphic and palaeoecological data to identify sediment, fire frequency and vegetation responses to European land-use practices.

The Barmah forest is the largest *Eucalyptus camaldulensis* (Denh.) (River Red Gum) forest in southern Australia. It is the Victorian section of the Barmah-Millewa Forest that lies between Tocumwal, Deniliquin and Echuca and occupies a flood-prone, low-lying region of 28,900 ha adjacent to the Murray River. Sediments consist of vertically accreting, seasonally dry silts and clays. Edward Curr first used the forest for grazing sheep in 1842. Cattle grazing and logging followed with gold-mining in upper catchment streams a major activity during the 1860s. Completion of the Hume Dam in 1937 and intensive regulation of Murray River flow for irrigation downstream of the forest has resulted in high summer flows replacing the natural high winter/spring flows. Summer floods within the forest are now common.

Sediment cores were extracted from six sites within the forest to identify historical spatial patterns within the forest. These cores have been sampled to give the fine temporal resolution necessary for determining short-term landscape evolution. To date the cores have been analysed for sediment particle size and magnetic susceptibility (6 cores); charcoal (3 cores); organic content (2 cores); and pollen (2 cores). AMS radiocarbon dates have been obtained for all cores and OSL dates are pending for 2 cores. In addition results are available from an earlier preliminary study. Pollen results are presented as concentrations rather than relative percentages of the dryland pollen sum as this gives a better indication of each species response to changes in landscape conditions in this semi-arid environment.

The pre-Historic Murray River floodplain was a relatively stable landscape. There is little variability in sediment composition, water content and loss on ignition values. The charcoal record shows fire to be an integral part of the landscape. However, the pollen record at Hut Lakeand the Millewa site indicate variability over time in *Eucalyptus,* Cupressaceae, *Allocasuarina* and wetland taxa. The Poaceae record indicates Hut Lake has always been a grass plain.

For the Historical period sediment analyses show there is now greater variability over time with recent, major changes in sediment composition and increased deposition rates. Each site has responded independently to changes during this time. Micro-charcoal data and CP:pollen sum ratios suggest that regional fire frequency has increased although charcoal particles in the record have decreased (this may be due to the increase in sediment deposition rates). The macro-charcoal records show that at Hut Lake fire frequency within the forest has remained unchanged, while at Gower's Gate the near-by charcoal burning activities are evident in the record.

The presence of *Pinus* pollen was used to determine the stratigraphic cultural boundary. The pollen record shows major changes at Hut Lake, Gower's Gate and the Millewa site. Comparisons between the pollen and sediment records show *Eucalyptus* regeneration after major flood events at the first two sites. At all sites *Eucalyptus* density increases. This increase verifies historical accounts of a more open forest at the time of European settlement. The loss of Cupressaceae at the Millewa site may be due to early European preference for this wood, whereas the increase at Hut Lake may represent a Cupressaceae plantation nearby. At Gower's Gate the MDS analysis shows a gradual change in vegetation over time. Wetland taxa indicate hydrological changes consistent with river regulation and increased flooding in the forest.

Grazing pressure, combined with hydrological changes has resulted in an increase in the unpalatable *Carex appressa* in the forest understorey. Completion of the Hume Dam and management of Murray River flows primarily for summer irrigation have resulted in increased *Eucalyptus camaldulensis* germination success and progressive loss of the Moira grass plains due to *Eucalyptus camaldulensis*. Changes to catchment land-use have caused changes in sediment composition and deposition rates.

# THE LAST MILLION YEARS AROUND LAKE KEILAMBETE, WESTERN VICTORIA

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Lake Keilambete has been a major focus of palaeoenvironmental research for over 30 years. Palaeo lake and salinity records derived from the study of sediments (Bowler and Hamada 1971), ostracodes (De Deckker 1982), ostracod chemistry (Chivas et al. 1985), palynology (Dodson 1974) and diatoms (Churchill et al. 1978), and hydrological modelling based on these studies (Jones et al. 1998), have combined to provided an unprecedented, high resolution record of effective precipitation through the Holocene period in Australia.

The availability of crater lake and swamp sediments from sites older than lake Keilambete, but within of few kilometres of it, provide the opportunity to examine patterns of climate change, as indicated in proxies within closed systems, through a much longer period of time. Here we present preliminary results from two sites which provide a discontinuous record of climate through the last one million years. The focus to date has been on palynology which, unfortunately for comparison with the Lake Keilambete record, was the least useful proxy at that site, due to the apparent insensitivity of the basalt plains vegetation to Holocene scale climate change. Pejark Marsh provides a record that extends from about 1 million to 740,000 years BP according to fission track dates on zircons within volcanic ashes located close to the base of the sequence and capping the sequence. Lake Terang contains sediments that extend from present to beyond 350,000 years B.P., according to uranium/thorium dating. Some additional chronological control for the last 200,000 years is provided by comparison with the more remote but better dated volcanic crater pollen record of Lake Wangoom (Harle et al. 1999, Harle 1998). The base of the Lake Terang sediments has not been reached, but as site formation may relate to the tuff capping Pejark Marsh, a 740,000 year sequence may be preserved.

Glimpses of the vegetation in the lower part of the Pejark Marsh record suggest a much less variable climate in the early Mid Pleistocene than in more recent geological time. Relatively low values of trees, particularly *Eucalyptus*, combined with high values of herbs, especially grasses, indicate domination of the landscape by open forest or woodland vegetation perhaps under average effective precipitation levels similar to, or slightly lower than the Holocene. However, traces of taxa considered to have higher moisture requirements, now extinct within the area, suggest survival of 'Tertiary' remnants, probably in small pockets. One regionally restricted taxon, relatable to the tree fern *Cyathea,* had a much more conspicuous representation.

Distinct climatic cyclicity is suggested in the upper part of the sequence with clear variation in the representation of trees, particularly *Eucalyptus*, and herbs. The beginning of this increased cyclicity is marked by major drying event which could relate to oxygen isotope stage 22, identified by Shackleton and Opdyke (1977) as the first glaciation of duration and intensity similar to the glacial stages of the Brunhes epoch. The 'Tertiary ' taxa appear to have succumbed to these increase climatic fluctuations but *Cyathea* maintained its representation.

Variability is a feature of the Lake Terang record although the record is not sufficiently clear or palynologically continuous to consistently separate glacial from interglacial periods. Based on correlation with Lake Wangoom, acceptance of the uranium/thorium 'age' of greater than 350,000 years, and consideration of patterns in terrestrial records from other parts of the world including Schŏ ningen (Urban 1999), and interpreted in terms of 'megacycles' (Kukla and Cilek 1996), the sequence could embrace the last five glacial-interglacial cycles. The lower part of the sequence suggests that the climate, possibly during isotope stage 11, was wetter than during any other recorded period at these sites during the last million years. It is likely that wet sclerophyll forest was extensive in the area and that *Nothofagus* forest, now restricted to small patches in the Otway region, was regionally expanded. *Cyathea* values also achieved their highest recorded values.

From this point, with the notable exception of the last interglacial period, there is a clear drying trend towards the present. *Nothofagus* is not recorded after what is considered to be isotope stage 9 while *Cyathea* appears to have been restricted to its present day distribution after isotope stage 7. The cause of this drying trend, evident in many other records from the Australian region, has not yet been determined for certain, but unlike other aspects of the climate history, seems to be a feature of this part of the world.

These records demonstrate that southeastern Australia has had a complex Quaternary climate history with patterns of variability evident on a number of timescales. A full Quaternary record is needed in order to properly address question like the time of onset of aridity and the impact of Aboriginal burning.

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# Sea level in the Australian region during the Holocene

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Sea-level studies for the Holocene are relevant to (i) the understanding of ice sheet evolution, (ii) the natural background signal for evaluating recent change, and (iii) evaluating the mantle rheology. Comparison of sea-level observations with model predictions based on glacio-hydro-isostasy leads to the conclusions that (i): For the past 6000 years (C-14) sea levels were higher than today for most of the Australian coastal region, the exception being Tasmania, (ii) the amplitude of the maximum highstand varies between 0 and about 3 m, (iii) the fall in sea level in this interval has been quite uniform with oscillations, if they occur at all, being less than about 0.5 m, (iv) ocean volumes continued to increase during this interval by enough to raise the global ocean level by 2-3 m. The apparent inconsistency between conclusions (iii) and (iv) is a consequence of the isostatic effects. Palaeoshoreline and water depth reconstructions, based on high-resolution isostatic models, will be presented.

# The lunettes of Lake Eyre:

# stratigraphy, chronology, palaeontology and meteorites.

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Lunettes have long been known to exist along the remote downwind north eastern and northern shoreline of Lake Eyre North, between the mouth of the Cooper Creek and Lewis Bay in the north west corner of the lake. Dulhunty (1983) was the first to map the distribution of lunettes and examine them on the ground. He provided a number of surveyed cross sections and noted an average height of 35 m above the lake shoreline and surveyed a maximum height of 48 m. He noted that the lunettes were currently being eroded, and that their structure was complex, with cores consisting of pale yellow-brown argillaceous sands. He generally recognised the presence of a single lunette, which diverged to two just south east of the Warburton Creek mouth.

The current study was initiated to analyse the deflation episodes of Lake Eyre to better define the stratigraphy and chronology of those parts of the palaeohydrologic record associated with low lake levels and aridity. Previous attempts to study these features on the ground had been thwarted by the difficulties of access, and a perceived lack of good exposure of the internal stratigraphy. However, low-level aerial reconnaissance indicated that the area between the mouths of Cooper Creek and Kalaweerina Creek had multiple parallel lunettes with relatively good deflation exposures of the internal stratigraphy. Additionally, access was deemed to be possible along the margin of the elongate inlet on the north side of the Cooper mouth, which extends about 30 km into the Tirari Desert dunefield to the east (‘North Harbour’). This area was visited in 1998 and 1999 with the expectation that the multiple lunette phases represented deflation episodes of different ages.

The area was found to be more stratigraphically and topographically complex than expected. Up to 3-4 multiple lunettes, which trend NNE and occur as isolated remnants with deep deflation exposure, are embedded in a younger longitudinal dunefield with a more northerly trend. The original lunettes appear to have varied in height, and perhaps width, along their length and generally only the eroded remnants of the higher portions remain as isolated inliers within the dunefield. The presence of a number of playas, including inlets from North Harbour, the

Horseshoe Lake (which extends south of the Kalaweerina mouth) and a number of isolated playas within the dunefield, adds further complexity.

**Stratigraphy:**

Occurring commonly at the margins of the playas, particularly the Horseshoe Lake, there is a bench of grey-brown sediment with a relatively flat surface, which underlies both the lunettes and the dunefield. The only stratigraphic sections of this unit were some gully exposures of up to about 2 metres which showed a pedogenically modified zone, with relatively abundant secondary displace gypsum. Unmodified sediments, indicative of depositional origin, have not been examined. The flat low-gradient topography and elevation (- 5 m AHD) suggest either deposition as a fan delta during a high-lake phase or as vertical accretion deposits on a low-gradient alluvial fan during a low-lake phase. The secondary gypsum zones might contain either or both groundwater deposited displacive gypsum and pedogenically translocated gypsum. *Genyornis* eggshell and marsupial skeletal remains were both found in the upper portion of the unit.

The eroded lunette remnants often expose up to 6-8 m of fresh sediment, from the core of the dune, on the floor of deflation hollows and on the vertical sides of residuals. The stratigraphy is essentially the same in all of the multiple lunettes with two units of slightly clayey yellowish-grey sands occurring in virtually all deflation exposures. Primary sedimentary lamination in the form of long sub-horizontal sets, typical of lunette sediments, is poorly preserved in both units. The upper 0.5 — 1.0 m of the lower unit usually contains small (0.5 — 1.0 cm diameter) pedogenic rhizonodules, which are gypseous and also contain some carbonate. The rhizonodules are usually moderately abundant but vary from sparse to very abundant. The lower unit is truncated at its upper boundary, commonly at the top of the rhizonodule-zone. The upper unit is lithologically very similar, but does not contain rhizonodules. It has a well-defined clay-rich horizon up to 1.0 m thick in its upper portion which is probably due to pedogenically translocated clay. This horizon often forms an erosion-resistant bench and is characterised by abundant rilling. The upper unit is probably truncated at the top of this horizon at some sites, though exposure of the upper part of the unit is often very poor, and its relationship to the overlying sediment is not clear. Separating the two units is a thin red-brown clay-rich unit which is absent in some sites and varies from a few cm to 20 cm in thickness. The unit has sharp erosional upper and lower boundaries and clearly has a depositional origin, but its environmental implications are not yet clear. Thin sections are under preparation but not yet available. The upper lunette unit is overlain by a top unit of poorly consolidated pale-yellowish medium sand, with the boundary between the units rarely exposed. The lower unit contains abundant *Genyornis* eggshell and occasional emu eggshell, which are patchily distributed; marsupial and*Genyornis* skeletal remains also occur. The upper unit contains rare eggshell, including *Genyornis*. The top unit is thought to relate to the longitudinal dunefield and contains only emu eggshell.

## Chronology:

*Genyornis* eggshell from upper part the basal grey-brown gypseous bench, has a D/L ratio of 0.98, indicating a stage 5 age. D/L ratios of eggshell from the two primary lunette units indicates that both are equivalent to the Williams Point aeolian unit (Magee and Miller, 1998) and date to the period 50-60 ka. The lower portion of this unit at Williams Point is dominated by sediment derived from a regressive beach phase, containing quartz, ooids and biogenic carbonates, and the upper part is dominated by sediment derived from playa deflation, with abundant clay pellets and gypsum. The upper part of this depositional phase was previously recognised by Magee and Miller (1998) as associated with the excavation of the current Lake Eyre playa basin. We relate the upper and lower units at North Harbour to the upper and lower parts of the Williams Point aeolian unit These latest results, from North Harbour, indicate the formation of multiple large lunettes at this time and support the interpretation of this phase as a major deflation episode. The stratigraphic complexity, in the North Harbour lunettes, indicates a more complex depositional history through this stage, than was evident at the Williams Point section (Magee et al, 1995). This more complex depositional sequence has also been noted in lunettes of Williams Point aeolian unit age on the eastern margin of Jackboot Bay.

A whole but partially fractured emu egg was found in aeolian sediment on the western side of the Horseshoe Lake and was retrieved with a dense mass of infilling sediment. With a D/L of 0.48, which indicates an age between 25 and 30 ka, the egg provides an excellent opportunity for a four-way dating comparison between AAR, AMS $^{14}C$ and U/Th on the eggshell and OSL on the contained sediment.

## Palaeontology:

Until now, megafaunal remains from the Lake Eyre region, with the exception of *Genyornis* eggshell, have been found reworked in fluvial sediments of greater than 60 ka age. In addition to abundant eggshell, the North Harbour lunette sediments contain *Genyornis*and marsupial megafaunal skeletal remains. The most spectacular find was an articulated *Diprotodon* cranium and mandible, almost 1 metre in length, in the upper portion of the lower lunette unit, though poorly preserved. These remains at about 55ka represent the youngest marsupial megafauna yet recovered from the Lake Eyre region. This Diprotodon will be dated by an OSL date from the surrounding sediment, an ESR date on tooth enamel, U-series on bone (by TIMS and Ge Gamma Spectrometry), and TIMS U series and AAR on stratigraphically associated Genyornis eggshell. A *Procoptodon* mandible was also found in a similar stratigraphic setting.

## Meteorites:

Two large meteorites were found lying on the surface of deflation hollows. These were both chondritic meteorites and found in a similar stratigraphic setting about 5 km apart. Thin-section analyses indicate they are not related.

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# Last Glacial Maximum terrestrial palaeotemperature estimates from New Zealand speleothems

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Over the last 30 years, speleothems have been increasingly investigated for their potential use as palaeoenvironmental and palaeoclimatic indicators. Particular attention has focussed on the oxygen isotopic variations in speleothem calcite as a proxy for temperature, based on the temperature dependent fractionation of stable oxygen isotopes between water and precipitated calcite. The method requires the isotopic composition of past waters to be either known or accurately estimated. As speleothems are deposited from percolating rainwaters, an adequate expression is required to describe changes in the long-term averaged isotopic composition of precipitation with time.

Quantitative and semi-quantitative approaches to the derivation of palaeotemperatures from speleothems have to date met with limited success, owing to the difficulty in quantifying the parameters that control oxygen isotope variability in speleothem calcite. This has led to the extensive interpretation of speleothems as representing qualitative palaeotemperature signals, where the direction and magnitude of change in the isotopic composition of speleothem calcite is interpreted as long term surface temperature variations at the site.

Here we use the modern isotopic data from six Australian and New Zealand IAEA/WMO stations to characterise variations in the isotopic composition of regional rainfall. The dominant climatic factors controlling the modern isotopic variability in the region are constrained. An expression for the spatial and temporal variations in the isotopic composition of precipitation, and a speleothem temperature equation for the region are presented. The equation was evaluated at sites of known modern calcite composition before being applied to two published New Zealand speleothem $\delta_{18}$O records, the only ones from the region which span the LGM.

The results suggest LGM temperatures ~6°C cooler than present in New Zealand, with cold conditions between 30 and 21 ka with several minor warming events. This is followed by a progressive warming from 18 to ca. 13 ka, reaching a temperature maximum of ~1°C at ~9 ka. The late Holocene appears to be characterised by temperatures slightly cooler than present. Good agreement is obtained with other independent records from the Southern Hemisphere, in particular the Antarctica ice core records.

## A 500 ka high resolution effective precipitation record for South-West Western Australia from speleothem formation events.

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Most of the evidence for past changes in effective precipitation in southern Australia comes from the south-east of the continent, with comparatively little information available from the western margin. Dating limitations beyond the limit of radiocarbon has also resulted in most of the evidence being restricted to the last glacial cycle. Because the processes controlling speleothem formation are closely linked to water availability, and because they can be accurately dated by the TIMS 230Th/234U method back to Å500 ka, cumulative frequency distributions of speleothem deposition events over time can provide high resolution long term effective precipitation records. We successfully applied the method to the Naracoorte region, in south-east SA, where a good agreement with the Australian lake level and fluvial record was obtained, particularly for the last glacial cycle. Here we present results from a data set of 51 $^{230}$Th/$^{234}$U TIMS dated speleothem samples from the Margaret River region, south-west WA.

The results show a good agreement with the Naracoorte record, indicating that deposition occurred predominantly during stadials and interstadials of the last 4 glacial-interglacial cycles. Synchronous depositional events in both records occur in the stadials preceeding glacial maxima. Four principal depositional events are identifiable: 0-16 ka; 19-32 ka; 170-200 ka and 280-360 ka. Deposition is initiated sometime after the interglacials, and in 3 of the last 4 cycles occurs right up to the glacial maxima. Glacial maxima appear as comparatively arid, as do the previous 4 interglacials. Significantly, the Holocene is the only interglacial that appears comparatively wet. The record suggest that the Holocene, at least for south-west Western Australia, is a poor analogue for past interglacials.

# MASS SPECTROMETRIC U-SERIES DATING OF *GENYORNIS* EGGSHELLS AND THE EXTINCTION OF AUSTRALIA'S MEGAFAUNA: SOME PRELIMINARY RESULTS

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Since the discovery over a century ago of megafaunal fossil remains there has been an ongoing debate as to what caused such a massive and widespread extinction. Was it due to changes in climate or hunting by humans who first colonised the Australian continent? In order to better constrain the timing of megafaunal extinction we report here thermal ionisation mass spectrometry (TIMS) 234U-230Th ages for eggshells from the now extinct Australian megafauna, *Genyornis newtoni*. *Genyorni* eggshells have been analysed from a variety of locations in South Australia (Lake Eyre, Lake Frome, Cooper Mouth) and New South Wales (Perry Sand Hills).

The possibility of using TIMS U-series dating, an inherently very precise chronological system, for archaeological purposes is a relatively recent innovation. Its widespread application has however limited by the generally open system behaviour of U especially in bone and teeth samples. TIMS methods for U-series dating has the important advantage compared to alpha counting of being able to analyse both smaller and importantly lower U concentration samples. From studies of amino acid racemization (Miller etal., 1999) it is has been shown that the organic proteinaceous constituents of *Genyornis* eggshells are retained without diffusional loss, and may potentially provide a stable host for U in its reduced form. An initial set of reconnaissance TIMS U-series studies from a number of shell fragments exposed in a deflation playa from Wentworth, New South Wales was undertaken. These samples give a highly self consistent set of ages despite a relatively wide range in U concentrations (74 to 233 ppb). One difficulty, with these initial results is the relatively high proportions of common 232Th, presumeably due to incorporation of detrital material in the shell micropores. At this level, incorporation of 230Th together with 232Th becomes significant relative to that produced by in-situ decay of 234U. Subsequently, a more refined mechanical procedure has been adapted which involves drilling and removing detrital material incorporated in the pores of the shell and abrading external surfaces. For this latter group of samples correction for detrital 230Th is in most cases insignificant. In addition analyses of several shell fragments from the same site show excellent reproducibility. These results are consistent with rapid, early uptake of variable amounts of U, and as far as can be ascertained, indicate an approximately closed system behaviour for U-Th.

Using these more refined analytical methods a range of precise ages of from 230 ka to 41 ka has been obtained with a peak in the age distribution pattern at 50-70 ka, with relatively few ages younger than 50 ka. These results indicate that *Genyornis* was prolific at 50-70 ka, the same period during which the first humans occupied the Australian continent. From ~50 ka to 40 ka the *Genyornis*population diminished with no ages being found younger than 40 ka, the upper limit of radiocarbon dating, consistent with *Genyornis*becoming extinct at that time. Thus while humans probably played some role in the diminution of the *Genyornis* population, they co-existed for at least 10 ka, and there is no evidence for a catastrophic decline in population as occurred for the New Zealand moa. This suggests that the extinction of *Genyornis newtoni* probably resulted from a combination of factors; a reduction in numbers due to human preditation followed closely by major changes in the environment as the Australian continent became cooler and more arid in reponse to glacial cooling.

# THE SMALL MAMMALS AND SEDIMENTS OF ROBERTSON'S CAVE, WORLD HERITAGE NARACOORTE CAVES CONSERVATION PARK, SOUTH AUSTRALIA.

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A fossil deposit was excavated in Robertson's Cave, within the World Heritage Naracoorte Caves Conservation Park, which yielded extinct and extant mammal, bird and reptile remains. This paper focuses on the small mammals, which appear to have been deposited by the accumulation of owl pellets. The deposit was excavated in $3x1m^2$ overlapping pits to a total depth of 2.5m, which represents an accumulation spanning the late Pleistocene and Holocene. Two radiocarbon age determinations (8080 ± 100 BP and 27650 ± 500 BP) have been obtained using large discrete pieces of charcoal from the upper and middle layers of the deposit. A further 6 radiocarbon samples have been submitted and are currently being processed. Analysis of small mammal remains, which include *Bettongia lesueur*, *Ningaui yvonneae*, *Notomys* mitchelii and *Lagorchestes* sp. cf. *L. conspicillatus*, suggest that environmental conditions were cooler and drier than present during the late Pleistocene and remained so into the Holocene.

# PROBLEMS IN ESTABLISHING CHRONOLOGIES FOR CAVE DEPOSITS

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Establishing accurate chronologies is a major challenge facing vertebrate palaeontologists studying Australian Quaternary deposits. This is particularly so for cave environments which preserve much of this fossil record. The accumulative mechanisms and depositional environments associated with caves range from the simple to the complex. Processes such as sediment reworking and slumping, differential transport and mixing of skeletal elements and datable material, multiple collection modes and bioturbation have the potential to confound attempts to establish a reliable chronology. The signatures left by these processes within cave deposits must be identified to ensure the accuracy of chronological inferences. Results of case studies from sites in the World Heritage Naracoorte Caves Conservation Park are discussed as examples.

## MID-HOLOCENE TO PRESENT CORAL RECORDS OF CLIMATE VARIABILITY IN THE WESTERN PACIFIC WARM POOL, PAPUA NEW GUINEA.

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The Western Pacific Warm Pool (WPWP) plays a key role in modulating tropical climate and in the initiation of El Niño - Southern Oscillation (ENSO) events, however it is not known how the warm pool and ENSO will respond to future greenhouse warming. This study aims to use records of Sea Surface Temperature (SST) and rainfall extracted from mid-Holocene fossil corals to examine the nature of ENSO when SSTs appear to have been slightly warmer than present.

Modern and fossil *Porites sp* corals were drilled from Koil and Muschu Islands, Papua New Guinea, located in the central WPWP and within the path of the Sepik River flood plume. Here reduced SST and rainfall manifest ENSO events and changes in these parameters are reflected in coral skeletal oxygen isotope ($\delta^{18}O$) and Sr/Ca ratios.

Fossil coral $\delta^{18}O$ results show an average decrease in $\delta^{18}O$ values from 7055 to 4675 yrs BP followed by a small increase to present $\delta^{18}O$ values. Reduced interannual range in $\delta^{18}O$ values (~0.4‰ range) compared to the modern corals (~0.6‰ range) persists until 1865 yrs BP. The fossil coral $\Delta\delta^{18}O$ results for 7055 yrs BP indicate cooler/drier than present conditions, assuming that the $\delta^{18}O$ of monsoonal rainfall for the Warm Pool area was similar to modern values in the mid-Holocene. The dry condition persisted to 4985 yrs BP when coral Sr/Ca ratios indicate a warm SST peak ~1° C higher than present. By 4675 yrs BP conditions are perhaps slightly cooler and wetter than present.

The $\delta^{18}O$ results suggest that the ENSO may have been weaker from 7055 to 1865 yrs BP, however some years with higher $\delta^{18}O$ values may reflect weak-moderate ENSO events. Although the initial Sr/Ca results need to be verified, the 1° C warmer than present temperature at 4985 yrs BP, coupled with drier conditions, suggests there was no thermostat effect acting to regulate SSTs in the mid-Holocene Warm Pool. This result indicates that it may be possible to have warmer SSTs coupled with ENSO events.

## Testing the impact of early humans: PRELIMINARY records of environmental change from Lake Gregory and Wolfe Creek Crater,

## NW Australia

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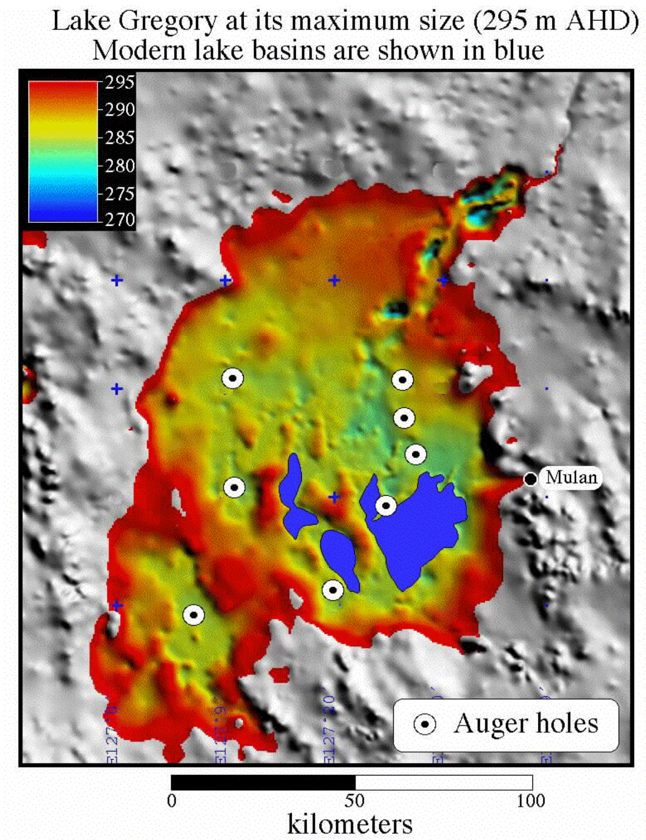
Based on our studies at Lake Eyre and Lake Victoria, we hypothesize that systematic burning by early human colonizers led to rapid ecosystem change across semi-arid northern Australia. This change in vegetation structure and density led directly to the extinction of the Australian megafauna, and through a reduced transfer of moisture from biosphere to atmosphere, to a weakening of monsoon moisture penetration into the continental interior. The primary evidence on which this hypothesis is based is 1) the presence of a deep-water phase in Lake Eyre 60 ka ago, when monsoon forcing was modest, and the lack of a deepwater lake in the Holocene when monsoon forcing was stronger (Magee, 1997), 2) evidence that monsoon-dependent grasses were abundant around Lake Eyre 60 ka ago, and have been much less abundant through the Holocene (Johnson et al., 1999), and 3) our dates on the timing of megafauna extinction (Miller et al., 1999). The concept is supported by GCM simulations suggesting that the sensitivity of monsoon moisture penetration to vegetation density over northern Australia is high (2 to 4 mm $day^{-1}$ during the wet season). This hypothesis has specific predictions for monsoonal Australia: it predicts that the wettest phase of the last 150 ka occurred early in the last interglacial, with lesser wet phases later in stage 5, about 60 ka ago, and the Holocene. The Holocene monsoon is predicted to be most intense in the early Holocene. Finally, we predict that much of the northern semi-arid zone carried a C3-dominated shrub-tree vegetation 60 ka ago, changing to C4 desert scrub by ca. 50 ka ago and remaining so through to the present.

Previous work at Lake Gregory has shown that a megalake phase more than 10 times the modern lake occurred within the past 300 ka (Wyrwoll et al., 2000). Stratigraphic and geomorphic studies across monsoonal Australia have suggested that the summer monsoon was re-invigorated in the Holocene after a period of quiescence during the Last Glacial Maximum (LGM). However, it has been difficult to date the megalake phase and to find records that span the entire Holocene to test when the monsoon was reestablished.

**Lake Gregory**: Interbedded littoral sands and carbonates mark a distinctive shoreline during the megalake phase of Lake Gregory. We surveyed the shoreline at 295 m asl, 25 m above the current lake. We refined earlier estimates of the megalake shoreline by superimposing the leveled shoreline elevation on a regional DEM and verified the simulated lake outline in the field by identifying lacustrine sediments in augered holes (up to 10-m-deep) in the major basins (Fig. 1). To test the age of the megalake phase we collected shoreline ironstones for U/Th dating, and sampled beach and dune sands below the shoreline for OSL dating (dating in progress at RSES, ANU). Carbonate deposited at the 295-m level during the last highstand has a $^{14}C$ age $^{3}$40,600 (AA-33400). Based on changes in dune morphology, we suggest that dunes dated more than 200 ka (J. Bowler and K.-H. Wyrwoll, pers. comm., 1998) may have been partially reworked by subsequent high lake events, hence may provide minimum dates on the megalake phase. Dunes from late stage 5 have not been reworked.

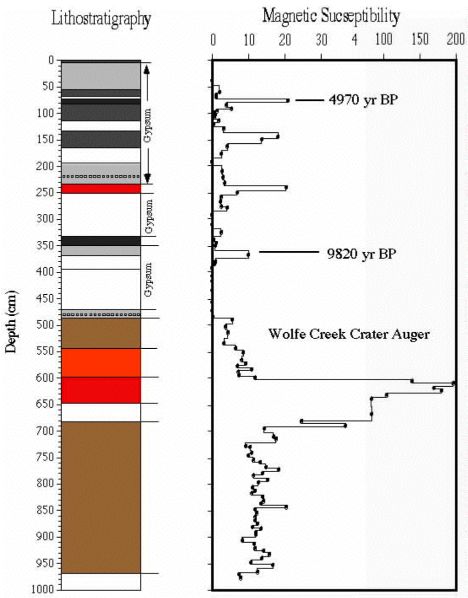



A 90-cm-thick section of post-LGM lacustrine mud at Gilwah Waterhole, nearly 8 m above the floor of modern Lake Gregory, contains common limnic gastropods and bivalves at the base of the section. One gastropod has been dated by AMS $^{14}C$ at 12,505±80 BP. Large (30 cm) calcite rhyzoliths at about the same elevation that formed when regional precipitation was high and $Ca^{+2}$ was mobilized, have a date of 11,145±75 BP. These two dates support our prediction that the summer monsoon was reinvigorated at the end of the LGM during a Southern Hemisphere summer insolation minimum, consistent with our contention that Northern Hemisphere conditions exert a dominate control on the Australian Monsoon.

A 6-m-thick sequence of interbedded lacustrine, fluvial, and eolian sediment is exposed along lower Sturt Ck; augering allowed us to recover a continuous section more than 9 m deep. At least two, and possibly four eolian cycles are represented in the section, representing >100 ka of episodic sedimentation. Carbon isotopes in the bulk organic matter preserved in this section are primarily of terrestrial origin.

They indicate dominance by C3 vegetation except in the upper meter of section, where there is a rapid shift to much heavier $\delta^{13}C$ values, suggesting a replacement of regional C3 vegetation by C4 grasses. Although the dating is still uncertain, the pattern is consistent with our hypothesized environmental changes.

**Wolfe Creek Crater** is a roughly circular impact crater formed in late Precambrian quartzitic sandstone; the floor is 25 m below the surrounding landscape. The crater's geometry precludes excavation of sediment by eolian processes, and the crater is expected to contain a continuous sedimentary record since impact. Clastic sediment input comes from crater wall erosion and from desert dust off the surrounding dune fields, the latter likely to be enhanced during arid phases. The crater also acts as a ground-water window. We recovered two short (4 m) and one long (10 m) augered sections. The physical stratigraphy documents alternating periods of dominance by red desert dust, lacustrine sedimentation, and periods of landscape stability and pedogenesis. Groundwater gypsum dominates the upper 4.5 m, punctuated by intervals of clastic sediment input. Magnetic susceptibility (MS; Fig. 2) tracks the flux of desert dust (oxidized Fe-rich clays coating fine-grained quartz grains) as spikes in MS, as well as the general increase in magnetic minerals below 4.5 m. Oogonia, which occur at several levels, have been $^{14}C$ dated at 75 cm (4970±65 BP) and 368 cm (9820±90 BP) depths. Dates on humins appear less reliable. We tentatively estimate that the gypsum-dominated upper 4.5 m of section represents relatively high water tables of the last 10 to 12 ka, and that the dominantly minerogenic sediment of the deeper levels was deposited much more slowly, representing at least the previous 60 ka of record. Bulk carbon in these sediments is dominantly of aquatic origin; pollen is not preserved.




*Although secure conclusions await the results of ongoing dating and measurements of specific environmental proxies, the preliminary results currently available support several predictions of our hypothesis derived from more southerly sites.*

## Climate Variability over the last 2000 Years in SE Australia

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### Introduction

This paper aims to introduce the 'late Holocene' session by describing some of the Australian work focussed in this time period, and by describing the themes and problems encountered at this temporal scale. It is argued that one way of ensuring that Quaternary studies are seen to be relevant (to Government, funding bodies and the wider community) is by addressing contemporary problems (eg. applying palynology to re-vegetation programs, elucidation of recent fire history and documenting the recent eutrophication of lakes and reservoirs). Such studies bringing the palaeoenvironmental community into contact with a wider audience, which may potentially be of importance to the discipline as a whole.

Studies in the late Holocene also have application to the discipline as a whole. Climatic fluctuations of the late Holocene may prove particularly important in deciphering the causes of shorter-term climatic fluctuations, the degree of anthropogenic versus ‘natural’ variation and the potential impact of climatic oscillation on human or other biotic communities. It is also important to recognise that even small changes in climatic averages 'could be associated with substantial changes in the magnitude and frequency of extreme events' (Wasson 1996, p14). It is also probable that some environmental systems are highly sensitive to such extreme events (Chappell, 1991).

As noted by Villalba (1994) the late Holocene has been somewhat neglected in the Southern Hemisphere, however, such studies are necessary for a truly global examination of climatic fluctuations and their possible causes.

### A Literature Review of the Last 2000 years in SE Australia

The results of a review of palaeoenvironmental studies in south-eastern Australia, covering the last 2000 years are also presented. This review examined periods of change as a proxy for climatic fluctuations, and reveals that the various palaeoenvironmental studies have identified periods of change that are not notably consistent. This may reflect site-specific environmental thresholds, lags and response to as yet to be identified climatic changes, or might suggest that other explanations are needed. It is likely, even in the region examined, that spatial differences and differences in climatic sensitivity may be evident.

Bradley *et al*. (1987) demonstrated how potentially important changes in ENSO events can be to global climatic systems. Quinn and Neal (1992) have reconstructed El Nino events back to the start of the 16th century, allowing examination of periods of change. With regard to the time frame of this review, this record shows that there was a higher frequency of ENSO events between AD 1539-78, 1600-1624, 1701-1728, 1812-1832. These periods of higher frequency ENSO events are not evident in Australian palaeoenvironmental studies to date.

The evidence is still relatively coarse, but suggests climatic variability ending at approximately 2000 BP and from about 1750-1500 BP. The review indicates that palaeoenvironmental change in the last 1000 years has been identified less frequently than in the preceding millennia. Notably, however, the highest frequency of change occurs in the period from 750-500 BP, which is traditionally portrayed as representing the late stages of the Medieval Warm Period. This change may thus represent the expression of the end of that anomaly and the initiation of the more recent cool anomaly.

The potential forcing mechanisms of climatic fluctuations over the last 2000 years are also briefly reviewed. Despite some dissension (eg. Jones and Bradley, 1992; Bradley and Jones, 1993), in Europe the climatic variability of the last 1000 years is increasingly being tied to solar variability, recorded for example, in natural archives of cosmogenic radioisotopes (Wigley and Kelly, 1990; Karlen and Kuylenstierna, 1996; Van Geel *et al*., 1996).

This suggests that the challenge is to try and determine the synoptic consequences of a change in solar irradiance. In Europe, again for comparison, it is thought that periods of lower solar activity coincident with colder periods (eg the Maunder minimum and the 'Little Ice Age') may have seen an increasing importance of the polar anticyclone over central Europe, resulting in a more continental climate.

If late Holocene climatic oscillations are related to solar forcing, then the solar changes may have fed into, and filtered through, local synoptic patterns. The synoptic response may hence explain regional variations (eg. wet versus dry or warm versus cold) within a particular time period, especially if different synoptic systems have different susceptibility/resilience to such forcing. Again this suggests that in Australia we should confine any future study to a region with a demonstrable similar synoptic control.

BIOME300, a new PAGES initiative is also introduced. Biome300 aims to make the best possible contribution to the reconstruction of changes in land cover over the last 300 years on as nearly global a scale as possible. This reconstruction of land cover at 300 years ago is mainly to provide empirical evidence for assessment of these changes to atmospheric carbon concentrations.

One of the primary aims is to provide information for modellers (eg. carbon reservoirs and changes, vegetation, land use and climate interactions) and for re-vegetation programs. Notably the project should have implications for evaluation of proposals to meet Kyoto protocols via manipulation of land cover.

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# Late Holocene fire in the Sydney coastal region from sedimentary charcoal and palynology

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## Introduction

There are several issues of contention regarding the recent history of fire in Australia and the Sydney region in particular. This debate has recently been re-ignited by Flannery's (1994) book *The Future Eaters*, which popularised the debate concerning Aboriginal use of fire (eg. Cleland, 1957; Tindale, 1959; Jones 1969; Hallam 1975; Horton, 1982). Flannery (1994) claimed that regular burning of the Australian landscape meant that the vegetation encountered by European settlers was a cultural artifact resulting from thousands of years of manipulation by Aborigines. This interpretation relies heavily on evidence gleaned from writings of early settlers, especially in the Sydney area, which may be misinterpreted and/or exaggerated (Williams and Gill, 1995; Benson and Redpath, 1997). Ryan *et al.*(1995) and Langton (1998) have since proposed the application of Aboriginal burning practices in the modern setting for conservation reasons. They suggest that the introduction of low intensity, high frequency fire will return the landscape to its 'natural' state as was maintained by the Aborigines.

The way in which fire regimes changed with the coming of European settlers is another issue surrounded in contention (Head, 1989). It is generally reported that when Aboriginal influences were removed there was a build up of fuel and the clearing of land for agricultural purposes saw an increase in the frequency and intensity of fires (Recher and Christensen, 1981; Pyne, 1992; Flannery, 1994; Kirkpatrick, 1994). A policy of fire suppression followed (Recher and Christensen, 1981; Pyne, 1992; Flannery, 1994), which has in recent times given way to hazard reduction burning (Pyne, 1992). This generally constitutes low intensity fires at pre-determined intervals often out of the normal fire season (McLoughlin, 1998).

This study aims to apply to the analysis of charcoal to a $^{210}$Pb dated sediment core from Jibbon Lagoon in Royal National Park, to the south of Sydney. Notably, this differs from previous palaeoecological studies in the Sydney region in several ways:

1. the recent sediment chronology is better constrained through the application of $^{210}$Pb dating;
2. it utilises larger charcoal size fractions; and
3. it attempts to compare the sedimentary charcoal record to the recent history of fire at the study site to test the methodology.

## The Study Site

Jibbon Lagoon (located 20km south of the Sydney CBD in Royal National Park, NSW at 34° 5'S, 151° 9'E) is a fresh-water shallow lagoon occupying a deflation hollow below sea level. There are no streams flowing into the lagoon: precipitation and runoff from the surrounding catchment are the only surficial flows of water. The bedrock underlying the lagoon consists of Hawkesbury Sandstone, and the main feature of the catchment is a moderately steep hill to the south-west of the lagoon that leads to the township of Bundeena. The soils of the area are highly erodible, skeletal, sandy-loams with low humus content, poor water-retaining properties and low fertility.

The Jibbon area experiences a temperate coastal climate and the fire season is during spring and summer. Royal National Park supports a complex mosaic of eucalypt woodland, heaths and open scrub communities (NPWS, 1994). The exact composition of these assemblages is highly dependant on the time since last fire as the dominant species (*Banksia ericifolia, Casuarina distyla* and*Hakea teretifolia*) are fire sensitive and are unable to persist if the fire frequency is too high or too low (NPWS, 1994; Wright, 1996).

It is thought that Aboriginal people from the Dharawal language group occupied Royal National Park for at least 7500 years prior to European settlement (Megaw, 1969; Goldstein, 1976; Flood, 1990; Wright, 1996). The abandonment of traditional lifestyles probably occurred in the early Nineteenth Century (Carter, 1969). The European history of the study area began as a large property known as Yarmouth Estate. This was subdivided in 1898 to form the township of Bundeena (Pettigrew and Lyons, 1979).

## Methods

The recent fire history (back to 1942) of the study site was derived from the National Parks and Wildlife Royal National Park GIS (post 1968) and from Keith (1995) who analysed aerial photographs.

Sediment cores were removed from a site adjacent to the south-western shore, below a steep slope, where it was thought that the delivery of charcoal would be best. The charcoal content of the sediment was assessed in three size classes. Charcoal was quantified using the point count method (Clark, 1982) and wet sieving (Long *et al.*, 1998), which resulted in size fractions of 125-250μm and >250μm. These larger size fractions should travel shorter distances and reflect local fire (Clark, 1988 1990; Morrison, 1994; Tinner*et al.*, 1998).

Pollen slides were produced following standard palynological techniques (Faegri and Iverson, 1975; Moore *et al.*, 1991). For the point count method at least 1650 random points were applied. The concentration of *Alnus*, *Pinus* and *Banksia* pollen grains present was also determined. Charcoal was expressed both as a concentration and influx, with the latter calculated using sedimentation rates derived from the $^{210}$Pb analysis.

The amount of sand present in each of the (macro-) charcoal sub-samples was estimated. The bulk density, water content, dry weight (at 105° C for ≥ 12 hours) and loss-on-ignition (2hrs at 550° C) of the samples were determined. Lead-210 dating was applied to 0-4, 4-6, 6-9 and 9-11cm intervals and contiguous 1cm depths below that to 21cm. The sediment accumulation rates were calculated based on the constant rate of supply model as described by Appleby and Oldfield (1978).

## Results and discussion

One of the aims of this research was to derive a sensitive index of fire activity by comparing documented historic fires with their sedimentary expression. It was hoped that the fire events of the recent European period at Jibbon Lagoon would be reflected as distinct peaks in the charcoal record. Investigations into the documented fire history of the Jibbon area resulted in a large number of fires, however the fires of 1942, 1946, 1964, 1977, 1988 and 1994 were considered 'signature' fires to be examined against the sedimentary charcoal record.

The fires of January 1994 and October 1988 were devastating, and hence it was expected that the upper section of the sediment core would contain abundant charcoal. In this section, however, both the concentration and influx of charcoal was relatively low. It was thought that this result may have reflected the high organic content of this upper section of the sediment column, so the (macro-) charcoal concentrations were re-calculated as number of particles per gram of material not ignited in the LOI procedure. Even with this recalculation, the most recent fires (1994 and 1988) are not unambiguously reflected in the charcoal record.

Notably several peaks in the charcoal record did occur at a depth that approximated the timing of earlier historic fires. This includes the 1976/77 fire (the charcoal peak at 4-4.5cm depth), the 1964 fire (6-7cm) and the peak in charcoal (centred on 10 cm depth) seems to well reflect the large fires of 1942 and 1946. It is uncertain why these fires show up as peaks in the record when the two most recent fires do not.

## Post European Fire

The charcoal values between the European and pre-European periods at Jibbon Lagoon are very different. The pre-European period is characterised by consistently low concentrations of macroscopic charcoal with only one apparent large local fire event (at 47-49cm). Even at it's lowest, the charcoal of the post-European period exceeds the pre-European levels, suggesting that fire has been more prevalent during this time, and that the fire regime does not mimic the pre-European pattern.

The early European period (from 16.5-19cm *viz*. 1850-1916) in the sediment column contained the lowest influx of charcoal of the European period. This is likely to reflect the absence of fire, an interpretation supported by the relatively high concentration of *Banksia* pollen as it has been well established that species of *Banksia* are negatively affected by high fire frequency (Keith, 1995; Keith and Tozer, 1997). This may reflect a period of little human influence in the catchment, representing the period between the decline of Aborigines in the Sydney region and the expansion of Bundeena.

The influx of charcoal is high in the section of the core corresponding to *ca*. 1939 to 1954 (9.5cm to 14cm). This period covers WWII, during which time there was a large influx of people moving to the growing township of Bundeena (Pettigrew and Lyons, 1979). This also corresponds to a period of increased sedimentation, suggesting that the increase in fire activity in the catchment is largely responsible for the post-European increased rate of sedimentation in Jibbon Lagoon.

**Aboriginal Fire**

The generally low levels of charcoal in the pre-European period is likely to reflect either the absence or rarity of fire, or that fires were small, and as such the vegetation surrounding any burnt patch impeded the transport of charcoal to the lagoon. The rationale for the broadcast use of fire by the Aboriginal people must be considered. In the vegetation surrounding Jibbon Lagoon there may have been little advantage in the use of fire to manipulate resources, as is implied by Jones' (1969) "Fire-Stick Farming" hypothesis.

**Comparison to Previous Studies**

The finding that there has been a noticeable increase in fire activity since the arrival of Europeans at Jibbon contradicts the findings of other studies carried out in the Sydney Basin (Kodela and Dodson, 1989; Johnson, 1994; Martin, 1994; Dodson *et al.*, 1995). Nonetheless, a post-European increase in charcoal and presumably fire has been recorded before: by Boon and Dodson (1992) at Lake Curlip in east Gippsland, Victoria and by Gell *et al*. (1993) at a site on the Delegate River, also in southeastern Victoria.

There are a number of reasons for the differences between the current study and previous Sydney palaeoenvironmental studies. Perhaps of greatest concern is the temporal control of previous studies. No study to date in the Sydney basin has utilized $^{210}$Pb dating, but rather they rely on the presence of *Pinus* pollen in the sediment as a proxy boundary between the pre- and post-European periods. In this study *Pinus* pollen is not present in the sediment until a depth of 12.5cm (*ca*.

1945). Aside from methodological differences it is possible that site specific features are of importance. This may include different groups of Aborigines, different vegetation communities or notably, the proximity of urban areas.

As concluded by Bowman (1998) the management of our conservation estate must have the clear aim of conserving extant biodiversity, meaning that the lessons of the past may not be entirely relevant given that conditions are now different. Nonetheless, knowledge of pre-European fire history may help to ensure that management decisions are made in a well informed manner. This study suggests, for example, that Aboriginal burning in the heath and *Angophora* forest that dominates the Jibbon Lagoon catchment was relatively rare. In contrast, fire in the European period, particularly from the 1930s onwards, was frequent. This study thus supports the view held by Clark (1983, pp. 32) that "the frequency and areal extent of Aboriginal burning may well have been overestimated and European burning underestimated".

# ENVIRONMENTAL CHANGE IN THE HUMID TROPICS OF NORTHEASTERN AUSTRALIA OVER THE LAST 250,000 YEARS

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The ODP 820A and Lynch's Crater pollen and charcoal records suggest that there has been significant environmental change in the humid tropics of northeastern Australia over the last 250,000 years. Both records reveal clear cyclical vegetation patterns for the region, with complex rainforest communities expanding during interglacial periods (oxygen isotope stages 7,5,3 and 1) and contracting during glacial and stadial periods (oxygen isotope stages 8,6,4 and 2). In addition, there have been expansions in araucarian-rich drier rainforest and/or sclerophyll communities during glacial periods. Spectral analysis conducted on both records suggests that orbital forcing, particularly eccentricity and obliquity, play a major role in controlling the abundances of these various community types within the humid tropics region. Superimposed on these cyclical alterations in vegetation is an abrupt alteration in vegetation and burning in both the ODP 820 and Lynch's Crater records. There has been a marked increase in sclerophyll taxa and burning, as well as a sharp decline in the fire sensitive conifers (Araucariaceae and *Dacrydium*) within the region over the last 250,000 years. This alteration occurred in two stages, at 137,000 to 130,000 years BP, possibly caused by the onset or intensification of ENSO (El Nino/Southern Oscillation) conditions during a very dry period, and at 40,000 years BP, possibly due to the influence of human activity.

# THE LAST INTERGLACIAL SHORELINE IN SOUTHERN AUSTRALIA: NEOTECTONICS, SEA-LEVELS AND PALAEOCLIMATE

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Southern Australia preserves a rich assemblage of coastal landforms and sedimentary successions of last interglacial age (Oxygen Isotope Substage 5e). The sedimentary facies have many features in common with adjacent Holocene coastal facies and contemporary peritidal environments, but are partly lithified, mostly elevated and laterally displaced inland. Sediments are dominantly biogenic skeletal carbonates of cool-temperate water affinities (foram-mollusc-coralline algal association). Surficial calcrete development has aided preservation of morphostratigraphic forms and sedimentary structures.

Large coastal barrier complexes comprising aeolian, foredune and back-dune lagoon facies characterize exposed coastal tracts facing the Southern Ocean. In contrast, broad, low-gradient peritidal complexes, with a shoaling-upward sequence of subtidal, intertidal and supratidal mud/sand flat facies, characterize protected shorelines of major gulfs and embayments. A similar upward-shoaling sequence is preserved in back-barrier lagoons.

Differential shoreline elevations of last interglacial, intertidal facies reveal subtle differences spatially, that largely relate to tectonic setting. Along the more tectonically stable parts of southern Australia such as Eyre Peninsula (Gawler Craton), the last interglacial shoreline is consistently recorded at 2 m above present sea level (APSL) for over 500 km. This is an important regional datum that is significantly below the +6 m level globally attributed to this sea level highstand. Elsewhere, neotectonic variations in shoreline elevation are clearly discernible. In Gulf St. Vincent, the last interglacial Glanville Formation does not crop out in the Adelaide region, reflecting ongoing subsidence by up to ca. 11 m, but at Normanville, southern Fleurieu Peninsula, it occurs up to 12 m APSL. The Murray River mouth area indicates subsidence and the Coorong Coastal Plain reveals a gradual rise in the elevation of the last interglacial shoreline from near present sea level in the northern Coorong Lagoon to18 m APSL near Mount Gambier, the latter associated with Quaternary volcansim.

The last interglacial strata contain a number of distinctive fossils of subtropical affinity that no longer live in the local waters and include the estuarine, arcoid bivalve *Anadara trapezia*, the Shark Bay pearl oyster *Pinctada carchariarium*, and the conical-fusiform gastropod *Euplica bidentata*. Benthic foraminifers of similar affinity include the megascopic foraminifer *Marginopora vertebralis*, *Pseudomassilina australis* and *Quinqueloculina polygona*. These species appear to be associated with an enhanced Leeuwin Current coinciding with higher, less seasonally concentrated levels of precipitation and river discharge during the last interglacial maximum. Collectively, the evidence suggests that for much of southern Australia, the last interglacial maximum (Oxygen Isotope Substage 5e) was wetter than the present, Holocene interglacial.

# FLOODING DURING THE LAST GLACIAL MAXIMUM IN THE TOP END OF THE NORTHERN TERRITORY

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Sediments preserved at the base of rare types of waterfalls provide records of terrestrial floods to 30 kyr or more, being approximately 6-10 times longer than that usually obtained from the traditional slackwater method. These coarse-grained sand deposits form ridges and levees adjacent to plunge pools at the foot of unindented escarpments and within gorge overflow bedrock channel systems. Our results are derived from three separate widely distributed stream catchments in the Top End of the Northern Territory. Two distinct episodes of flooding are recorded at all three sites. The earliest during the last glacial maximum (18 - 23 kyr calendar years) and the most recent during the Holocene climatic optimum (4 - 8 kyr calendar years).

Enhancement of the monsoon during the LGM possibly resulted from increased pressure gradients between northern and southern Australia. This may have involved the broadening and intensification of the Pilbara and Cloncurry heat lows of Western Australia and Queensland, respectively, across to the Top End of the Northern Territory. Strengthened anticyclogenesis across southern Australia combined with the increased continentality of northern Australia could have resulted in a stronger temperature gradient between the two regions causing extra-tropical cold fronts to be displaced further north towards the heat trough and into a moister air mass resulting in convection. While such mechanisms are a feature of tropical Australia’s climate today they more have been more active during the LGM resulting in a steeper meridional pressure gradient causing the monsoon to intensify but in a more latitudinally restricted region.

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# Age of the conversion from palaeochannel to present-day fluvial activity on the Murray River near Albury


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The purpose of this paper is to place a number of dates, obtained from two palaeoecological studies on the Murray River between Albury N.S.W. and Tocumwal, and on 3 tributaries, into the context of the late Quaternary evolution of channels and floodplain (Bowler 1978; Page *et al.* 1991, 1996). Large palaeochannel traces flank the modern rivers of the Riverine Plain. Their stratigraphy and common association with source bordering sand dunes suggests a substantial component of bedload transport, in contrast to the predominantly suspended load transport of the smaller, modern rivers (Bowler, 1978; Page and Nanson 1996). From detailed geomorphic and stratigraphic analyses of the Goulburn River and the Murray River near Echuca, 250 km to the west of Albury, Bowler identified two phases of palaeochannel activity. Based on radiocarbon dates, the Kotupna Phase extended from about 17-29 ka BP, and the Green Gully-Tallygaroopna Phase (GG-T) from 29 ka BP to beyond the limits of radiocarbon dating (Table 1; all radiocarbon ages reported here have been corrected using Bard 1998). The Goulburn Phase of channels with modern features began at least 9 ka BP, leading Bowler to speculate that the conversion from palaeochannel activity occurred in the late Pleistocene, around 17 to 11 ka BP. On the Murrumbidgee River to the north, Page *et al.* found evidence of 4 phases of palaeochannel activity. Thermoluminescence dating of floodplain deposits suggests these occurred between 13-20, 25-35, 35-55 and 80-105 ka BP. The phases were named, from youngest to oldest, Yanco, Gum Creek, Kerabury and Coleambally. Moreover, Page *et al.* re-dated some of the Kotupna and GG-T deposits, and found Kotupna (34 ka BP) and GG-T (65-95 ka BP) coincided with the Gum Creek and Coleambally phases, respectively.

Basal sediment infill from 7 billabongs (abandoned channels) with similar features to modern rivers (i.e. Bowler's 'Goulburn Phase') has been dated using radiocarbon. Comparison of radiocarbon ages of base-soluble and insoluble fractions of bulk sediments from 3 billabongs indicates contamination with younger carbon, but suggests the channels were cutoff between about 1,100 and 6,000 years BP. The ages are in agreement with relative ages estimated from proximity to the river, elevation on the floodplain, and channel intersections. Radiocarbon dates on wood embedded in basal sediments from four other billabongs on the Murray River below Yarrawonga, the lower Kiewa River, the lower Ovens River, and the upper Goulburn River (Callemondah Billabong), returned ages of 3,010 BP, 4,720 BP, 4,210 BP and 12,510 BP, respectively. Errors for the age of these and other wood samples (below) were <100 years and are not reported here. The sample from Callemondah Billabong is about 2000 years older than the oldest Goulburn Phase deposit dated by Bowler (1978) from the Murray River. Therefore, it appears that Goulburn Phase fluvial activity has occurred for at least the past 12,500 years, consistent with the conclusion of Bowler (1978) that the conversion to Goulburn Phase activity occurred in the late Pleistocene. However, it is worth noting that late Pleistocene and early Holocene evidence for the activity of small, suspended-load rivers has not been identified from around Albury. For this area, and for the Ovens and Kiewa Rivers, the conclusion relies on the assumption of a synchronous conversion from palaeochannel to Goulburn Phase activity with the Goulburn River.

Palaeochannel traces and low source bordering sand dunes occur north of the Murray River to the west of Albury, adjacent to Goulburn Phase active and cutoff channels. Two palaeochannel deposits were dated using OSL, a point bar deposit and a source bordering sand dune 44 km and 35 km west of Albury, respectively. Because of their close association with the modern river, it was expected that these would represent a terminal phase of palaeochannel activity. The palaeochannel point bar yielded an age of 13.8±2 ka BP, which correlates with late Yanco Phase activity on the Murrumbidgee River (Page *et al.* 1991, 1996). (Note: the OSL dating was carried out several years ago, and the ages may need to be adjusted slightly to account for recent refinements, e.g. variations in cosmic ray dose. This will be done before publication). Thus, the palaeochannel appears to be from the waning period of palaeochannel activity. In contrast, the source bordering sand dune returned an age of 23.5±2.1 ka BP, which may coincide with Gum Creek/Kotupna Phase activity on the Murrumbidgee and Goulburn Rivers. Therefore, there may be deposits from more than one phase of palaeochannel activity in this region.

Finally, a sand and gravel deposit underlying the floodplain at Albury was dated using OSL on sand and radiocarbon on cellulose from two pieces of wood embedded in the gravels. The floodplain in this area is mainly confined by terraces, but may at times in the past have received sediment inputs from colluvial fans extending from nearby hills (Bowler, pers. comm.). An overbank deposit 2.3 m thick was underlain by about 4.5m of cross-bedded sand, then gravel at about 7m. The sand sample used for OSL was from the middle of the sand unit, and the pieces wood were buried about a meter into the gravels. Both of the wood samples were aged about 12.1 ka BP. The OSL sample returned an age of 10.1±1.3 ka BP. The depth of these sediments is below where the modern river is reworking the floodplain. Moreover, sediments from the gravel pit suggest considerable bedload transport, although with regard to the gravels, it is unclear whether the channel was transporting gravels from upstream or reworking previously deposited gravels or colluvial gravels input from nearby hills. In contrast, modern channels on the Riverine Plain are suspended load rivers. Therefore, it appears that the palaeochannel that deposited these sediments may have been similar to the palaeochannels evident on the margins of the floodplain west of Albury, or at least intermediate between the modern, suspended load channels and the bed or mixed load palaeochannels.

In summary, channels with modern features appear to have been active throughout the Holocene and possibly the closing stages of the Pleistocene, around 10-13 ka BP. However, to be applied regionally, this conclusion assumes the conversion to modern drainage was synchronous in the Goulburn River, the Murray River near Albury, and other tributaries. At Albury, examination of billabongs further towards the margins of the floodplain may uncover older Goulburn Phase channels. Deposits from at least two palaeochannel phases occur adjacent to and underlying the modern channel just west of Albury. These require detailed morphostratigraphic analysis to clarify their relation to palaeochannels to the west and north, and to late Pleistocene climatic conditions.

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***Table 1.*** Chronology of sediment deposition on the Riverine Plain (ka years B.P.).

| Bowler, 1978 Goulburn & Murray | age, based on $^{14}C$ | Page *et al.*1991, 1996 Murrumbidgee | age, based on TL | this study, Murray near Albury & tributaries | age, based on $^{14}C$*, OSL |
|---|---|---|---|---|---|
| Goulburn | 0 - 10 | | | ‘Goulburn Phase’ channels | 0 — 12* |

| | | | | | |
|---|---|---|---|---|---|
| | | Yanco | 13-20 | palaeochannel | 13 |
| Kotupna | 15-25 | Gum Creek Kotupna | 25-35<br>34 | sand dune | 24 |
| | | Kerabury | 35-55 | | |
| Green Gully-Tallygaroopna | 25-? | Coleambally<br>Green Gully-Tallygaroopna | 80-105<br>65-95 | | |

# The Southeast Asian Monsoon and its relation to Changes in Salinity, and Productivity in the Australasian Maritime region

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The atmospheric $CO_2$ of the Last Glacial Maximum (LGM) was approximately 30% less than the preanthopogenic value of 280 ppmv. Numerous hypotheses have been proposed to explain this shift in atmospheric $CO_2$ levels. Most scientists working in this field would agree that this change has its origins in the marine realm, though the mechanism is hotly debated. It is also agreed that the mechanism that causes the reduction in atmospheric $CO_2$ content has something to do with lower accumulation rates of $CaCO_3$ in the shallow and the deep sea. Two of the favoured mechanisms are the Coral Reef Hypothesis which points to reduced amounts of "reefal" carbonate during the glacials compared with interglacials and simply changing the ratio of organic carbon to carbonate carbon burial in pelagic regions. The Coral Reef Hypothesis has the advantage that it is potentially fast, with a possible sea level response, but mass balance constraints indicate this can not be the whole story. The other mechanism, we will call the "Archer Hypothesis" is feasible but has no obvious mechanism to "turn on" and "turn off" productivity. Areas such as the Southern Ocean were obvious candidates to such variation but total productivity appears to have shifted but not changed dramatically on this time scale.

On the Scott Plateau we have found very clear evidence of decreasing oceanic productivity from the LGM through the climate transition to Stage 1. We would like to present a new model which links these changes in productivity with the onset and strength of the South East Asian Monsoon. There is mounting evidence that the fresh water flux into the South China Sea and the Indonesian region in general was comparatively low during the LGM resulting in higher salinities in the whole Australasian region through the equatorial eastern Indian Ocean. Today a freshwater "cap" acts to reduce any potential for vertical mixing and hence diminishing the chances of higher productivity in the area . We are proposing that this "cap" is directly related to the strength of the South East Asian monsoon and as the SEA monsoon gained strength during the deglacial, productivity in the Indonesian Archipelago and eastern Indian Ocean declined to its present state. AMS C14 dates from the South China Sea and the Scott Plateau show the establishment of the full monsoon and the final reduction in productivity correlate perfectly. Given the strength of the SEA monsoon has an obvious link with the warming of the Asian continent (presumably Milankovitch driven warming), this model would provide a strong link between the climate of the largest continent, oceanic productivity over a wide area of the planet, and hence the mysterious synchronicity of atmospheric $pCO_2$ change and Milankovitch cyclicity.

**Aeolian history of northern King Island, Bass Strait.**

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This paper outlines work in progress on the aeolian history of northern King Island, Bass Strait. It builds on the pioneering work of Jennings (1959) and includes areas proximal to Egg Lagoon, where palaeoecological work has been undertaken (D'Costa et al. 1993).

The coastal Older and Newer Dune systems on the island mark interglacial periods of higher sea levels (Jennings 1959). Extensive sand sheets inland of these systems have not previously been studied and, given their potential to broaden knowledge of aeolian activity on the island, these form a focus of the present study.

A total of 61 sites in 5 transects have been sampled by augering, and 299 samples collected. Two major transects were surveyed in detail to record surface forms. Particle size distributions, determined variously from dry and wet seiving and hydrometer methods, reveal variations in sedimentary sequences and soil profiles. The role of weathering and soil formation in altering the distributions after deposition is determined by insoluble residue analyses, in conjunction with sample composition and field profile observations. Grain roundness and surface texture analyses indicate likely modes of deposition within the sand sheet sequences.

Though work is still in progress on this project, results to date enable some preliminary interpretations to be made. Sand dunes and sheets in the west have particle size distributions distinctly different from the east coast dunes, and the majority of the north part of the island consists of sediments derived from the west. Particle size distributions of the sand sheets are not substantially different from the western coastal Older and Newer Dunes, differing largely in the degree of weathering and soil formation, and the implications for their genesis will be outlined. Weathering and soil formation produce predictable variations in particle size distributions.

Aeolian and other palaeoenvironmental variations are indicated by sediment variations in the Older Dune and sand sheet sequences. These include variations in particle size distributions, evidence for expansion and contraction of Egg Lagoon in marginal sand sheet sequences, deflationary episodes preceding and within the Older Dunes, and unusual sedimentary units in the Older Dune fields. Limited existence of polleniferous sediments in the sand sheets add minor further details to the palaeoenvironmental record. An implication of the variability is that aeolian activity in the area of King Island is not limited to interglacial coastal dune phases, and activity during glacial periods is likely. This interpretation has not yet been tested by dating. Samples for optical dating have been collected from eight sites in the dunes and sand sheets, and this dating is still to be completed.

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## TL CHRONOLOGY AND STRATIGRAPHY OF RIVERINE SOURCE BORDERING SAND DUNES NEAR WAGGA WAGGA,

## NEW SOUTH WALES, AUSTRALIA


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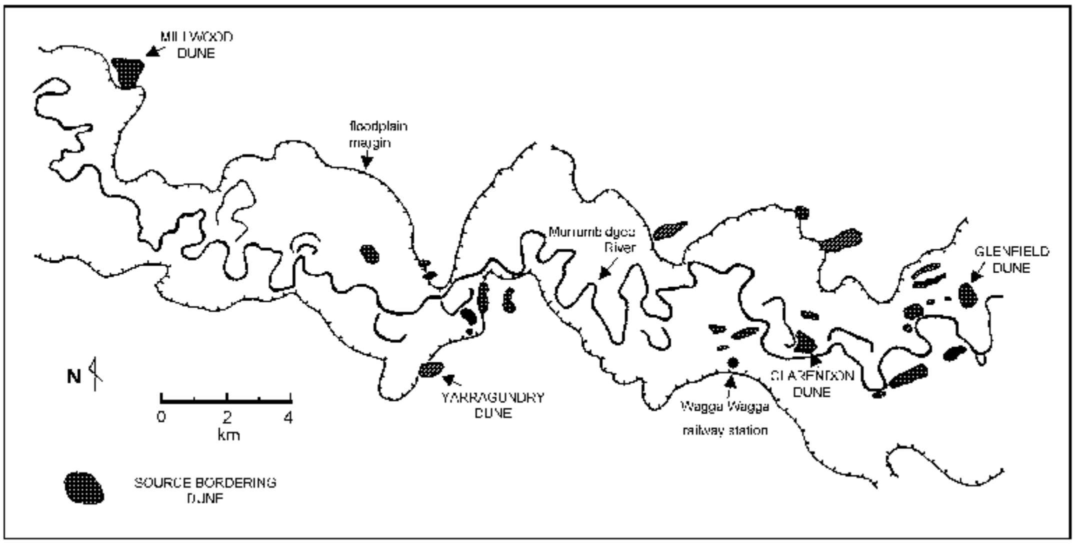
### Introduction

Source bordering sand dunes are found at the eastern and northern margins of palaeochannel systems in the Murray Basin of eastern Australia. Their sediments are dominated by fine to medium sand but often contain a minor clay component that gives rise to red and dark brown soil colours and may be manifested in the profile as multiple clay-rich (argic) bands. In the Murrumbidgee sector of the Riverine Plain Page et al. (1996) noted that source bordering sand dunes were associated with three of the major palaeochannel systems dated by thermoluminescence (TL): the Coleambally (80 to 100 ka), Kerarbury (35 to 60 ka) and Yanco (12 to 20 ka).

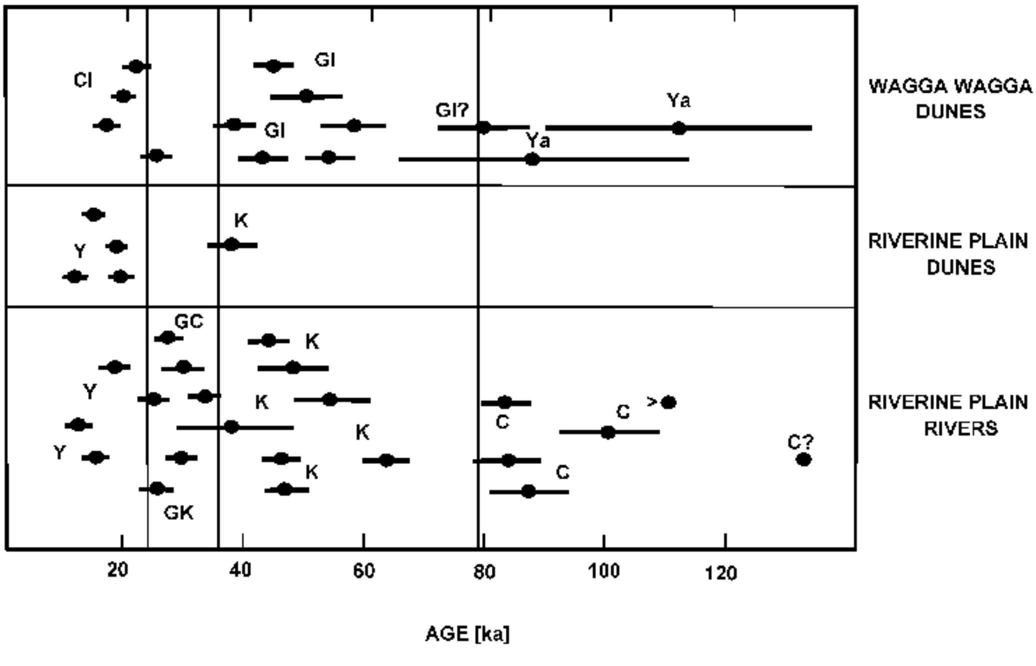
Upstream of the Riverine Plain, in the mid-catchment reach of the Murrumbidgee near Wagga Wagga, low bedrock hills confine the alluvial valley fill to a width of 2 to 4 kilometres. Here, fossil source bordering dunes were first described by Sturt (1813). Subsequent studies by Beattie (1972) and Chen and McKane (1997) described the sediments and soils of the dunes but did not establish a chronology of formation beyond noting that they appeared to correlate with Beattie's (1972) Yarabee depositional phase.

The present study investigated the stratigraphy and TL chronology of the Wagga Wagga dunes at quarry exposures and auger sites. Near Wagga Wagga the dunes occur both as mounds on the floodplain surface and as drapes over adjoining bedrock ridges. In places, the dune sands are on-lapped by more recent alluvium. Fieldwork and sampling were carried out at Millwood, Clarendon, Glenfield and Yarragundry Dunes (Figure 1).




## Stratigraphy and Chronology

At all sites a thin artefact-bearing post-European surficial layer overlay an aeolian depositional sequence which rested, in turn, upon either floodplain alluvium or clay-rich hillslope soils. At Yarragundry, three aeolian units separated by soil groundsurfaces were identified. These are named, in increasing order of age and on the basis of the type sites, the Clarendon, Glenfield and Yarragundry Units. The separation of three aeolian units is strongly supported by the TL dates (Figure 2).




The Clarendon Unit occurs at all field sites as a loamy sand or sandy loam with a brownish black to reddish brown soil profile overlying yellow brown medium sands with well-developed large-scale cross beds. Argic layers are occasionally found in the Clarendon Unit but they rarely exceed 5 mm in thickness. TL dating of the Clarendon Unit suggests that it was deposited between about 15 and 25 ka at about the time of the Last Glacial Maximum (LGM) in Oxygen Isotope Stage 2. At Clarendon Quarry the Clarendon Unit rest directly on fluvial silts and pebbly sands from which it appears to have been derived given that two TL dates on the fluvial deposits are not statistically distinguishable from those in the overlying aeolian material. At the other three sites the Clarendon Unit rests unconformably on the Glenfield Unit which is characterised by a truncated bright red soil with strongly developed argic layers that may be either accordant or discordant with the primary dune bedding. Where the argic layers occur deeper in the profile they are typically conformable with the primary dune bedding. When traced up the cross-bed planes they tend to thicken and darken in colour and then merge with a complex zone of criss-crossing sub-horizontal wavy bands that are discordant with the primary bedding. The argic bands, which are typically from 10 to 30 mm thick but occasionally exceed 50 mm, are separated by sand bands averaging 100 mm thick. The absence of appreciable silt in the argic layers is typical of aeolian dust deposits in Australia (Dare-Edwards, 1984) and consistent with the transportation of fine sand-sized clay aggregates from a distant source. At Glenfield and Yarragundry Quarries the Glenfield Unit contains carbonate, either as fine earth, soft glaebules or vertical rhizomorphs. The clay and carbonate content of this unit is consistent with the pedogenic reworking of the clay aggregates and carbonate in the profile.

The seven TL dates from the Glenfield Unit show a strong clustering between approximately 35 and 60 ka with only one outlier at 78.5 ka. At Millwood Dune the TL ages clustered between 37.2 and 44.2 ka over a vertical sequence of more than six metres sugggesting a rapid sand accumulation. Here, the Glenfield Unit rested unconformably on a mottled and pedogenically well-structured heavy clay thought to represent Beattie's (1972) Brucedale groundsurface.

At Yarragundry Quarry, the Glenfield Unit yielded dates of 53.6 and 57.6 ka and unconformably overlay a unit with bright red colours and appreciable clay. TL dates in this lower Yarragundry Unit of 86.6 and 111 ka indicate an earlier phase of aeolian activity. The Yarragundry Unit unconformably overlies a mottled medium clay which, on the basis of soil characters, is thought to represent the Brucedale groundsurface.

## Discussion

TL dating of the source bordering dunes near Wagga Wagga confirms that they were deposited since the last Interglacial at 125 ka (Martinson et al., 1987) and were derived from sand from local bedload dominated rivers very different from the intrenched suspended load systems of today. However, the calcareous clay component of the dunes appears to have been derived from a source region to the west, probably during active phases of swale deflation in the Mallee dunefield

(Bowler and McGee, 1978). Given the irregular morphology of the argic bands it seems likely that they are produced by mobilisation and illuviation of the clay rather than direct deposition. It is unlikely that phases of sand and dust accretion were synchronous. The last major phase of dust accretion probably occurred in Oxygen Isotope Stage 2.

The stratigraphic separation of the Clarendon, Glenfield and Yarragundry phases of dune formation is strongly supported by the TL dates which form three distinct clusters with little error overlap (Figure 2). A comparison of the Wagga Wagga dune ages with the TL chronology for the Murrumbidgee sector of the Riverine Plain shows a strong correlation respectively between the Yarragundry and Coleambally Units, the Glenfield and Kerarbury Units and the Clarendon and Yanco Units. Although this correlation between dune building phases in the mid and lower Murrumbidgee Valley is not surprising, it does provide a useful corroboration of the reliability of the TL dating method for aeolian and fluvial sand deposits in the Murray Basin.

## Conclusion

It is now clear that Beattie's (1972) Yarabee phase of dune formation extended over approximately 100 000 years and includes at least three soil surfaces, two of which are normally buried. In terms of the Oxygen Isotope record, Yarabee sand dune formation occurred mainly in Stages 5, 3 and 2 in association with enhanced fluvial activity by rivers carrying significantly more bedload than those of the present.

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# TREE AND LAKE CORES FROM THE NORTH-WEST OF NSW

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The Paroo (far north-west NSW) may help fill a gap in the environmental history of western New South Wales. Cores from massive southern lakes such as Lake George, Eyre and Tyrrell have provided important environmental information. The Paroo area does not have any lake sediments that have been cored or dated despite the interest in the area. The vegetation, invertebrate (Timms 1997) and bird communities indicate this an ecologically interesting ecosystem that may be sensitive to ENSO and other climatic systems that force responses through complex hydrological regimes (Walker et al 1995). These systems are also currently politically loaded by the issue of river regulation and water extraction (Kingsford *et al* 1998). There are geomorphic and pollen records in the numerous lakes and gypsum dunes on the western edge of the Darling Basin. Detailed research is underway to determine the duration and nature of the pollen record in both lake and dune deposits. The length of the cores and the apparently slow accumulation suggests the records will be long. The small basins are less deflated than the larger southern lakes and this suggests the sediment record may be more intact than in other lakes. Discontinuities in the lake sediments are expected to be recorded in the dune materials. In tandem, the tree rings of*Callitris glaucophylla* are being tested to determine the weather data record available. Preliminary research suggest the lake records give long but temporally discontinuous information whereas tree rings provide short and relatively continuous information. This will provide information about climate changes over the last few thousand years and the impact of European management on the vegetation and rates of soil erosion. Those involved in State of the Environment monitoring and seeking understanding of ecosystem processes operating over long time periods (such as water regime variations over thousands of years) need this kind of information (Kingsford 1999).

Two stands of *Callitris glaucophylla* in the Paroo area were sampled for tree-ring data. From the widths of the rings it is hoped that a climatic/rainfall record may be extracted for the last 150-300 years. Preliminary samples have shown that ring width patterns can be compared between trees — allowing the construction of a master chronology (Fritts 1976). These particular stands are characterized by widely spaced *C. glaucophylla* with little in-between vegetation. This circumvents the spread of fire, fatal to Callitris (Bowman *et al* 1988, Bowman & Panton 1993, Bowman & Latz1993). This gives the potential for construction of a longer chronology than has been obtained for this species (Pearman 1971, LaMarche *et* *al* 1979, Ash 1983). A lack of fire also allows the preservation of dead trees, which will take the climatic reconstruction even further back into the past.

Three lake cores were extracted from *Palaeolake* in semi-arid Paroo area (NW NSW) for sediment and pollen analysis. In the course of this study, the pollen data will be compared with the lake sediment data as well as other geomorphological features related to the lake and its surroundings in order to reconstruct the past climatic conditions/variations. To further aid the lake sediment interpretation a core from *Palaeolake* lunette was also extracted to find out if traces of the dry/wet cycles can be traced and correlated with the other results. To place the results in time two samples (one from the middle and one from the bottom of the lake core) were sent for radiocarbon dating and the core top is analysed by Caesium. Initial results are promising with the samples rich in relatively well preserved pollen and the sediments down-core show a high degree of variability.

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**Late Quaternary Biomes of Australia, South East Asia and the Pacific (SEAPAC) region**

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The region encompassing Australia, South East Asia, and the Pacific (SEAPAC) is climatically and physiographically diverse. Understanding the role of long term climatic changes on the evolution of this diverse flora has motivated the reconstruction of its vegetation history using pollen records on a variety of timescales. However, the very diversity of the flora makes it difficult to make objective comparisons between vegetation records from different subregions. Neither do previous palaeo-vegetation syntheses encompass the whole of the SEAPAC region.

This paper represents a first attempt to map the vegetation of the SEAPAC region from pollen data using an objective method based on the recognition of biomes characterised by a unique assemblage of plant functional types (PFTs). The method is broadly successful. Tests using 414 modern pollen surface samples showed that the biomization scheme is capable of reproducing the broad scale patterns of vegetation distribution. The changes in biome distribution at 6ka compared to

present are small, implying that the climate of the mid-Holocene was not significantly different from present. The changes in biome distribution at 18ka are more striking, and suggest that the SEAPAC region was drier than today and, at least in the tropics, colder. These reconstructions are consistent with earlier, subjective reconstructions of vegetation and climate changes in the SEAPAC region. This work also extends the current BIOME 6000 (Global Palaeovegetation Mapping Project) synthesis and provides a unique data set for the evaluation of climate and earth system models.

# Holocene Palaeohydrology of the Mnt. Arapiles Lake Complex, Wimmera, southwest Murray Basin

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The southern Wimmera region of western Victoria is situated in the semi-arid southwest Murray Basin, at the confluence of the Mallee Limestone hydrogeological province and the Southern Riverine hydrogeological province. This confluence is occupied by a ~100 km long, 4-5 km wide, relict stream valley. Except at Mnt. Arapiles, where Grampians Group quartz arenites outcrop in a monolith which rises to > 200 m above the plain, the palaeochannel is approximately 30 m lower than the surrounding landscape. It is called the Douglas Depression (sensu Brownbill *et al.*, 1995) to the south of Mnt. Arapiles where it consists of a thin veneer of sediments (<30 m) draped over an apparent extension of Grampians Group (basement) from the main range. The water table lies within five metres of the surface over much of the Douglas Depression, or outcrops in a chain of brackish to hypersaline lakes which are groundwater dominated in solute terms. Lakes are particularly abundant around the margins of Mnt. Arapiles because it is a recharge area.

At Mnt. Arapiles, rainwater enters the groundwater system through fractures in the sandstone or through the porous colluvium at its margins. These two groundwater components can be differentiated hydrochemically. Significantly, the monolith provides a driving force (high heads) which sustains many of the lakes at its periphery. Depending on lake position, groundwater moving northward up the depression can also enter the lakes. During wet periods, Mount Arapiles is to some of the lakes what a roof is to a rainwater-tank; a large, mostly impermeable surface, which captures and conveys surface-waters. These surface waters have the effect of diluting solutes which have been evaporatively concentrated in the lake basins. Holocene palaeosalinty records for two the lakes in the region (Jacka Lake and North West Jacka Lake) are interpretated keeping the above hydrological model in mind.

The palaeosalinity records were constructed from an ostracod-based (shelled micro-crustaceans) weighted-averaging transfer function using CALIBRATE (S. Juggins, unpublished program), which relied on a 179 sample paired ostracod-hydrochemistry lake study. The records are supplemented with other biological evidence (*Campylodiscus clypeus* (diatom), charaphyte oogonia, *Coxiella* (gastropod), *Elphidium* (foram),*Daphniopsis* ephippia (water flea), and brine shrimp faecal pellets) which are used (non-quantitatively) in the absence of ostracods, the $\delta$ 18O of ostracod values, and with >130 $\mu$ m quartz counts. At NW Jacka Lake it is believed that most of the quartz is wind-blown and is derived from the Lowan Sands which cap the NNW-SSE trending still-stand dunes located to the immediate west of the Depression. At Jacka Lake, which has a surface water conduit and therefore a much bigger effective catchment than Northwest Jacka Lake, quartz can also be waterborne. Quartz samples were dated by optically stimulated luminescence using the single aliquot regenerative protocol, and these dates supplement radiocarbon-based chronologies.

The most important feature of the palaeosalinity records at Jacka Lake and Northwest Jacka Lake is their broad correspondence to the lake level curve at Lake Keilambete (Bowler, 1981). Relatively wetter conditions are evidenced by lower salinities between ~10 000 cal. years BP to ~ 6000 cal. years BP. However, mutually exclusive high and low salinity ostracod communities contribute to the ostracod assemblages over this time intervol suggesting more variability, in terms of effective precipitation, than implied at Lake Keilambete. Moreover, drier conditions are evident from ~8200 cal. years BP to ~8600 cal. years BP. This dry interval includes a wind-blown quartz peak at ~8400 cal. years BP (OSL dated at $6750 \pm 800$ cal. years BP), and may be a southeastern Australian expression of an "abrupt early to mid-Holocene climatic transition registered at the equator and the poles" (Stager and Mayewski, 1997). A drier climate was firmly in place by about 4500 cal. years BP, and is marked, at the groundwater dominated NW Jacka Lake, by a rise in windblown quartz, and by a salinity increase inferring less dilution by fresh surface- and groundwaters. A switch from surface-water to groundwater-domination occurs at Jacka Lake at this time. Jacka Lake has a higher sedimentation rate and provides a much more detailed account of the late Holocene than Northwest Jacka Lake. An important feature of the late Holocene record at this site is a switch to variable conditions at ~1000 cal. years BP. During this time NW Jacka Lake probably entered a regime of winter filling with summer precipitation of a halite crust that has carried over into the present.

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## Early Pleistocene Vegetation and Climate Change at Stony Creek Basin, Western Uplands of Victoria, Australia.

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Evidence of vegetation change during the early Pleistocene is provided by a high resolution pollen record from the Stony Creek Basin, a palaeo-maar near Daylesford, in the western uplands of Victoria. A maximum age of 1.74 Ma is provided by detrital zircons intercalated within lake sediments. The 2.7 m long sequence shows changing proportions of tree taxa indicative of a continuously forested environment. The early part of the sequence is dominated by *Eucalyptus* forest including some mesotherm (warm temperate-subtropical) angiosperm rainforest taxa. Subsequently, regional drying is indicated by loss of rainforest taxa, increases in aquatic taxa reflecting lower water levels, and expansion of *Callitris*. Later, apparently in response to regional cooling, forests of *Casuarina*expanded at the expense of *Eucalyptus* and *Callitris*. Finally ferns, Podocarpaceae, and other rainforest angiosperms became important, indicating the expansion of microtherm (cool temperate) rainforest in response to increased moisture. The low representation of herbaceous taxa including the Pleistocene indicator taxon *Cassinia arcuata* type ( = *Tubulifloridites pleistocenicus* Martin) suggests that open-canopied vegetation was not so extensive on the southeastern Australian mainland by 1.74 Ma as has previously been proposed. Both mesotherm and microtherm rainforests were still present in western Victoria, at least in upland situations, around 1.74 Ma. Consistent trace quantities of *Nothofagus* (subgenus *Brassospora*) imply the regional persistence of this taxon in southeastern Australia during the early Pleistocene.

The Stony Creek Basin record suggests that the transition from 'Tertiary' to 'Quaternary' vegetation was more heterogenous, and longer lasting, than has previously been documented. The co-existence of diverse sclerophyll and rainforest taxa in the relatively cool and dry west Victorian uplands, now lacking rainforest and dominated by dry sclerophyll forests, may be best explained by lower climatic variability during the early Quaternary than during the late Quaternary. This suggests that modern ranges of rainforest taxa are truncated with regards to minimum rainfall requirements, and for some taxa, minimum temperature requirements. Palaeoclimate estimates based on modern taxon ranges may therefore be misleading.

# A DIATOM MODEL FOR HINDCASTING LAKE WATER PHOSPHORUS ANDAPPLICATION TO BURRINJUCK RESERVOIR CORES.

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Concentrations of total phosphorus (TP) in the water column are the primary factor determining productivity in many Australian freshwater ecosystems. The nutrient enriched state of these ecosystems and consequent ecological change (e.g. cyanobacterial blooms) is frequently argued to be the most important issue facing water managers.

However, despite extensive recent research into the problem of eutrophication, relatively little is understood about the degree to which systems have shifted from a "natural" state, the rate of such change and, in many cases, their cause. Transfer function models can fill many of these knowledge gaps by providing quantitative estimates of past TP concentrations.

A transfer function model for predicting lake water TP concentrations has been developed. In the model, diatom assemblages in surface sediment samples from 35 south-east Australian lakes were related to monitored water chemistry data. The transfer function has reasonable performance ($r^2$=0.80 inferred vs. measured TP) and is suitable for use in natural lakes and reservoirs.

Application of the model to diatom cores from Burrinjuck Reservoir (first filled in 1925) shows that, early in the system's history, nutrient status was low (diatom inferred TP around 10 $\mu$ g $l^{-1}$), with increases in nutrient status registered in the late 1930s/early 1940s (to 25-30 $\mu$ g TP $l^{-1}$). In the late 1960s reconstructed TP values reached a maximum (> 40 $\mu$ g $l^{-1}$) and since then have declined to approximately 30 $\mu$ g TP $l^{-1}$ (in 1995). Apparent causes of these shifts are discussed.

Potential future applications of the model (particularly to natural lakes) along with the possibilities for increasing its range and accuracy are also presented.

# POLLEN STRATIGRAPHY, SOILS AND EVIDENCE FOR EARLY HUMAN OCCUPATION IN THE MID-LATE PLEISTOCENE OF CENTRAL EUROPE

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In the Schöningen open lignite mine (Northeastern Lower Saxony, Germany), Tertiary strata are unconformably overlain by Quaternary sediments and soils of Middle and Late Pleistocene and Holocene age. The complex Pleistocene sequence contains a number of interglacial and interstadial deposits and soils and is of significance for the subdivision of the younger Middle Pleistocene in NW Europe and for archaeological evidence of early human occupation by *Homo erectus*. Recent studies reveal evidence for three interglacial periods between the Elsterian and the Saalian ice advances. At the base of Holsteinian interglacial deposits, artifacts and remains of large mammals have been excavated. Burnt flint of a fireplace gave a Thermoluminescence age of 450+/-40 ka (D. Richter, unpublished) and suggests a correlation of the Elsterian glacial period with isotope stage 12.

The next youngest warm stage after the Holsteinian, named the Reinsdorf interglacial, is the subject of debate as it has no clear palynostratigraphic equivalent elsewhere in Europe. Recently, layers of travertine of the *Homo erectus* site of Bilzingsleben (Thuringia, Germany) have been correlated with the Reinsdorf interglacial by palynological data. In addition to pollen, the deposits of the Reinsdorf are also rich in small and large mammal remains, and contain a variety of invertebrates and plant macrofossils. The interglacial layers and soils contain two lower Palaeolithic horizons. Of great importance are seven already excavated, extremely well preserved wooden artifacts (spears) made from spruce trunks, found within the layers of Reinsdorf Interstadial II, following the Reinsdorf interglacial (H. Thieme). These layers are rich in skeletal and bone remains of horses. The spear finds and remains of hunt prey are demonstrating the capability of organized hunting by Early Humans.

The peaty horizon of the Schöningen interglacial is considered to be the youngest of the three interglacial periods. Based on Uranium/Thorium dating of peat, the Holsteinian, Reinsdorf and Schöningen interglacials are tentatively correlated with oxygen isotope stages 11 (Holsteinian > 350 ka), 9 (Reinsdorf about 320 ka) and 7 (Schöningen about 200 ka).

There is evidence of a soil complex developed in glacial sediments of the Drenthe Stadial (Saalian). These Stagno-(Calcaric) Gleysols are overlain by reworked loess-like material with cryoturbations and eolian loess attributed to the Warthe

Stadial (Saalian). The hydromorphic duplex soils have not yet been studied in detail.

Travertine and peat layers of the last interglacial (Eemian) were deposited during the second half of the warm stage over a time span of about 6000 years. Local hydrologic conditions during late Eemian interglacial and early glacial (Weichselian) periods have been reconstructed by pollen analysis and plant macro remains, specifically by moss analyses. Eemian peaty layers reveal a Thorium/Uranium age of 115-149 ka (H.Heijnis) and are correlated with oxygen isotope stage 5.

In relation to overall patterns and time correlations of palaeosol sequences, interglacials are regularly and immediately followed by development of heathland, steppe and two or more short forest periods at the transition to a cold period. Interstadials, depending on geographic location, indicate different climatic conditions and are best understood by comparison with the climax vegetation and soil of the preceding interglacial. Therefore, it seems clear that for pedocomplexes of the Mid-Late Quaternary, at least in Central Europe, the first most strongly developed soil of the pedocomplex represents the climax soil of the interglacial. Interstadials, which had temperate forests that follow an interglacial, seem to be related to conditions existing in the respective interglacial isotope stage.

# Kowhai, drift bottles and beachcombing

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*I believe you are afraid to send me a ripe Edwardsia pod for fear I sh$^{d}$ float it from N.Zealand to Chile !!*

Thus wrote Charles Darwin to his friend Joseph Hooker in 1853, taunting him about the ability of plants to disperse across wide stretches of ocean, and the floristic connections between the southern continents. The present distribution of species and the composition of island floras formed an important part of Darwin's evidence for the Origin of Species by Means of Natural Selection(1859), and thus lies at the roots of our understanding of historical biogeography. Argument between "diffusionists" and "bridge-builders" dominated biogeographical debate for more than a century, and although muted since the acceptance of plate tectonics, these debates continue. Outside New Zealand and southern Chile, Kowhai (*Sophora microphylla = Edwardsia*) has an insular range as a native species. Some seeds collected in 1955 on Gough Island (S.Atlantic) floated in water for three years, and were then germinated by Dr Eric Godley at Lincoln.

Experiments with 1000 empty bottles jettisoned in Drake Passage and the far SW Atlantic from 1977 to 1991 resulted in 15 stranding on beaches in South Africa (1), Seychelles (1), mainland Australia (5), Tasmania (2), New Zealand (4), Easter Island (1) and Chile (1). Times between launching and recoveries confirms what is known of drift rates in the Antarctic Circumpolar Current. The bottle recovery sites are compared to the natural range of Kowhai

Systematic beachcombing of the 26km strand at Anxious Bay on Eyre Peninsula in South Australia showed that the beach is visited by foxes, cats and rodents living in the dunes and scavenging along the strandlines at night. This suggests that plants with buoyant seeds, such as Kowhai which appear to have a preference for growing on oceanic islands, may owe their natural ranges in part to the absence of such animals in island faunas. Details of beachcombing at Anxious Bay 1991 can be seen at

*http://www.sardi.sa.gov.au/aquatic/aquatic/communit.htm*

## Towards an environmental history of the Kimberley region of northwest Australia: Phytolith Analysis at Carpenter's Gap 1

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There are limited numbers of Holocene palaeoecological sites in the northwest of Australia, these being largely confined to the coastal lowlands, and even fewer extending into the late Pleistocene. This situation is principally due to deleterious preservational conditions associated with highly seasonal monsoon rainfall patterns, coupled with the lack of suitable depositional sites to be found in this very old and stable landscape. Hiscock and Kershaw (1992:47) have suggested that archaeological sites, particularly rockshelters, may offer one of the best sources of data relating to the environmental history of the region.

The site of Carpenter's Gap 1 is located in the limestone reef system of the Napier Range in the inland southwest Kimberley (O'Connor 1995). It provides a well stratified, although compact, cultural sequence extending from the recent past to ca. 40,000 BP, with approximately one-quarter of the deposit having accumulated during the LGM.

Phytolith analysis has been applied to the Carpenter's Gap 1 sediments as a means of investigating the vegetation history in the site vicinity. Phytoliths, being silica based microscopic plant fossils, are not subject to the usual processes of decay that tend to destroy organic materials in northern Australian sites. They are, however, significantly different in many aspects to pollen and do not provide the same taxonomic resolution as pollen studies. Taphonomic studies at the site, such as modern phytolith trapping and examination of faecal pellets, have revealed information about the processes of phytolith deposition. These suggest that the grassland component of the assemblage may be largely derived from natural sources, with only minor anthropogenic input. Other phytolith types in the assemblage, such as those that represent the palms and sedges, are probably present as a direct result of human introduction.

Careful assessment of the taphonomic issues relating to phytolith deposition at the site has permitted a general picture of vegetation to be reconstructed. This picture is complemented by the extensive macrobotanic remains recovered from the excavation (McConnell 1997; McConnell and O'Connor 1997), and provides one of the first palaeoenvironmental studies of the region.

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# COASTAL STRANDPLAIN NEAR FINGAL HEAD, NSW

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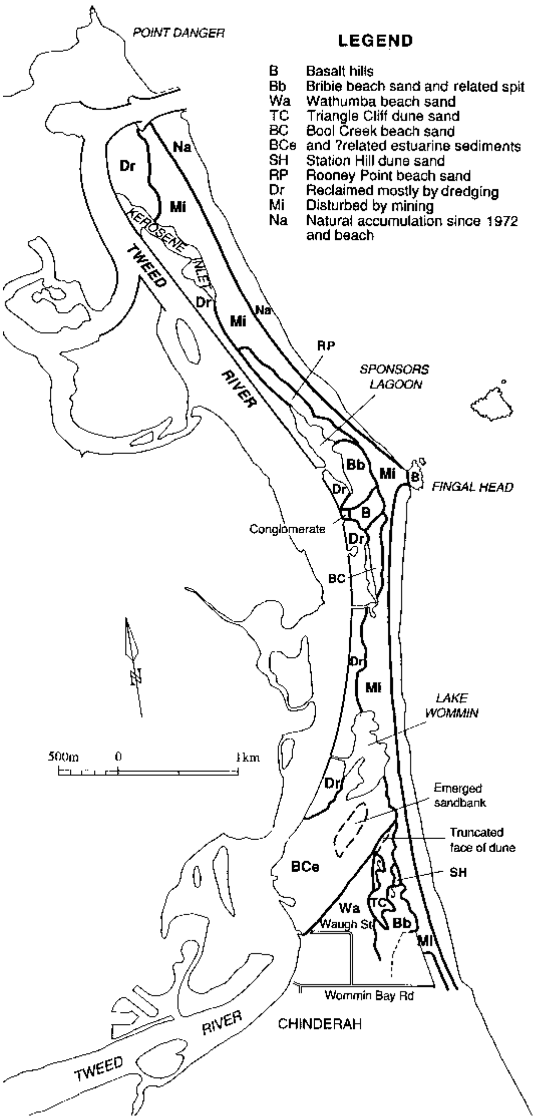
The Tweed River, like others in northern New South Wales, turns north before entering the sea. This change in direction is customarily attributed to a northern drift of sand at the beach. The lowest reach of the river, however, is a coastal lagoon, which the Tweed enters at its southernmost point. The orientation of the lagoon decides the direction of this part of the river. Previous studies have stressed the importance of sediment deposition, littoral drifting, sea-level change, and the timing of particular events, but make no effective use of soil information, which can differentiate ground surfaces formed at different times by deposition and erosion. Moreover, they neglect the fine details of geomorphology and sea-level change. The landforms, sediments and soils that form the barrier at the outlet of the Tweed River confirm that sea level change is important. Sand carried shorewards by the rising sea at the end of each glacial age builds the barrier that encloses the lagoon. The deposits would have appeared first as a sand bar, and then emerge to form the barrier as the sand accumulated. Littoral drift would favour a northern outlet for the combined river and lagoon, and would maintain that position as the sea approached its highest level. The soils developed on the strandplain identify their parent sediments with stages of strandplain development recognized in southern Queensland.

For this locality stranded pumice deposits and emerged tidal channels and sandbanks give evidence of a significant postglacial fall in sea level.




**Pleistocene Pitfalls: A Palaeontological Perspective**

**Rod Wells, Flinders University**

The Naracoorte Caves have acted as natural pitfall traps for animals and sediment from mid-Pleistocene circa 500ka to the present. The caves contain a wealth of beautifully preserved dis-articulated skeletons of frogs, birds, reptiles and mammals, including most members of the extinct megafauna. High precision thermal ionisation mass spectrometry (TIMS) U/Th dating of intercalated flowstones has shown a distinct cyclicity in depositional events. Cave chambers with large openings tend to accumulate bones and sediment over several climatic cycles while those with smaller blockable entrances contain faunas restricted to shorter intervals. Notwithstanding differences in sample size there appears to be little faunal change over at least three glacial- interglacial cycles. Extinction is largely confined to browsers or grazer-browsers, while the extant forms outside their current range are largely species confined to sclerophyll forests with a dense understory and /or adjacent patches of grassland. Current research is focussed on narrowing the time interval for last appearance of megafuana in these deposits.

# The enigma of a late glacial desert lake in the Flinders Ranges, South Australia.

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The presence of fine-grained lacustrine sediments in and upstream of Brachina Gorge in the central Flinders Ranges dated by AMS radiocarbon and OSL to 35-13.5 y BP raises some interesting questions. This interval spans the Last Glacial Maximum and was a time of glacial aridity when most of the lakes in southern and central Australia were becoming dry. The Flinders Ranges are presently arid to semi-arid, with very high rates of evaporation in summer, and there are no lakes within the ranges today. The streams draining the ranges are ephemeral or highly seasonal coarse bed-load streams. During sporadic but intense summer storms, these streams may flow for several hours to depths of several metres, and are competent to move rocks up to a metre or more in diameter. The sedimentary structures and granulometry of the piedmont alluvial fans along the western and eastern margins of the ranges are characteristic of ephemeral desert stream channels. It is therefore surprising to find that the late Quaternary valley fills within the ranges consist primarily of very fine sandy clays to depths of 10-15m, with minor cut-and-fill structures of fine to medium gravel close to the main ridges. Almost all of these valley-fill clays are now deeply dissected by ephemeral coarse bed-load channels. The answer to how and why did Pleistocene Lake Brachina exist during a time of glacial aridity is complex. Initial damming by a plug of fine sediment from a major tributary valley immediately downstream of a very narrow section of the gorge may have led to ponded drainage and reed growth. The progressive demise of River Red Gums along the valley floor in response to increasing cold, windiness and lower atmospheric carbon dioxide levels may have initiated a steady rise in local ground-water levels, resulting in lateral seepage from valley-side springs. Calcareous tufas accumulated on either side of the bottleneck as well as within the fine-grained fluvio-lacustrine sediments. The shallow dam consisting of tufa, reeds and fine sediment led to ponding of drainage and the gradual creation of a small lake within and upstream of Brachina Gorge. The diatoms, shells and ostracods associated with the tufa and the lake clays are consistent with relatively shallow, sluggish, ponded drainage. The ratio of catchment area to lake area is very high, so that once the dam had formed the lake would have functioned as an amplifier lake. The ranges lie athwart one of the major late Quaternary dust paths and were effective traps for aeolian

dust blown from the west. Some of the fine sediment within the lake appears to be reworked from hillslope dust mantles. Remnants of these mantles occupy the interstices on the rocky summits of the surrounding Cambrian quarzite ridges.

# Monsoon events in northwestern Australia during the last c. 300 000 years - a summary of the paleohydrological findings


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Only a limited understanding of the Quaternary history of the Australian monsoon is presently available. And even fewer studies make any attempt at understanding the dynamics which may have controlled Quaternary paleomonsoon variations. Here we present our findings from the Lake Gregory region of northwestern Australia, which demonstrate that the region experienced a wide range of hydrological conditions during the last c. 300 000 years, indicative of variations in monsoon activity over this time. We link this work to related field findings from the Fitzroy Trough, to provide a more comprehensive outline of Quaternary monsoon events in northwestern Australia.

Luminescence dating of lake marginal dunes at Lake Gregory indicate that large extensions of the lake were middle Pleistocene events. During the Late Pleistocene the areal extent of the lake was still significantly greater than today. During Marine Isotope Stage 5, the lake was more extensive than during the Holocene. The morphostratigraphic evidence indicates a progressively contracting lake during marine Isotope Stages 5-4. No evidence of early/middle Holocene lake events have been found. The early Holocene is also not represented in the flood stratigraphies of the Fitzroy basin. The apparent absence of early Holocene events may be taken to indicate more subdued monsoon activity at that time. However, it is clear that the northwest Australian monsoon was active, albeit for possibly a short period of time during the very latest Pleistocene. The indications from our paleohydrological findings are that the monsoon regime of northwestern Australia has remained relatively stable since the middle Holocene.

Luminescence dates have also been obtained from desert dunes located along the northern margins of the Great Sandy Desert. These indicate that significant dune mobility occurred at various times during the middle and late Pleistocene. However, better stratigraphic control is required before the full significance of the dates can be realised.

There may be some suggestion that Milankovitch insolation variations play a role in controlling the activity of the northwest Australian monsoon. However, these are tentative indications and any attempts to explain variations in monsoon activity must be placed within the context of the details of hydrometeorological controls.

# Sea-level in the Australian region during the Last Glacial Maximum and the Late Glacial period.

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The Last Glacial Maximum (LGM) is an important period in recent Earth history when ice sheets covered large areas in northern latitudes and global temperatures were significantly lower than today. The volumes and geographic distribution of the ice during the Last Glacial Maximum and the subsequent late-glacial stage remain uncertain despite recent progress in understanding the evolution of the late Pleistocene ice sheets. Reconstructions of these quantities are important constraints to the understanding of the global atmosphere-ocean system during a glacial cycle. Few direct estimates of these volumes, timing and rates exist, and the available information rests largely on indirect measurements, such as the oxygen isotope signal of marine sediment cores.

New sea-level data have been obtained from the tectonically stable Bonaparte Gulf, Northwestern Australia, from shallow-water sediment cores using sedimentological, micropalaeontological and 14C AMS dating methods. The observations indicate that locally sea-level stood at a nearly constant level of —120 m from 18 to 16.5 14C ka BP. This was followed by a very rapid rise of about 15 m within 500 14C years, followed by the less-rapid Late glacial sea-level rise. At the LGM, grounded ice on the continental margins and seas, is 52.5 x 10^6 km^3 greater than the present value and volume of the ice discharged amounted to about 5.2 x 10^6 km^3. We conclude that the LGM terminated at 16.5 14C BP with a rapid discharge of continental ice into the oceans.