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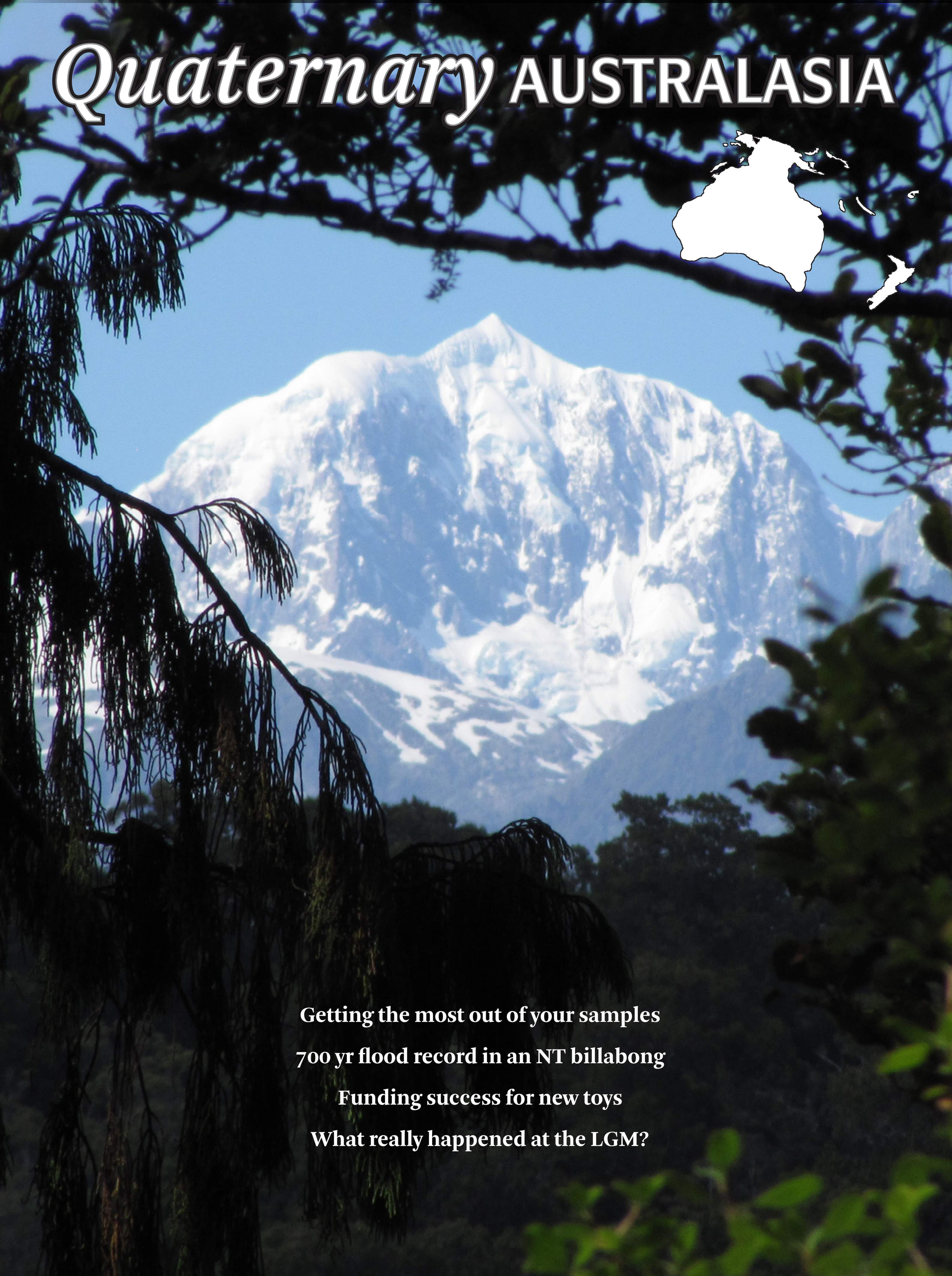
Quaternary AUSTRALASIA



Getting the most out of your samples

700 yr flood record in an NT billabong

Funding success for new toys

What really happened at the LGM?

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COVER: Mt Tasman (Horo-Koau) viewed from within podocarp rainforest on a moraine of South Okarito Forest, near Franz Josef on the West Coast of NZ's South Island.
Photo: Peter Almond, Lincoln University

BELOW: The Australian ice core drilling camp on Law Dome, East Antarctica after a week-long blizzard.
Photo: Joel Pedro, University of Tasmania.

Editorial


Dear Fellow Quaternarists,

This is an exciting year for Quaternary science, with the 18th INQUA Congress in Bern, Switzerland, taking place at the end of July (not long after you've finished perusing these pages!). The conference promises to be an interesting one with a strong interdisciplinary flavour, reflecting increasing recognition of the importance of interconnections between research fields. The group of sessions focussing on interactions between humans, the biosphere and geosphere, is a case in point. In addition, the meeting will include a dedicated session on the Australasian INTIMATE initiative, a project which many Quaternarists on both sides of the Tasman are involved with. This issue includes a short report by Jessica Reeves and Helen Bostock updating us on the progress of the Australian and New Zealand components, highlighting the importance of communication between both communities.

We also publish reports on several recent workshops of interest to the Australasian Quaternary community, including a meeting in Hong Kong on coastal change (pertaining to the IGCP 588/INQUA 1001 initiative) and the Aus2K workshop, held in Perth, which aims to reconstruct palaeotemperature across the region. Quaternary research in Australia also got lucky in the recent ARC LIEF funding round; we list the successful bids for scientific equipment in this issue.

In this issue we also publish several research articles by early career researchers from the Australasian region. Xinrong Zhang from Jilin University, and her colleagues from ANSTO, discuss environmental change in Australia's tropical north based on sedimentary and geochemical analyses from Annaburroo Billabong. Josh Larsen encourages reflection with his discussion on evaporation regimes during the Last Glacial Maximum. And Lucy Gayler provides useful information on new extraction methods for pollen and silica microfossils from organic-poor semi-arid sediments.

Finally we would like to remind you that we now officially publish Quaternary Australasia online in full colour. QA is available through the Humanities and Social Sciences Collection of InformIT, which most Australasian institutions already subscribe to. We urge you to recommend it (and AQUA membership!) to your colleagues now that we offer wider access. However, the hard copy will still be distributed to the pigeon hole of our paid-up members. Your membership is vital to the continuity of AQUA and we value your support. To help spread the word, we have included a flyer in this issue, which you may like to put on your noticeboard. New student members are particularly encouraged.

Yours Quaternarily

Kathryn Fitzsimmons and Jessica Reeves

Editors, Quaternary Australasia

President's Pen

Last week (20 May) I was privileged to be able to attend a talk by Dr Jim Hansen - often dubbed the grandfather of Global Warming – at the Christchurch Horticultural Centre. He had drawn large crowds in Auckland and Wellington earlier in his speaking. The talk, organised by the NZ Green Party, was entitled *Climate Change: a scientific, moral and legal issue*. I had seen Jim Hansen speak and draw a large crowd at the AGU in 2005, soon after he revoked his self-imposed exile from the media, prompted by the experience of giving evidence before Congress in the US in 1989. And now again in 2011, here was a man who clearly still didn't sit comfortably with being the orator for climate change, but one who strongly felt a burden of responsibility to future generations. This is reflected in his recent book *Storms of my Grandchildren*. His message was that there is a total load of carbon we can subject the atmosphere to – if we exceed it the possible risks to Earth's life sustaining capacity outweigh the benefits of burning that carbon: a simple and wise message and one taken up by initiatives such as *350.org*. After the talk Jim mingled with the crowd drinking Green Party organic soup, addressing all sorts of climate-change related questions, some of them sophisticated, some more naive. What was reinforced for me was how many of us in Quaternary science could contribute to raising the level of the debate. Knowledge (or knowing how to get the knowledge) is not usually our short-coming; the challenge is being willing to engage and to do so in a humble manner. Public belief in human-induced climate change is waning after cold winters in the Northern Hemisphere, "climate-gate" and fatigue. We need to send out simple messages about the physics of CO_2, and interactions between CO_2 and climate in the past. Although extending beyond our realm of the Quaternary the recent revelations about the behaviour of the West Antarctic Ice Sheet and its relation to atmospheric CO_2 are stark and grave warnings. The science is complex but there are simple messages we can put out there that justify a precautionary approach. The analogy Jim Hansen made was with the civil rights campaign in the US in the 1960s: Governments, protecting their re-election chances, will do nothing till the people demand it.

Kind regards,

Peter Almond

Membership update

AQUA is currently undertaking a major overhaul of its finances and administration. Since its formation, AQUA has grown rapidly in size, and we now have more than 300 members listed on our database. The current paper-based membership system was designed when we were much smaller, and no longer meets our needs. AQUA is struggling to keep track of its large membership base, and this is probably responsible for a slight drop in membership numbers over the past few years.

Over the course of 2011, AQUA will therefore be moving to a fully online membership system. We are currently evaluating different options, and we will send out information about the new system later in the year. However, in future you will be able to join, renew your membership and update your contact details online. The new system should be much simpler for our members, and will provide a basis for AQUA to grow its membership further in future.

This year has also seen a modest increase in membership fees. The annual subscription is now $50 for ordinary members, and $35 for students and concessional persons. This is the first increase in membership fees since 2004, and reflects increases in the costs of running the association over this period. Compared to other professional associations, membership of AQUA remains exceptionally cheap.

AQUA has always offered strong support for student researchers, and the overhaul of our finances ensures that we can continue to offer such support in future. Our paid-up student members will therefore enjoy ongoing access to the following travel fellowships:

- INQUA Congress – three fellowships every four years
- AQUA biennial meeting – three fellowships every two years
- Science meets Parliament – one fellowship each year (Australian members only)
- Quaternary Techniques Short Course – one fellowship each year (NZ members only)

We will also continue to award prizes for the best student presentations at each biennial meeting.

If you are reading this issue, then the chances are that you are already a member of AQUA. In which case, we thank you for your support and hope that you will continue to support us in future. Please encourage your colleagues and fellow students to join AQUA too, to that we can continue to grow as a strong and vibrant association. There is a colour poster included in this issue highlighting the benefits of paid-up AQUA membership, which you may like to put up on a noticeboard or pass on to a colleague.

New position: Assistant IT Editor urgently required

The Australasian Quaternary Association is looking for a candidate to fill a new committee position of Assistant Information Technology Editor. The candidate will have a keen interest in the Quaternary and be willing to playing a role in the organisation of AQUA. The new committee position will assist the Information Technology Editor in updating the organisation's web site and explore ways to increase its functionality, including online membership database and subscription payment. They will need to have experience creating modern web sites. The new committee member will be expected to run for office of Information Technology Editor in 2012 upon retirement of Tim Barrows.

Enquiries can be made to Tim Barrows and applications for the position can be forwarded to the Secretary, Craig Woodward Secretary@aqua.org.au.

AQUA Conference, 2012

The next AQUA Biennial Conference will be held in New Zealand in 2012. The venue is Lake Tekapo in the McKenzie Basin, a dry inter-montane basin on the eastern front range of the Southern Alps near Aoraki/Mt Cook. The dates for the conference are **February 13 to 17**. A mid-conference field trip is planned for Wednesday 15 February and a pre-conference field trip on Sunday 12 February will leave from Christchurch to get participants to the venue. This field trip will cover Quaternary highlights in Canterbury with a particular focus on loess. The mid-conference field trip will visit the moraine systems around Lakes Pukaki and Ohau reviewing the intensive dating campaigns that have been active over the last 5-10 years.

MARK YOUR DIARIES NOW.

We will be offering support for 3 students to attend. Details will be made available shortly on AQUA-list.

Lake Tekapo panorama. Photo: John Magee, Geoscience Australia

Environmental changes indicated by grain-size and trace-metal analysis over the past 700 years at Annaburroo Billabong, NT, Australia

Xinrong Zhang, Henk Heijnis, John Dodson, Atun Zawadzki, Gary Buchanan

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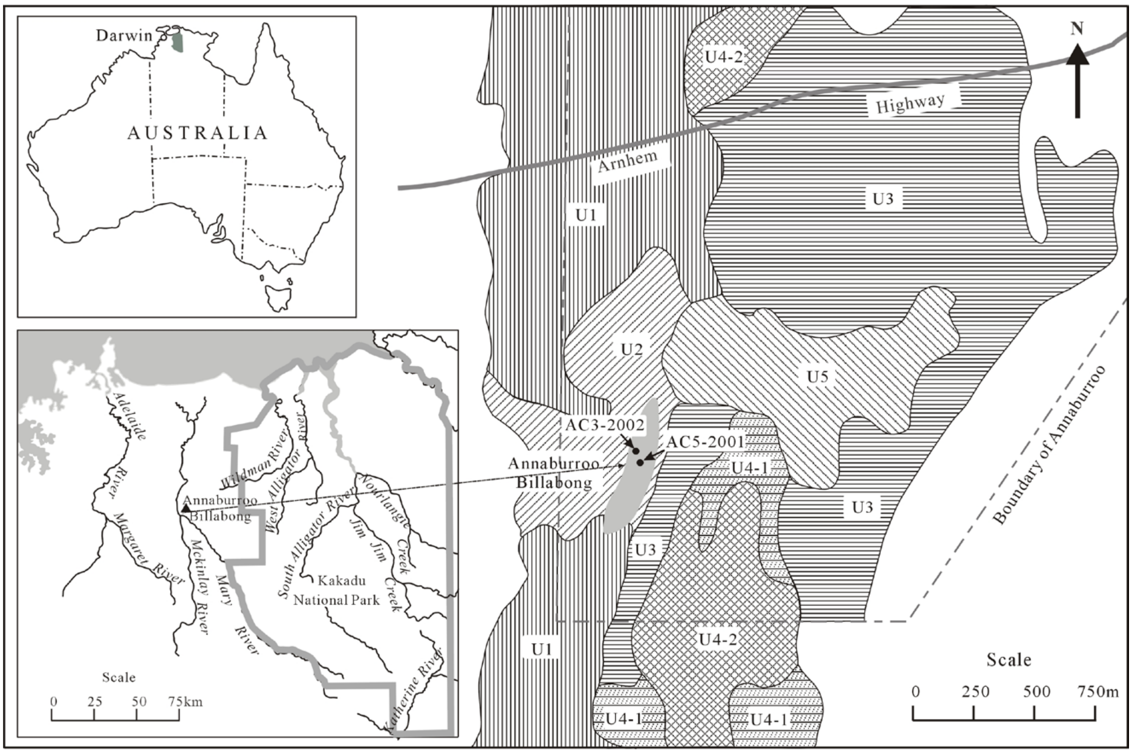

Figure 1. Location map of the study area and major land units (Modified from Fett & Hall, 1983)

U1: floodplains, deep gray earths, Perennial grassland, **U2**: Colluvial footslopes and slopes, moderately deep to deep gravelly yellow, deep red and yellow earth, open woodland; **U3**: Erosional slopes, shallow stony lithosols and gravelly yellow and brown earth, woodland; **U4-1**: Low hills and strike ridges, shallow stony lithosols and shallow yellow earth, woodland; **U4-2**: High hills and strike ridges, very shallow stony lithosols, woodland; **U5**: Head of alluvial plains, deep weakly developed solodic soil, low shrubland.

Introduction

Lakes are important connection points of the hydrosphere, atmosphere, biosphere and lithosphere (Shen, et al, 2007; Shen, 2009). As a relatively independent system, lake sediments may record important information about the local past environment (e.g. Von Gunten et al., 1997; Wang and Zhang, 1999, Harle, et al, 2002). By dating lake sediment samples, analyzing changes in trace-metal concentrations, grain-size distributions, organic contents, pollens, diatoms, phytoliths, algae, humus, magnetism, and other proxies, past natural and anthropogenic environmental changes can be documented.

Around the Annaburroo Billabong catchment, a variety of land-use activities including mining and farming as well as natural climatic events influence and drive sediment supply to the lake. Therefore, sediments in this billabong carry and integrate the relative influences of these processes in conditions of little bioturbation in the deep water body. To understand the environmental effects of human activity and climate variability in its catchments, several cores from this lagoon were taken by the group for research in the Human Activity and Climate Variability Project at the Australian Nuclear Science and Technology Organisation (ANSTO). Cores collected in 2001 and 2002 were analyzed and results are herein described to establish the deposition rates, the variability of grain-size distributions and trace-metal concentrations over the past centuries in this lagoon, and then their relations with natural climate changes and local human activities were examined, which aims to investigate and determine what proportions of changes in natural archives are due to human activity and climate variability in the past 700yrs of the Annaburroo area.

The studied site

The Annaburroo billabong (12°55'S, 131°40'E) is a localized depression on the flood plain of the Mary River, just west of Kakadu National Park, Northern Territory, Australia (Fig.1). It is located just to the north-east of the junction of the Mary and McKinlay rivers. The water-levels are maintained by groundwater and filled by floods from both the Mary River and McKinlay River. The lagoon lies in the tropics and its climate is affected by anticyclones in winter and monsoon troughs during summer. Temperatures are high all year round, with mean daily temperature variation from 22.4°C to 34°C. Annual potential evaporation exceeds rainfall in most years (Bureau of Meteorology, 1998). The main lithologies around the lagoon are: siltstone (greywacke and ferruginous siltstones), shale, cherty tuff, argillite, silicified dolomite and phyllite. The land units surrounding the billabong are floodplains, colluvial footslopes, slopes, erosional slopes, and heads of alluvial plains, low hills, high hills and strike ridges (Fett & Hall, 1983).

Archaeological studies show that Aboriginal people have been living in the area for at least 25,000 years and perhaps as long ago as 60,000 years (Young, 1991a). Non-aboriginal people arrived there in the last quarter of the 18th Century (Levitus, 1995). Farming and mining are the main current economic activities in this area. The farming of buffalo started around the 1840s, which resulted in environmental disturbance of pastoral lands in soil health, plant diversity and community structure (Ens, et al, 2010). Mining activities can be dated back to 1865 around Annaburroo station (Needham and Roarty, 1980). The mined deposits include uranium, uranium-gold, silver-lead-zinc, copper, gold, tin, tungsten, tantalum, copper and barium, iron, iron-gold. Exploration and mining of these resources impacted greatly on the local ecological environment, such as altering the heavy metal dispersal in the river systems adjacent to mine site, changing the natural dynamics of the sediments and waters, and influencing the depositional mechanism of the local basins (Miller, 1997).

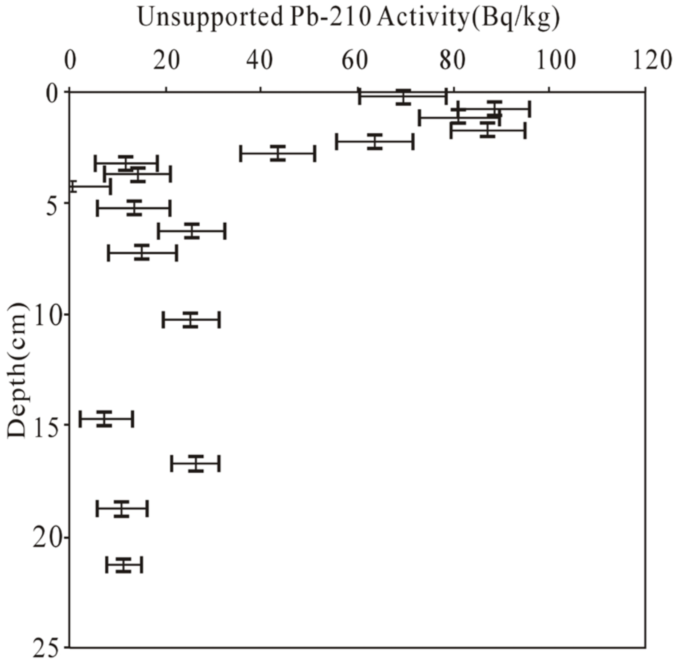

Figure 2. Unsupported ^{210}Pb activities against depth from core AC3-2002

The landforms to the north of the Annaburroo Billabong are floodplains and colluvial areas with generally low slope angles and widespread surface lag of gravels. This in combination with the afforded protection by perennial grasslands and open woodlands (U1, U2 and U3) leads to a very low erosion rate. Southeast of the lagoon, significant erosion takes place because the hills and some strike ridges have relatively high slope angles, some coarse gravels, and low shrubland on the head of alluvial plains (U3, U4, and U5) when the natural surface is disturbed (Fig.1).

Materials and Methods

Cores were taken by using a messenger operated gravity corer (Glew, et al., 2001). The messenger operated vacuum seal prevented core sediment falling out of the bottom on extraction. The corer was allowed to gently enter the sediment column using onboard sonar as a guide. After collection, each core was extruded and sampled on-site, labelled and stored for transport. The longest core was AC3-2002, of 23cm, and was taken in 2002. Its location was close to the west shore and in about 7 m water at the time of sampling. Core AC5-2001, 12cm long was collected in 2001, in a water depth of 8m (Fig.1).

The cores were sub-sampled every 0.5cm. The variability in sedimentation rate, sediment grain-size distributions and trace-metal concentrations were examined to analyze the environmental changes around this area due to climate variability and land-use activities. A total of 44 samples from AC3-2002 were analyzed, including 19 samples for lead-210 (^{210}Pb) dating, 2 samples for AMS^{14}C dating and 23 for grain-size and trace-metal analyses.

The ^{210}Pb dating method has been used over the past 4 decades to date recent aquatic sediments up to 150 years (Goldberg, 1963; Oldfield and Appleby, 1984). Unsupported or excess ^{210}Pb is present in aquatic sediment as a result of atmospheric fall-out. The activity of unsupported ^{210}Pb decays exponentially with time, or with increasing depth in the case of sediment cores, consistent with its half-life of 22.3 years. In this study, unsupported ^{210}Pb activities were determined by measuring the total activity of ^{210}Pb, from the activity of its grand daughter polonium-210 (^{210}Po), minus the activity of the supported ^{210}Pb, from the activity of its grand parent radium-226 (^{226}Ra), in the sub-sampled sediment layers from the core. Samples were chemically processed to isolate polonium and radium. Once isolated the polonium fraction was deposited onto a silver disk, the radium was co-precipitated with barium sulphate and collected by filtration. The polonium on the silver disk and radium precipitate were counted for ^{210}Po and ^{226}Ra activities by alpha spectrometry. The method is outlined in Haworth, 1999.

Grain-size analyses were determined using the Malvern Mastersizer 2000 laser diffraction spectrophotometer. About 0.5g dried sample was soaked in about 20ml water overnight. Hydrogen peroxide (H_2O_2) was added into the sample, and then heated at 60°C to remove organic matter. The treated sample was transferred into a beaker containing 1L of water, mixed and ultrasonicated before measurement (Wang, et al, 2007; Xiao, et al, 2009). Duplicate analyses were performed to ensure results show less than 1% variability.

Twenty-three samples were analyzed to determine the concentrations of cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), lead (Pb), tin (Sn), and uranium (U), using a Varian VISTA AX CCD Simultaneous Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES) and the Varian Quadrupole Inductively Coupled Plasma Mass Spectroscopy (ICP-MS). Samples were dried at 70°C overnight. About 0.2g of each sample was digested on a hot plate at 70°C in a combination of concentrated nitric acid (HNO_3), hydrochloric acid (HCl) and H_2O_2. The digested residue was dissolved in 1M HNO_3. Un-dissolved residue was removed by centrifugation. Each digested sample was made up to 50ml and submitted for ICP-AES & ICP-MS analyses (Azcue, et al, 1998; Matthai & Birch, 2001; Chopin & Alloway, 2007; Carman, et al, 2007; Sakata et al, 2008).

Since all of the samples in the upper 4.0cm of AC3-2002 core were used for ^{210}Pb dating, the top of nearby core AC5-2001 was used to elucidate environment analyses for the proceeding period.

Results

The unsupported ^{210}Pb activities from core AC3-2002 are plotted against depth and shown on Fig. 2. In the top 3.5 cm, unsupported ^{210}Pb activities exhibit an overall decay profile with increasing depth. However, between 0 and 1.5cm, unsupported ^{210}Pb activities show a typical mixed sediment profile, where the activities are close to being constant, not decreasing with increasing depth. Below 3.5 cm the unsupported ^{210}Pb activities are relatively

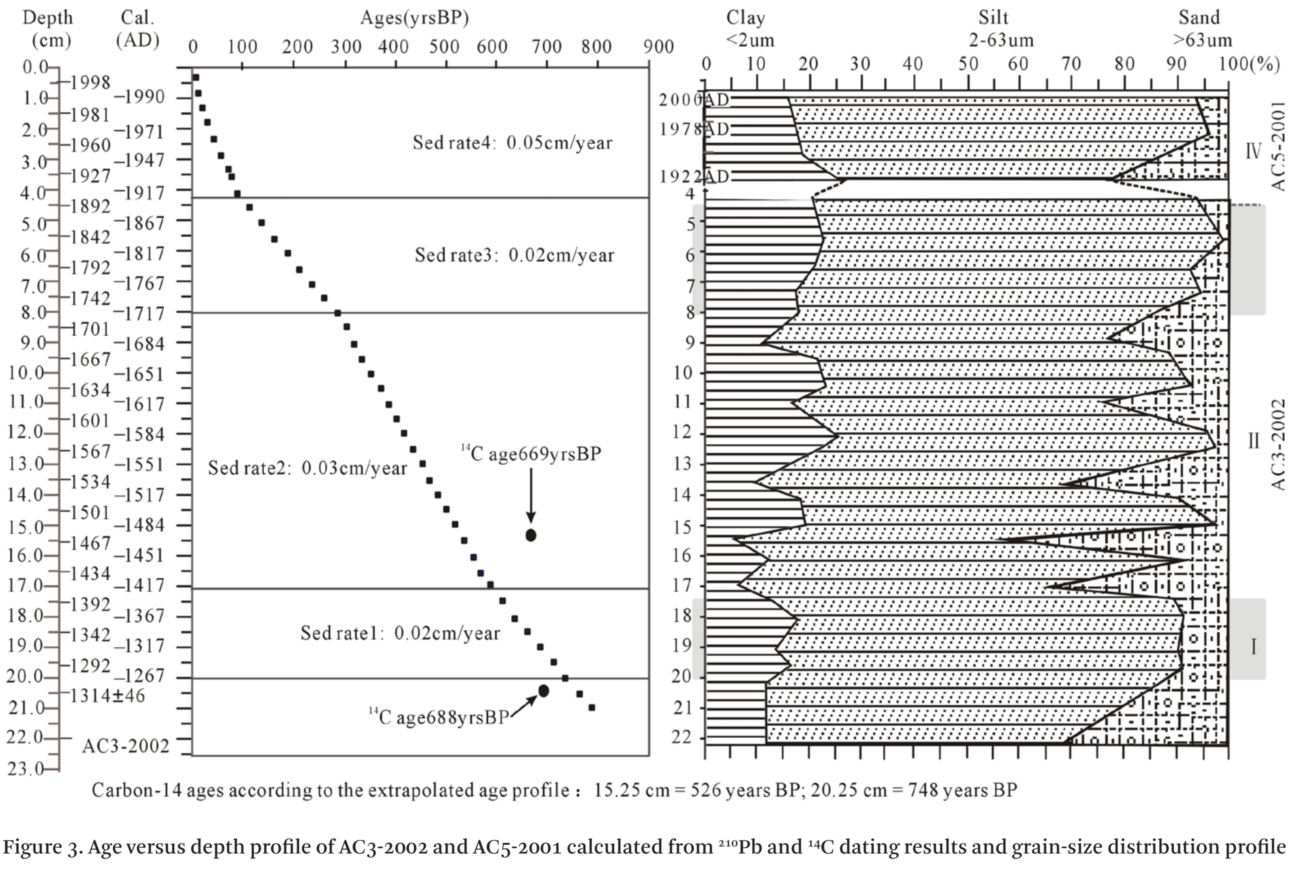

Figure 3. Age versus depth profile of AC3-2002 and AC5-2001 calculated from ^{210}Pb and ^{14}C dating results and grain-size distribution profile

Table 1. ^{210}Pb and AMS^{14}C dating results of sediments from AC3-2002 core

Depth (cm)	Dating material	^{210}Pb ages(yrs)		AMS^{14}C date (yrsBP)	Calendar dates (calAD)
		CIC ages	CRS ages		
0.0-0.5	Sediments	3.8 ± 3.8	2.2 ± 0.9	-----------	1998 ± 4AD
0.5-1.0	Sediments	13.1 ± 4.4	7.0 ± 1.3	-----------	1990 ± 6AD
1.0-1.5	Sediments	24.0 ± 4.8	14.4 ± 1.6	-----------	1981 ± 8AD
1.5-2.0	Sediments	35.0 ± 5.0	24.1 ± 1.8	-----------	1971 ± 9AD
2.0-2.5	Sediments	45.2 ± 5.0	35.2 ± 2.0	-----------	1960 ± 9AD
2.5-3.0	Sediments	57.4 ± 5.2	48.9 ± 2.2	-----------	1947 ± 8AD
3.0-3.5	Sediments	74.7 ± 5.8	62.5 ± 2.3	-----------	1932 ±10AD
15-15.5	Total organics	-----------	-----------	655±30	1333 ± 42AD
20-20.5	Total organics	-----------	-----------	705±35	1314 ± 46AD

Note: the calendar dates from AMS^{14}C analyses were calibrated using *Quickcal2007 ver.1.5*. (Danzeglocke, et al. 2007).

low and no longer exhibit a decay profile. Therefore, samples deeper than 3.5 cm were not able to be dated by the ^{210}Pb method. Two models of the ^{210}Pb dating methods were used: the Constant Initial Concentration (CIC) and the Constant Rate of Supply (CRS) to determine the chronology in the top 3.5 cm of the core. Due to the possible mixed layers in the top 1.5cm of the core, the CIC model was calculated using unsupported ^{210}Pb data between 1.5 and 2.5 cm only. The calculated CIC model mass accumulation rate of 0.02 g/cm/y (r^2 = 0.9999) was assumed to be constant for the top 3.5 cm of the core. The mass accumulation rates according to the CRS model range from 0.03g/cm^2/y (at the top of the core) to 0.02g/cm^2/y (between 2cm and 3cm depth). The CIC and CRS calculated sediment ages are shown on Table 1. The calendar ages on Table 1 were calculated from the sample collection year (2002) minus the CIC and CRS models age ranges.

The AMS ^{14}C dating method was used in the deeper section of the core at 15 cm and 20 cm, with resulting ages of 655±30 yrs BP and 705±35 yrs BP, respectively. Their calibrated ages are 617±42 cal BP, 636±46 cal BP (see Table 1).

According to the ^{210}Pb dating method, the sedimentation rate from the surface to 3.5 cm is 0.047 cm/y (CRS) or 0.056 cm/y (CIC) or approximately 0.05 cm/y. Assuming a constant sedimentation rate, according to the AMS ^{14}C dating result at 15 cm, the sedimentation rate from the surface to 15 cm is 0.02 cm/y, whereas according to the result at 20 cm, the sedimentation rate is faster at 0.03 cm/y. In the absence of any dating data between 3.5 and 15 cm, due to the lack of sample availability, the grain-size distribution data for this core was investigated to estimate relative sedimentation rates for the whole core.

Generally, in a small or shallow lake (such as Annaburroo), higher sand concentrations in the sediment core suggest an increase in the transport of more coarse particulates, due to an increase in the surface runoff from the catchment, which may be caused by high rain fall and/or flood events (see Discussion), thus causing a faster sedimentation rate in the lake. Lower sand concentrations in a sediment core, therefore, suggest a slower sedimentation rate. The grain-size distributions from the two cores analyzed are shown on Fig. 3. The distributions can be divided into 4 zones according to the sand concentrations. Starting from the bottom of the core:
zone I, between 17.5 and 20 cm, where the sand concentrations are relatively low and constant; zone II, between 8 and 17.5 cm, where the sand concentrations are relatively high and fluctuating greatly; zone III, between 4.5 and 8 cm, where the sand concentrations are relatively low and constant again; and zone IV, between 0 and 4.5 cm, where the sand concentrations are high and fluctuating again (see Fig. 3).

Therefore, according to the grain-size distributions for this core, the relative sedimentation rate (in order of zones) from zone I to IV was slow, fast, slow, fast, respectively. The ^{14}C sedimentation rates of 0.02 cm/y and 0.03 cm/y were used to estimate the slow sedimentation rate zones (zones I and III) and the faster sedimentation rate zone (zone II), respectively. The ^{210}Pb sedimentation rate of 0.05 cm/y was used to estimate the faster sedimentation rate of zone 4. Using these sedimentation rates, the sediment ages were calculated and plotted against depth (see Fig. 3). The calculated sediment ages below 3.5 cm are far from accurate, and therefore it must be emphasized the calculated ages below 3.5 cm are estimations only. It is assumed that the sedimentation rate was constant for each zone, which may be false. However, the extrapolated age profile calculated from the estimated sedimentation rates shows the two ^{14}C calculated ages fall just outside the age profile (see Fig. 3). At 15 cm, the ^{14}C age was calculated to be 669±42 years old; the extrapolated age profile age is 526 years old (a difference of 143 years). At 20 cm, the ^{14}C age was calculated to be 688±46 years old; the extrapolated age profile age is 748 years old (a difference of 60 years). The uncertainties associated with the calculated extrapolated age profile were not determined, but expected to be relatively high.

Grain-size results show that the sand (>63 μm) concentrations in the sediments change greatly between 12.0-17.0 cm depth. At about 15.0 cm depth (about 1484 AD), the highest value is 33.7%; then decreases sharply to 5.0%. Clay (<2 μm) increases from the bottom of the core to the surface, much more gradually than the sand, the highest value 25.6% appears at 12 cm, and the lowest value of 4.7% appears at 15.0 cm. Silt (2-63 μm) is a large component of the sediment in AC3-2002 core, with a mean composition of 70.2%, the highest value of 79.2% is at 16.0 cm depth, and the lowest value of 53.0% appears at 15.5 cm depth. The grain-size distributions of the AC5-2001 core show higher concentrations of sand and clay components and lower concentrations of silt (Fig.3). Trace-metal analysis results are shown in Fig.4. Co changes gradually with a mean value of 19.3 mg/kg, and the lowest value at about 12.5 cm depth (1567 AD). Below 15.0 cm (1484 AD), Cu shows a relatively high concentration with a

Discussion

1) Environment changes indicated by grain-size analysis

Sediment grain-size analysis is one of the important indicators in the reconstruction of past lake water depth. Generally, increasing of grain-size indicates a lake water level falling or a dry climate; while a reduction of grain-size reflects a lake water level rising (Dearing, 1997).However, in a small or shallow lake, the local precipitation maybe one of the controlling factors on the grain-size distribution, especially in tropical or subtropical regions with high rainfall, by influencing the intensity of the surface runoff and affecting the clastic sediment quantities despoiled into the basin. In a wet year, high surface runoff increases erosion, and transport more coarse particulates can be carried to the lake. In a dry year, the sediments in the lake will be finer grained (Chen, et al, 2003; Zhang, et al, 2004).

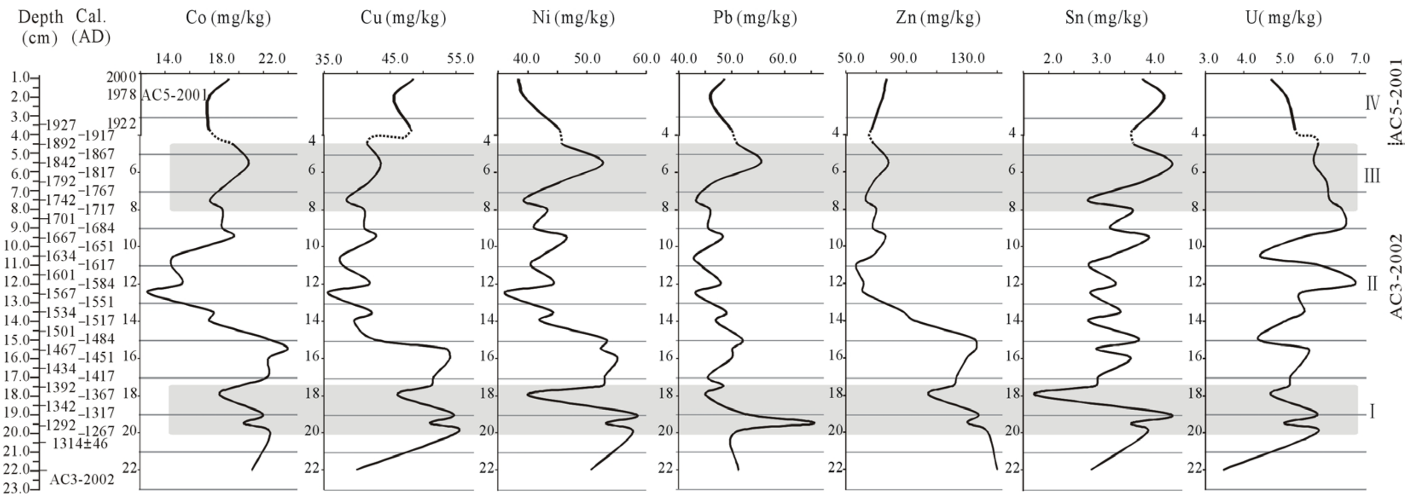

Fig. 4 Distribution of Co,Ni,Cu,Zn,Pb,Sn, U down profile at Annaburroo Billabong

mean value of 50.0 mg/kg, above 15.0 cm (1484 AD), the concentrations are relatively steady with an average value of 40.4 mg/kg. Ni follows roughly the same trend as Cu, except in the top 1 cm. The average value of Pb is 48.8 mg/kg, two peak values of 55.5 mg/kg and 65.6 mg/kg appear at 5.5 cm (1842 AD) and 19.5cm (1292 AD), respectively. Zn decreases irregularly from 149.9 mg/kg at the bottom of the core to 68.8 mg/kg at the top of the core. A high value of 136.3 mg/kg appears at 15.0 cm (1484 AD) and a low value of 43.0 mg/kg appears at 10.5 cm (1560 AD). The mean value of tin is 3.3 mg/kg and is relatively constant except a very low value at 18.0 cm (1367 AD). U concentration is relatively low. The concentration is steady from 20.0-12.5 cm, changes greatly between 12.5-9.0 cm, and then decreases. Two low values of uranium of 4.37 mg/kg and 4.42 mg/kg appear at 15.0 cm and 10.5 cm depths, respectively.

Annaburroo Billabong is a small lake and hence local precipitation is likely to be one of the main controlling factors on the sediment grain-size distribution. Another controlling factor would be the periodical or rare flood events from the rivers nearby. The landforms around it suggest that the main sediment source of the lake come from the south and southeast. The mean grain-size in Core AC3-2002 decreases from bottom to the top, which suggests a general drying climate since about 700 yrs ago.

As explained earlier in the Results section, the grain-size distribution can be divided into four zones:
Zone I, from 20.0 cm to17.5 cm (about 1267 AD-1392 AD). The median and mean sand concentrations are 8.5% and 10.0%, which are lower than zone II. The silt and clay concentrations are 75.7% and 14.2% respectively, higher than other zones. These indicate

that from 1267 AD to 1392 AD the surface runoff in this area provided less sediment to this lagoon (hence lower sedimentation rate). Rainfall events were relatively less intense and the climate was possibly drier.

Zone II, from 17.5 cm to 8.0 cm (about 1392AD-1717AD). The median sand concentration is 12.8% and the mean is 15.5%, which are both higher than for other zones. High median and mean sand (>63 μm) concentrations at 17.0 cm (1417 AD), 15.5 cm (1467 AD), 13.5 cm (1534 AD), 11.0 cm (1617 AD), and 9.0 cm (1684 AD), correspond with median values of 30.0%, 48.7%, 20.5%, 7.9% and 14.0% and average values of 33.7%, 42.4%, 30.8%, 23.4% and 22.7% respectively. These suggest that the influx of coarse sediments to the Annaburroo Lagoon occurred in a wetter climate with relatively high precipitation around 1417 AD, 1467 AD, 1534 AD, 1617AD, and 1684 AD. The magnitude of these peaks in sand concentration indicates large flood events which are likely to originate from the Mary River with a relative minor component from run-off of the nearby low hills.

Zone III, from 8.0 cm to 4.5 cm (1717 AD-1892 AD), the median sand concentration decreases gradually from 7.1% to 4.5%, and the mean decreases from 12.4% to 1%. The silt and clay contents increase gradually. The lower median and average sand concentrations suggest a drier climate to that of zone I.

Zone IV, in the top 4.5 cm, younger (<1892 AD) samples were analyzed in Core AC5-2001, which show a decrease in sand concentration from 1922 AD to 2001 AD. The high sand concentration of 33% occurred around 1922 AD suggesting another recording of a large flood event in the sediments. The increase in silt concentration in the top 4 cm of the core possibly indicates increased local sourcing of sediments due to land-clearance and permanent occupation of the Annaburroo homestead during the 20th century. The occupation of the site makes the interpretation of the grain-size as a proxy for climate more difficult. It is therefore possible that the climate did not change much from zone III to IV.

Overall, the grain-size analysis suggests re-occurring intense floods records caused by high precipitation in the Annaburroo Billabong over the last 700 years are becoming less intense.

2) Environment changes indicated by trace-metal analysis

In an aquatic environment, temporal trace-metal concentration changes are directly related to the concentrations in the soils and rocks of the catchment and their transport characteristics (Guo, et al., 2005). The geological and geomorphological units around the Annaburroo billabong have barely changed over the past 700 years. The trace-metal concentration changes in this billabong are therefore most likely to be caused by changes in sediment sources. The source of sediments largely depends on the total and intensity of the rainfall in the catchment.

Co, Ni, Cu and Zn can deposit from the pore-water into the sediments under reducing conditions (Du, et al. 2004). These elements are easily adsorbed to the surface of clay minerals (Pang and Huang. 2001) which form the finest fraction of the accumulated sediments. In a dry climate, the lake-level might fall and the pH value of the water decreases, a relatively oxidizing condition prevails, and enriches Co, Ni, Cu and Zn in the sediments (Dinescu, et al. 2000). In Core AC3-2002, Co, Ni, Cu and Zn show similar fluctuations.
Using the four zones of the grain-size distribution, the following observations about the trace-metal distribution can be made:

Zone I, 20.0 cm to17.5 cm (about 1267 AD-1392 AD), the mean values of Co, Ni, Cu and Zn are 20.7 mg/kg, 52.3 mg/kg, 51.7 mg/kg and 127.4 mg/kg, respectively, higher than zone II. This represents a relatively dry climate, with relatively oxidizing conditions and fine sediment supply to the lagoon.

Zone II, from 17.5 to 8 cm (about 1392 AD-1717 AD), the concentrations of Co, Ni, Cu, Zn decrease from the highest values of 24.0 mg/kg, 55.2 mg/kg, 54.1 mg/kg, and 136.3 mg/kg between 1417 AD and 1484 AD to 14.5 mg/kg, 40.5 mg/kg, 37.5 mg/kg and 56.9 mg/kg between 1484 AD and 1717 AD respectively. Those lower values in elemental concentrations are most likely to be caused by a gradual change towards a wetter climate.

Zone III, from 8.0 cm to 4.5 cm (1717 AD-1892 AD), the mean concentrations of Co, Ni, Cu and Zn are 19.2 mg/kg, 45.4 mg/kg, 41.3 mg/kg and 69.8 mg/kg, respectively, are a little higher than the lower values mentioned in zone II, indicating a relatively drier climate.

Zone IV, from 4.5 to 0 cm (1892 AD-2000 AD), the concentrations of Co and Ni decrease between 4.5 cm and 2 cm, which normally suggest a wetter climate, and increase between 2 cm and 0 cm, suggesting a drier climate. Cu and Zn do not follow this profile. However, as with grain-size analysis, occupation of the Annaburroo site and mining activity in the wider catchment in the 20th century make the interpretation of trace-metal as a proxy for climate change more difficult.

Pb has a high capacity to be immobilized by sorption to clays, pedogenic oxides, and organic matter (Agbenin, 2002). Pb in the sediment has several potential sources. Natural sources include atmospheric deposition, weathering of local soil and rocks, transport from sea salt, volcanic activities, and forest fires (Nriagu, 1989). Anthropogenic sources include smelting of ores, burning of coal, and use of gasoline containing lead (Nriagu, 1989). Pb concentration in core AC3-2002 seems constant except at 19.5 cm (1292 AD) and 5.5 cm (1842 AD). Before European settlement in the Northern Territory about 150 yrs ago, the aboriginal people led a nomadic life and did not introduce trace-metal into the local soils by mining or other activities. Where the Pb peaks appear, the median grain-size and Co, Cu, Ni, Zn concentrations are low indicating less precipitation and relative drier climates, which might indicate natural fires as the most likely explanation for these high Pb values. However, more evidence such as charcoal analysis is necessary to verify this.

Sn occurs in many silicate rocks. Part of the sedimentary tin may be from silicate lattices or from cassiterite (Agterdenbos & Vlogtman,1972). Sn exists mainly in the oxidation states Sn(0), Sn(II), and Sn(IV). Concentrations of Sn in air, soil, and water are usually low, except in areas with minerals containing high levels of Sn or in the surroundings of Sn processing industries (Rüdel, 2003). The concentration of Sn in the sediments of Core AC3-2002 is likely to be controlled by the silicate in the rocks around Annaburroo Billabong. The mean concentration is 3.3 mg/kg and there are no major deviations from this mean value. A relatively higher concentration appears at about 1842 AD. This may be caused by human activities such as mining. The Core AC5-2001 shows that Sn concentration decreases between 1978 and 2001 most likely due to the cessation of local mining activities.

The mean abundance of U in the continental crust is 2.7 mg/kg (Taylor, 1964). However, in core AC3-2002, the average concentration of U is 5.5 mg/kg, which may reflect the effect of local U and gold (Au) deposits in the catchment. The low concentrations of U of 4.37 mg/kg and 4.42 mg/kg at 15.0 cm and 10.5 cm may be due to dilution and high concentrations of sand.

Co, Cu, Ni, Zn values in Core AC5-2001 are unlikely to solely reflect natural environmental processes. However, the trace-metal variability over the past 150 years does not reflect a clear anthropogenic impact on the lake system either. An anthropogenic impact signal is usually evidenced by an increase in trace-metal concentrations. The variation of trace-metal concentrations over the past 150 years seems to be well within the natural variability of the preceding 550 years. The concentrations of U and Sn from 1978 AD to 2001 AD decrease compared to those between 1922 AD and 1978 AD. This may be related to the abandonment of local mines and a shift of sediment sources from catchment wide to local.

Nevertheless, the study here shows that natural environmental changes have not been completely overshadowed by human activities. Analysis of Co, Cu, Ni, Zn, Pb and U in the sediments indicate that the natural environment in Annaburroo Billabong has experienced the following stages: 1267 AD – 1392 AD, relatively dry climate conditions. The high Pb concentration at 19.5 cm, perhaps reflect an increase in forest fires around 1292 AD. 1392 AD – 1717 AD is a relatively wetter stage. 1717 AD – 1892 AD, a drier stage, like the current climate. Since about 1900 AD, interactions between humans and the environment altered the nature of the sedimentary record, for example mining activities, land clearance and farming.

Conclusions

Grain-size and trace-metal analyses in the sediment profile of Annaburroo Billabong suggest that major flooding in and around Annaburroo Billabong have become less prevalent over the last 700 years and sediments have been accumulating since 1267 AD. The distribution of the "coarse" sand fraction indicates a wet climate, causing the recording of several flood events in the Annaburroo Billabong sediments. These floods may have occurred at about 1417 AD, 1467 AD, 1534 AD, 1617 AD, 1684 AD, and 1922 AD, with the largest in 1467 AD, and the smallest of these around 1684 AD.

These depositional changes suggest that climates in the catchment could be divided into four stages: about 1267 AD-1392 AD, a dry climate; about 1392 AD-1717 AD, a wetter climate with distinct flood events recorded in the sediments; about 1717 AD-1892 AD, drier than the earlier period with somewhat lower rainfall than the first stage; about 1892 AD-2000 AD, wetter than the former stage.

The overall chemical fingerprints shows variable levels of metals, but no real increase due to possible "European" mining activities in the catchments. Despite the well documented mining activities in the area, the lagoon seems to be a natural sink for fine sediments and associated metals. This indicates that natural processes are dominant in the formation of the sediment record of this lagoon. Furthermore most of the sediment in the lagoon is very likely to be autogenic, and the billabong is only inundated in the most severe monsoonal or cyclone floods and most of the time has no connection to Mary River.

The high Pb values around 1292 AD and 1842 AD might be caused by forest fires with more airborne dust deposited in dry weather. The sedimentary record is unique for Northern Australia as not many are preserved in a monsoon dominated environment. Most billabongs are prone to erosion of the bottom sediments during flooding.

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Was evaporation lower during the Last Glacial Maximum?

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Abstract

A critical aspect of the water balance in Australian palaeoclimatic studies is evaporation. During the Last Glacial Maximum (LGM), lower temperatures have been assumed to facilitate lower evaporation, which in turn is used to explain anonymously 'wet' hydrological conditions within many fluvial and lacustrine records from this time. Here, the evidence for this relationship is briefly reviewed, and examples from modern climates are given to argue for a revision of the role of evaporation in LGM hydrological balances throughout Australia.

Introduction

In 1965 RW Galloway published the now classic paper 'Late Quaternary climates in Australia' (Galloway, 1965), and ever since this time authors searching for climatic controls on hydrological conditions on the Australian continent during the Last Glacial Maximum (LGM) have embraced the notion of lower evaporation to explain a wide variety of hydrological conditions (e.g. Bowler et al.,1976; Coventry, 1976; Singh et al.,1981; Williams et al., 2001; Kemp and Rhodes, 2010). However, despite its ubiquity in the Australian palaeoclimatic literature, the assumption of lower LGM evaporation has never been tested explicitly as a plausible climatic scenario.

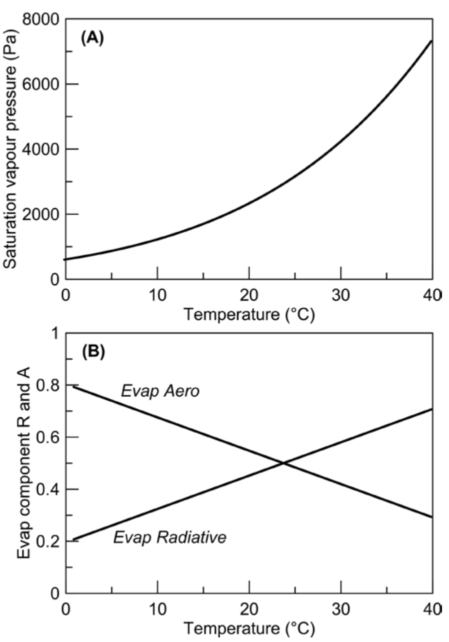

Figure 1.(a) The Clausius-Clapeyron curve for likely range of surface air temperatures throughout Australia during the LGM. (b) Increasing (or decreasing) temperature has an opposing effect on the separate radiative and aerodynamic components of evaporation. Although this does not include the effects of wind speed or vapour pressure on evaporation, it demonstrates that the direct effect of temperature on evaporation is potentially quite small. See Roderick et al., (2007) for a description and derivation of the full equations.Modified from Roderick et al. (2009).

Galloway (1965) estimated evaporation during the LGM around Canberra in Australia to be roughly half the modern annual average, and was suggested to be the result of lower temperatures, despite acknowledging the importance of other factors. Lower evaporation was required by Galloway to balance the water budget for Lake George, where a 30m lake level shoreline was inferred to be LGM in age. Subsequent work by numerous authors have also demonstrated good evidence for fairly wet hydrological conditions during the LGM (Nott and Price, 1994; Nanson et al., 1998; Haberlah et al., 2010a,b), although many lakes may have evolved to much drier conditions soon after the LGM (Bowler et al., 1978), however the timing is not yet conclusive in many of these cases. Nonetheless, for better or worse the notion of lower evaporation during this time has remained.

Discussion

The case for lower evaporation could be made if the atmosphere were considered in isolation, that is, a colder atmosphere stores less water vapour, and therefore has less evaporative demand. This is a well established thermodynamic relationship known as the Clausius-Clapeyron curve, whereby the saturation vapour pressure of the atmosphere increases as an exponential function of temperature (Figure 1a). However, since this relationship only describes absolute humidity, the resultant potential and actual evaporation can be considerably more complicated since the vital metric is relative humidity (or vapour pressure deficit), which is the saturation vapour pressure minus the actual (measured) vapour pressure. There are numerous equations to describe evaporation, and in terms of potential (or pan) evaporation, the penman equations are some of the most widely used. A model which uses modifications of these equations in an Australian context has recently been developed which accurately predicts measured pan evaporation rates across the continent (Rotstayn et al., 2006; Roderick et al., 2007). Using this model (PenPan), the Clausius-Clapeyron curve is incorporated into both a radiative and an aerodynamic component, which results in roughly contrasting effects in terms of changing temperature (Figure 1b). Crucial factors in determining evaporation which remain, namely net solar irradiance, wind speed, and the vapour pressure deficit, are therefore more likely to have the biggest impact on evaporation rates. In the modern climate for example, the observed decline in pan evaporation throughout Australia and many other parts of the world over the last 30 years can be attributed to a decline wind speeds (e.g. Roderick et al., 2009; Johnson and Sharma, 2010). Although temperature most certainly plays an important role in evaporation, the simple relationship between temperature and evaporation which is assumed in the Australian palaeoclimate literature since the work of Galloway (1965) needs to be carefully revised.

Another important factor when considering evaporation in the context of water balances is the actual amount of evaporation versus the potential rate. Although the above mentioned equations can accurately describe potential evaporation, it is the relationship between potential and actual evaporation, and also precipitation and actual evaporation, which is crucial for the water balance. If potential evaporation is greater than precipitation, then the rate of actual evaporation is limited by water supply. If on the other hand potential evaporation is less than precipitation, then actual evaporation is limited by the amount of energy available for evaporation. Many Australian environments at first glance would be considered water limited, however many areas of the country likely experience transitions between the two, since it is after all, a country of droughts and flooding rains.

This balance between potential evaporation, actual evaporation, vapour pressure, and precipitation is complicated, and depends on specific climatic forcings (van Heerwaarden et al., 2010). Nonetheless, many arid and semi-arid areas of Australia display a good negative relationship between increasing precipitation and decreasing pan evaporation, while some semi-arid, and most temperate or tropical regions do not (Figure 2). The reasons for this relationship in arid and some semi-arid areas most likely relates to the fact that wetter years would also have on average greater cloud cover, which in turn reduces solar irradiance and therefore lowers the measured evaporation (Hobbins et al., 2008). Because the vapour pressure deficit is already very large in arid areas, a comparatively small change in other factors such as solar irradiance and wind speed has a proportionately larger effect on evaporation than more humid or tropical climates. The weaker correlations at some arid and semi-arid locations in Figure 2 most likely reflect the contribution of wind speed to total pan evaporation rates at these locations, which is not accounted for in these regressions.

It is important to remember that the measured evaporation in this data is from Class A pan weather stations, which by definition have no limit to their water supply. In reality, the actual evaporation would match this pan evaporation only in humid environments (Brutsaert and Parlange, 1998), or above open water bodies such as lakes and wetlands, whilst in semi-arid and arid climates it would be limited by the ability of the soil to provide water to the open atmosphere or plants, depending heavily on soil properties and antecedent conditions. However if the local mean

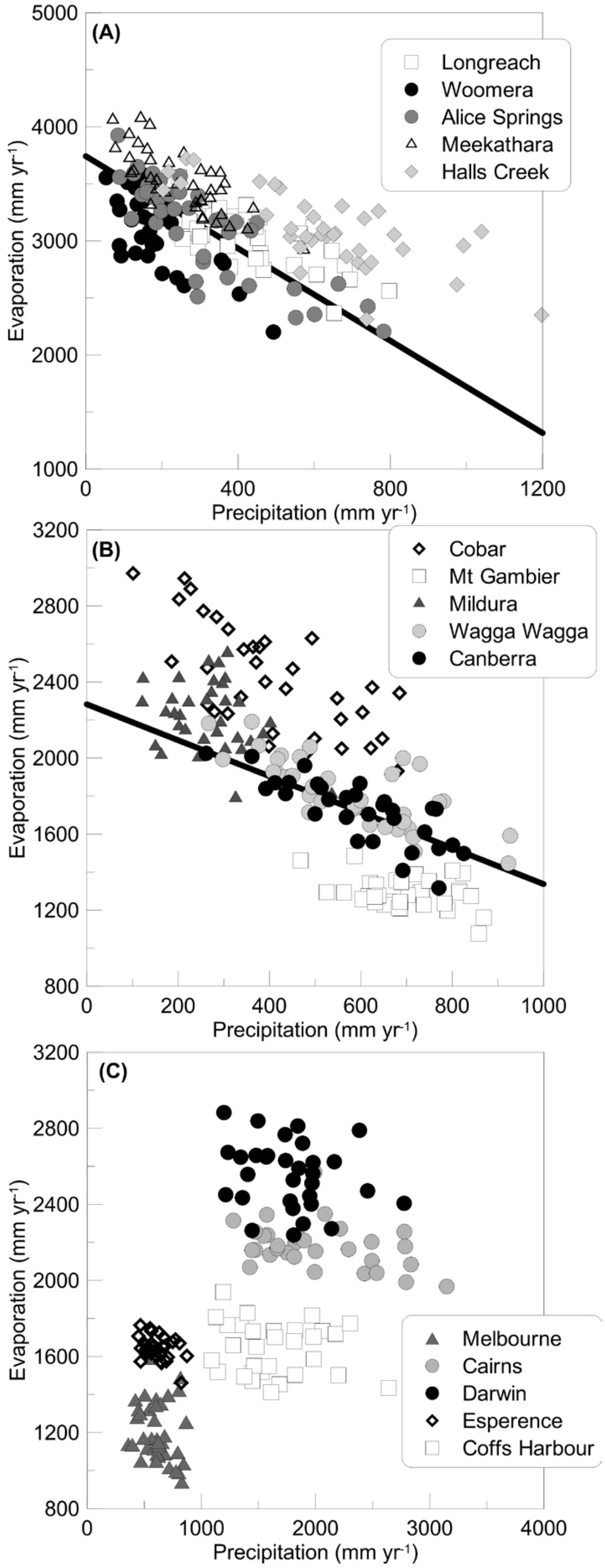

Figure 2. The relationship between total annual evaporation and rainfall as measured by the Australian Bureau of Meteorology at selected sites across Australia for the period 1970 -2009 (where available) for (a) arid, (b) semi arid, and (c) tropical and temperate stations across Australia. All arid stations (a) show good to weak correlations between total annual evaporation and rainfall (Longreach r2 = 0.51, Woomera r2 = 0.50, Alice Springs r2 = 0.70, Meekathara r2 = 0.60, Halls Creek r2 = 0.56), however only the regression line for Alice Springs is shown (y = -2.02x + 3743). For the semi arid stations (b) only Canberra and Wagga Wagga have good correlations between total annual evaporation and precipitation (r2 = 0.62 and 0.59 respectively, the regression line for Canberra is also shown, y = -0.95x + 2283), Cobar has a weak correlation (r2 = 0.49) and Mildura and Mt Gambier display no correlation. All tropical and temperate stations (c) have no correlation between total annual evaporation and precipitation. Note the changes in scale between graphs.

annual precipitation is reduced, and water can still be adequately supplied (e.g.: via more regionally supplied runoff in large basins), evaporation above lakes within arid or semi arid areas could potentially increase, contrary to conditions generally assumed in Australian palaeoclimates.

In addition, the role of vegetation in palaeo-water balances for Australia remains largely unaccounted for. Many pollen studies point to a widespread reduction in tree density during the LGM, which would in turn allow a rise in water tables in many areas of the continent. This may be compensated for in many areas by an increase in actual evaporation from the soil, possibly via an increase in wind speeds if the surface roughness is reduced. If this effect is not uniform, then some areas may experience an expansion in the area, and possibly rate, of ground and surface water connection, particularly following large storm events. This would also help explain the presence of some anomalously 'wet' hydrological conditions during the LGM, and demonstrates that understanding the coupling between the land surface, atmosphere, and vegetation is crucial if we are to properly interpret glacial climates.

Conclusions

It is proposed here that the well established drop in mean annual temperatures during the LGM may not have lead to the corresponding drop in mean annual evaporation that researchers have generally assumed since Galloway's influential paper. Many researchers (including Galloway, 1965) have also assumed and in some cases provided evidence for a decrease in precipitation during the LGM, which if true, would certainly limit the amount of actual evaporation, particularly for the majority of the continent's surface that is not permanently wet. However, for wet surfaces such as wetlands or lakes, whose palaeo-records are used to infer P/E conditions during the LGM, there is no *a priori* reason to suspect that evaporation would have been any lower. In addition, more recent studies suggest that strong, episodic precipitation could explain some apparently enhanced LGM pluvial conditions such as high lake stands, without the need for lower evaporation (Haberlah et al., 2010a,b).

These conclusions highlight the lack of a robust conceptual model for LGM hydrological conditions, since precipitation and evaporation are almost always considered to be uniformly lower, and the role of vegetation is rarely considered. The difficulty of course is quantifying precisely how much, and for how long, these processes impact the terrestrial water balance. Nonetheless, greater flexibility in explaining P/E relationships and the overall water balance from LGM climate records, and not simply assuming lower evaporation, is clearly required of further research.

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Laboratory notes on the extraction of pollen and silica microfossils from clay- and sand-rich sediments of semi-arid and arid environments.

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Abstract

The extraction of microfossils from sediments is laborious and time consuming. Standard processing methods often target a single palaeoenvironmental proxy, rarely allowing simultaneous recovery of multiple proxies. While this is of no great consequence in fossil-rich environments, fossil-poor sediments from semi-arid and arid environments might benefit from the use of multiple complementary proxies. The potential fragility of the arid and semi-arid zone fossils, due to oxidising and abrasive conditions, exposure to multiple wetting-drying cycles, combined with high mineral content of the sediments, calls for a more sensitive treatment to optimise recovery outcomes. This paper describes a new integrated protocol that allows simultaneous recovery of multiple palaeoenvironmental indicators. It reduces lab processing times, cost, and the volumes of sediment and chemical reagents required.

Introduction

Arid and semi-arid sediments often contain only small concentrations of pollen, and even those are usually in a poor state of preservation (e.g. Gayler, 2000; Horowitz, 1992). Furthermore, the sediment is often heterogeneous and a combination of clayey, silty, and sandy units within single cores are often encountered (e.g. Gayler, 2000, 2008). While it might be beneficial to use different methods to extract pollen from different sediment types (e.g. Lentfer and Boyd, 2000), it has been suggested that variation in extraction procedures, even as small as the change in the order of the processing steps, can introduce differences in the total concentration of recovered pollen and the variability of pollen types (e.g. Smith, 1998) affecting the comparability between samples or sites. It is also crucial that the techniques used in pollen extraction minimise the physical and chemical damage and can easily cope with large sample volumes of often highly variable sediment. Additional benefits are gained if the extraction procedure allows simultaneous separation of other complementary fossils such as biosilicas, including phytoliths and diatoms.

Pollen extraction

Initial pollen separation from lacustrine and dune sediments of the semi-arid Paroo/Warrego Region, northwest New South Wales, Australia, was conducted using a standard hydrofluoric acid (HF)-based method that is commonly employed in palynological laboratories (for details see Gayler, 2000). Unsatisfactory results, including low pollen counts, large amounts of non-pollen residue such as gypsum and clays, and safety concerns related to the handling of large amounts of HF when processing large samples, prompted a search for a better method. A literature review (Bowdery, 1998; Faegri and Iversen, 1989; Horowitz, 1992; Hunt, 1985; Lentfer and Boyd, 1998; Parr, 2002), contacts and visits to other palynological laboratories, including the University of Melbourne (M. Cupper, pers. comm. 2000) and the Southern Cross University (J. Parr, pers. comm. 2001-3), and laboratory trials led to a new extraction protocol (Table 1). This method resulted in better pollen recovery by minimising the physical/mechanical (abrasion) and chemical (corrosion, extensive expansion) impact on the individual grains. It also improved laboratory safety through elimination of HF.

The first step of the new protocol is a hydrochloric acid (HCl) treatment to remove carbonates and dissolve reference *Lycopodium* spore tablets. It is followed by 5% tetra-sodium phyrophosphate (Bates et al., 1978; Batten, 1999; M. Cupper, pers. comm. 2000) to disperse clays before sieving through 250μm mesh (Figure 1). The clay particles are then removed by still settling (Figure 1) rather than centrifuging based on guidelines by Lentfer et al. (2003) and unpublished laboratory notes from the Laboratory of Paleoecology, Northern Arizona University, for the following reasons:

i) Although the still settling procedure is slower (4.5-8 hours settling cycles repeated for a few days) than sieving through a fine (5-8 μm) mesh (as prescribed by the University of Melbourne protocol), trying to wash a large clay-rich sample through a fine mesh can be difficult (even when using dispersant) as the mesh constantly clogs (Lentfer and Boyd, 1999 as well as personal experience) and the sediment can easily spill and

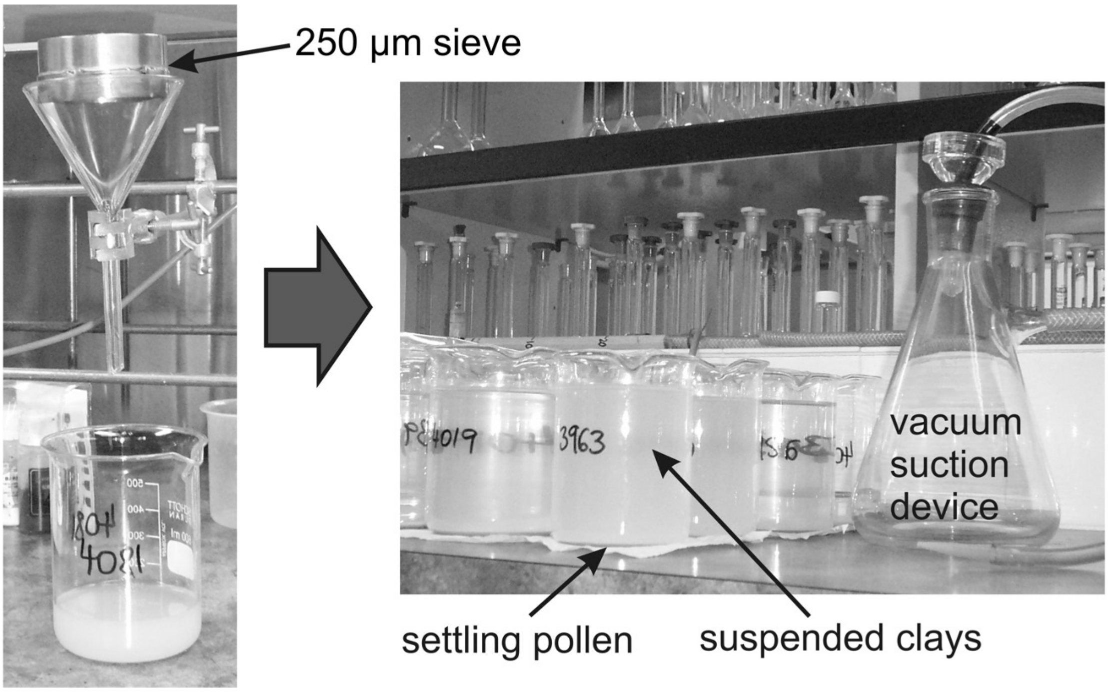

Figure 1. Sieving of the sediment through a 250 µm mesh followed by still settling.

became contaminated by splashes. In addition, microfossils may be further fragmented and abraded by forcing them through the mesh as well as by sand grains and/or gypsum crystals present within the sample (evidenced by damage to the reference *Lycopodium* spores). Finally, stirring or using a vacuum pump may lead to distortion and increase in mesh aperture size (Lentfer and Boyd, 1999) allowing larger than desired particles, including small pollen, to pass through the mesh.

ii) While Lentfer and Boyd (1999) reported satisfactory results from a centrifuge settling method, the technique is not recommended for clay-rich samples. During centrifuging, the clay-rich sediment can settle extremely tightly at the bottom of the tube often requiring intensive vortexing and agitation with a mixing rod to resuspend it (the author has broken a few glass rods and bended steel ones in the attempt). In addition, presence of larger hard and angular particles, such as gypsum crystals, combined with intensive vortexing can further abrade pollen grains (Gayler, 2000). In contrast, the sediment settled on the bottom of a beaker during still settling remains relatively loose and is easy to resuspend during preparation for the next settling cycle.

The still settling time was calculated using formulas and information in Lentfer et al. (2003). A considerable margin was added to allow for the slower movement of the grains due to non-spherical shape, protrusions on exine, and pore characteristics (Brush and Brush, 1994), as well as very high suspended clay content, particularly in the initial stages of the settling. Random checks of the water discarded from the settling confirm that pollen settled to the bottom of the beaker.

In next step, the pollen is separated from the silt and fine sand fraction by heavy liquid gravity separation using sodium polytungstate (Hart, 1988; Munsterman and Kerstholt, 1996). During this procedure, the sample is diluted in a liquid of a density (i.e. specific gravity) that after centrifuging, the lighter pollen and phytoliths floats on top of the liquid while the heavier mineral particles settle at the bottom of the sample container.

The specific gravities (SG) of heavy liquid used by different researchers for the separation of pollen fall within a range of SG 1.8-2.1 (Table 2). SG 2.0 (used in this study) is the most common density used. SG 2.0 provides a good margin for maximum pollen recovery with minimum interference from the mineral fraction, as the density of pollen and organic constituents is generally below 1.7 and that of mineral fragments (including gypsum) above 2.0. Although using higher SG to extract both the pollen and phytolith fraction (Table 2) was considered, in the end a two-step separation using two different SGs was used to maximise pollen concentrations by reducing the amount of other material recovered with the pollen fraction.

Following heavy liquid separation, samples are subjected to acetolysis to remove cellulose (not a very important issue in semi-arid and arid sediments). In addition, this process improves the appearance of pollen grains by increasing the size of the grains by up to 50% (Brown, 1960), darkening their colour, and possibly also removing some of the exine, making the morphological features more pronounced and easier to distinguish (Brown, 1960; Reitsma, 1969). Acetolysis

Multi-fossil extraction method using gravity settling and heavy liquid separation		
Step	**Action**	**Notes**
1	Place sediment samples (1-6 cm^3) in 50 ml centrifuge tubes. For larger samples increase volumes of added chemicals accordingly.	
2	Add 2-4 *Lycopodium* marker-spore tablets (depending on the expected concentration of the target; record the number of tablets used and the batch number). Add 5-10 ml 10% HCl to dissolve carbonates and 10-20 ml distilled water. Mix well. Centrifuge at 3000 rpm for 5 min. Retain supernatant.	
3	Fill tubes to 1/2 level with distilled water. Vortex, centrifuge (5 min at 2500 rpm), decant.	
4	Add 30-40 ml 5% $Na_4P_2O_7.10H_2O$ (tetra-sodium pyrophosphate) [or 4% Na_2SiO_3 (sodium silicate)] and leave (at least) overnight to disperse clays. A week in dispersant is advisable for larger and clay-rich samples.	
5	Sieve through 250 µm mesh into 500-1000 ml beakers (depending on the sample size).	
6	Fill beakers with distilled water, stir and leave to settle (5-6 hrs for 500ml (depending on the initial densities of suspended clay particles); 8hr for 1000ml). Siphon, refill and leave to settle again. Repeat until the water becomes clear at the end of settling (repeat step 4 if large amount of clay is still present – usually necessary for clay-rich samples). Return the remaining sediment into 50 ml tubes.	
7	Add 6 ml (to double the volume of sediment) $Na_6(H_2W_{12}O_{40}).H_2O$ (sodium polytungstate) specific gravity (SG) 2.0 (for pollen) or 2.3 for combined pollen and phytoliths. Mix well. Centrifuge at 1500 rpm for 20 min. Decant sodium polytungstate into additional centrifuge tube. Retain sediment fraction.	If pollen concentrations are expected to be low, extract the pollen and light phytolith fraction first using heavy liquid of 2.0 SG. Reserve the settled sediment fraction. Carry out acetolysis (steps 11-14) on the extracted pollen. From the reserved sediment extract heavy phytolith fraction using heavy liquid of 2.3 SG (change centrifuge settings to 5 min at 2000 rpm).
8	Top tubes with decanted sodium polytungstate (and pollen) with distilled water (at least 20-30 ml). Mix well. Centrifuge at 3000 rpm for 5 min. Retain supernatant. (Retain sodium polytungstate for recycling*).	
9	To retain sediment fraction from step 7, repeat step 7, decant heavy liquid into tubes containing extracted pollen fraction from step 8. Repeat step 8.	Repeat steps 7-8 for third time if sediments are expected to be poor in target material to ensure maximum recovery.
10	Fill tubes to 2/3 level with Glacial Acetic Acid (GAA) to remove water. Vortex, centrifuge, (5 min at 3500 rpm), decant. Repeat step 10.	
11	Fill tubes with approx. 9mL of Acetic Anhydride and vortex. Add 1 ml sulphuric acid. Place tubes in 90°C water bath for 2 min.	
12	Cool in/and centrifuge (5 min at 2500 rpm at 5°C), decant.	
13	Fill tubes to 2/3 level with GAA to remove sulphuric acid. Vortex, centrifuge (5 min at 3500 rpm, ambient temp.), decant.	
14	Fill tubes to 2/3 level with distilled water. Vortex, centrifuge (5 min at 2500 rpm), decant. When decanting aim to leave 1 ml of water in the bottom of the tube.	
15	Mix sediment with the remaining water and transfer the contents to Eppendorf tubes. Add 0.2-1 ml of glycerol to each tube. Do not vortex. Centrifuge for 53 min at 3000 rpm.	
16	Using small pipette decant the water from the tube leaving a minute amount of glycerol with the sediment.	
17	Sodium polytungstate recycling: Filter the sodium polytungstate twice through a 1-2 µm mesh. Concentrate the liquid though evaporation in hot (50°C) water bath.	

Table 1. The pollen/biogenic silica extraction protocol.

also removes the cytoplasmic material from within modern pollen. Since most reference pollen collections are prepared using acetolysis, use of this step in processing of fossil material improves comparability and identifiability.

Except for the burning caused by prolonged exposure, the contribution of acetolysis to pollen destruction during processing is not clearly defined. While some researchers (Lentfer and Boyd, 2000) believe it may be significant, others (Faegri and Iversen, 1989; Horowitz, 1992) consider its impact on the exine morphology negligible. The multiple advantages in using acetolysis led to its incorporation into the pollen processing protocol.

The concentrated pollen residue can be mounted in glycerol to ensure good preservation and later allow movement of grains on the slide, thus assisting with identification. After transfer onto the glass slide, the pollen can be stained with Saffranin to aid differentiation between pollen and non-pollen fossil and highlight the exine details, especially of the damaged grains (Brown, 1960).

Biogenic silica: phytoliths, sponge spicules, and diatoms

The change in pollen extraction procedures from dissolution (HF) to gravity separation (heavy liquid) of mineral silica results in retention of biogenic silica such as phytoliths, sponge spicules, and diatoms (Gayler, 2008). However, since the SG of phytoliths varies between 1.5-2.3 (Lentfer et al., 2003; Wilding and Drees, 1971), the SG of sponge spicules is below 2.3 (Jones and Beavers, 1963; Schwandes and Collins, 1994) and of diatoms is below 2.1 (Morley et al., 2004), while the SG of the heavy liquid in this protocol is 2.0, some of the biogenic silica (with SG >2.0) is likely to be retained in the mineral fraction settled to the bottom of the tube during the heavy liquid separation. It might be possible to separate them from the mineral residue by repeating treatment with heavy liquid (sodium polytungstate) concentrated to a higher SG, e.g. 2.3 (Table 1 and 2) (Bowdery, 1998; Thorn, 2004).

In the Paroo/Warrego region study diatoms were recovered using the new extraction protocol mainly from modern (<30cm depth) lake sediments. Sediments from a red sand dune overlying lacustrine muds and from three gypsum lunettes had diatoms present in only three samples (Gayler, 2008). While some of these diatoms still supported enough surface ornamentation to allow identification, the majority were highly degraded and visible only as an outline in phase contrast mode. Their condition also rapidly deteriorated with depth. Further experimental work is needed to determine if their scarcity and poor condition are a result of chemical dissolution within the sediments, as reported in extremely alkaline or saline waters (Gasse et al., 1997; Reid et al., 1995; Ryves et al., 2001), or due to the pollen extraction protocol.

Scanning for biogenic silica is best achieved in phase contrast mode as it helps to discern them it on a crowded background. Polarization can be also used to differentiate between biogenic and mineral silica (Bowdery, 1998).

Other micro- and macrofossils

The scanning of the residue captured in the 250 µm sieve (generally considered waste and discarded) under a dissecting microscope can also reveal, with minimal additional work, some interesting fossils including macrophyte seeds, charophyte oospores, rootlet/burrow concretions, as well as gypsum crystals (Gayler, 2008). Others, however, such as charophyte gyrogonites and gastropod and ostracod shells are potentially lost (dissolved) during the hydrochloric acid treatment. A better recovery of these might be possible with adjustments in the pollen extraction protocol.

Source	Specific gravity			
	Pollen	Phytoliths	Sponge spicules	Diatoms
M. Cupper (pers. comm., 2000)	2.0			
Faegri and Iversen (1989)	1.96-2.1			
Horowitz (1992)	2.0			
Paleoecology Laboratory, Northern Arizona University (unpublished)	1.9			
Macphail (2000)	2.0			
C. Thun (pers. comm. 2000)	1.8-2.0			
Bowdery (1998)		2.3		
Lentfer and Boyd (1999; 2000)		2.35		
Jones and Beavers (1963)			2.3	
Schwandes and Collins (1994)			2.3	
Morley et al. (2004)				2.1

Table 2. Specific gravities (SG) of heavy liquid used by different researchers in pollen and biogenic silica extraction.

Charcoal

Only low amounts of black particles (potential charcoal) were observed on the pollen slides and none were discovered in the >250 μm fraction retained during pollen sieving of the Paroo/Warrego region sediments (Gayler, 2008). Since a targeted macrocharcoal analysis of nine representative samples by S. Mooney (pers. comm. 2006) also failed to confirm charcoal presence (with exception of single sample with charcoal content of <1%), it is assumed that its absence was not related to the protocol described herein.

Conclusion

While challenging, the analysis of sediments and the fossils contained therein from semi-arid and arid regions can provide valuable palaeoenvironmental information. One of the biggest hindrances in such studies is the shortage of multi-fossil extraction protocols that can also cope with large sample volumes and high mineral content of the sediments. The work described above describes such a method, providing researchers with a tool to enrich records from fossil poor sediments. This research also sets ground for further experimental work that will optimise the quantities, quality, and type-richness of the recovered fossils.

Acknowledgements

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First annual international joint meeting of IGCP Project 588/INQUA 1001

Hong Kong, November-December 2010

Roland Gehrels and Craig Sloss

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UK National Correspondent for IGCP Project 588
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Co-leader of IGCP588 and INQUA1001
AQUA Vice President

IGCP Project 588 ("Preparing for Coastal Change: A Detailed Process-Response Framework for Coastal Change at Different Timescales") is the successor to the highly successful Project 495 (2004-2009), which was led by Antony Long (Durham University). It is the latest in a long series of IGCP projects related to Quaternary sea-level changes that dates back to 1974 and IGCP Project 61. The new project has four co-leaders: **Adam Switzer** (Earth Observatory of Singapore), **Craig Sloss** (Queensland University of Technology, Australia), **Ben Horton** (University of Pennsylvania, USA), and **Yongqiang Zong** (University of Hong Kong). This inaugural meeting of the project was jointly organised with INQUA Project 1001 ("Quaternary Coastal Change and Records of Extreme Marine Inundation on Coastal Environments"), who together with the Singapore-based Stephen Hui Trust and UNESCO provided funding for many early career scientists, PhD students and scientists from developing nations to participate in the meeting.

The conference was hosted by Hong Kong University between 30 November and 5 December 2010. It encompassed 2.5 days of oral presentations and 1.5 days of field excursions. At the ice-breaker party on the eve of the meeting delegates were welcomed by the Pro-Vice Chancellor of Hong Kong University **John Malpas**, a geologist, and we enjoyed delicious snacks and free-flowing beer. The meeting was truly international in scope, with 76 papers presented by scientists from 24 different countries, the majority coming from Southeast Asian countries, especially mainland China. Australia was represented by Colin Woodroffe (University of Wollongong), Craig Sloss (Queensland University of

Technology), Brendan Brooke (Geoscience Australia), and Juliet Harrington (PhD student, ANU). New Zealand was represented by Alistair Clement (PhD Student, Massey University).

Keynote speakers delivered presentations on various aspects of the history of sea-level research and the impact of early Holocene rapid sea-level rise on coastal landscapes. **Michael Tooley** provided an engaging personal perspective on the legacy of past sea-level researchers. He singled out the contributions of Sir Harry Godwin, Professor Rhodes Fairbridge, Dr Saskia Jelgersma, Dr Jørgen Troels-Smith and Professor Nils-Axel Mörner. The message to the audience was that these people were all exceptional field scientists (Nils-Axel Mörner is still active). Their papers form the foundation blocks of palaeosea-level research and are still deserving of citation, although many ideas may have been superseded by new ones. **David Smith** discussed the large sea-level rise during the early Holocene, when sea level rose globally by about 60 m in less than 5000 years, and highlighted its impacts on coastal societies and coastal landscapes. He provided insights on the various sources that may have contributed to the rise and on the feedback mechanisms between sea-level rise, inundation of continental shelves and climate change. **Julian Orford** fittingly addressed the problems facing the coastal communities in the deltas of the Gulf of Bengal in the light of future sea-level rise. Local knowledge about sedimentation processes and community support are key to successful adaptation in this region where 50-60 million people are confronted with the possibility of forced migration due to land loss. **Roland Gehrels** discussed methods of sea-level reconstruction from salt-marsh sediments, which have provided an important new dataset of sea-level data for the last half millennium. He highlighted the rapid early 20th century rise as a key feature of many proxy records and demonstrated that instrumental and proxy records were in agreement about the timing of this rise (i.e. the 1920s). He dedicated his talk to Orson van de Plassche, a former leader of IGCP Project 274, who passed away in 2009. Other keynote talks were given by **Yoko Ota** (National Taiwan University) who discussed Holocene environmental changes in tectonically active coast associated with coseismic uplift using examples from the western Pacific. **Yuki Sawai** (National Institute of Advanced Industrial Science and Technology, Japan) also presented a keynote on the geological evidence for unusually large tsunamis along central-south Japan Trench and **Bijan Kumar Saha** (Jadavpur University) presented on the impacts and responses of coastal environments to catastrophic events in on the east coast of India.

The inspired keynote address by **Colin Woodroffe** was of great significance to the project, as he spoke about the possible contributions that Quaternary coastal scientists can make to help address societal issues of coastal change and sea-level rise. He proposed that "if the present is the key to the past, then the past, seen from the context of the present, can be a guide to the future". This statement refers to the lessons that can be learnt from studying Quaternary sea-level changes and coastal processes: namely, that patterns of sea-level change are regionally variable, that simple models such as the Bruun Rule should be replaced, and that GIA models and behavioural models of coastal change should be tested and validated with empirical data. Colin concluded that our knowledge of coastal change on annual ("PhD time") and millennial timescales is substantial, but that our knowledge on decadal to centennial time scales, which is so important for future planning, must be significantly improved.

Yongqiang Zong and **Adam Switzer** lead the fieldtrip days. One afternoon was spent in the Mai Po marshes of the Pearl River Delta, where natural mangroves formed a wetland of international importance, although parts had been converted to shrimp and fish farms ("Gei Wei"). The city of Shenzhen loomed on the horizon on the other side of the border in mainland China. This is the fastest growing city in the world. About 30 years ago it was only a small fishing village, but now, mind-blowingly, Shenzhen is a mega-city bigger than London. The wetlands have somehow survived despite the impacts of pollution and increased sedimentation rates. We also spent half a day on the beach at Big Wave Bay, where we discussed the impacts of a recent typhoon and the response by government agencies to the event. There was controversial evidence of a mid Holocene sea-level highstand, which had been heavily debated in the literature, and also a Bronze Age rock carving.

The city of Hong Kong provided delegates with some diverse nightly entertainment in the form of a light show, viewed from Kowloon across Victoria Harbour, and the horse races at Happy Valley where some delegates, who will remain anonymous, enjoyed significant winnings and were not to be seen the next morning.

At the business meeting it was proposed that future annual project meetings will be held in Thailand towards the end of 2011 and in Singapore in 2012, with other future meetings being proposed by Chinese, Japanese, and US delegates. It was also decided to establish three working groups: catastrophic events in coastal environments, high-resolution reconstructions of sea-level change, and coast landscape evolution. At this year's INQUA congress the project will sponsor three sessions: "Late Quaternary Records of Coastal Evolution" (no. 46), "Quaternary Records of Rapid Coastal Change (Co-Seismic Uplift/Subsidence, Storm Impacts and Tsunamis)" (no. 47), and "Sea-Level Jumps: Evidence from Quaternary Proxy Records" (no. 48).

The organisers must be congratulated on a successful inauguration of IGCP Project 588, in particular **Yongqiang Zong**, who was a superb and dedicated host. For more information on IGCP Project 588 please contact the project co-leaders or visit the website www.coastal-change.org

2nd Aus2K Regional Network Workshop: data synthesis and research planning

27–29th April 2011, University of Western Australia, Perth Australia

Joelle Gergis, Pauline Grierson, Andrew Lorrey, Jonathan Palmer and Steven J. Phipps

Joelle Gergis: School of Earth Sciences, University of Melbourne, Australia
Pauline Grierson: School of Plant Biology, University of Western Australia, Australia
Andrew Lorrey: National Institute of Water and Atmospheric Research, Auckland, New Zealand
Jonathan Palmer: Gondwana Tree-ring Laboratory, New Zealand
Steven J. Phipps: Climate Change Research Centre, University of New South Wales, Australia.

The goals of the 2nd Aus2k workshop were to discuss the feasibility of producing an Australasian-wide temperature reconstruction, and identify a series of sub-regional studies to form a special Aus2K issue of *Journal of Climate*.

The Vice-Chancellor of the University of Western Australia, Professor Alan Robson, opened the workshop highlighting the importance of understanding natural climate variability. The two sessions on the first day were an open symposium devoted to showcasing state-of-the-art research developments in each of the main high-resolution Australasian palaeoarchives.

Ed Cook provided an overview of the three multi-millennial tree ring chronologies from Australia and New Zealand. He was followed by Janice Lough who reviewed the suite of Great Barrier Reef coral records and promising new work from the North West Australian coast into the Indian Ocean. Tas Van Ommen then outlined the utility of using the eastern Antarctic Law Dome ice core to infer changes in Southern Ocean circulation and precipitation anomalies in south-western Australia.

Around 120 palaeoclimatologists, hydrologists, ecologists, oceanographers, agricultural scientists and various natural resources managers attended the symposium resulting in very energizing debate during the sessions and the deliciously-catered breaks. The scale of the event was only possible thanks to PAGES funding and the generous support from Rio Tinto Iron Ore and the University of Western Australia.

The afternoon session was the start of the closed program for the core Aus2K group to discuss the issues associated with observational and proxy–climate data. Ed Cook reminded the group of the importance of replication wherever possible and the implications of using misdated series to infer high frequency climate variations.

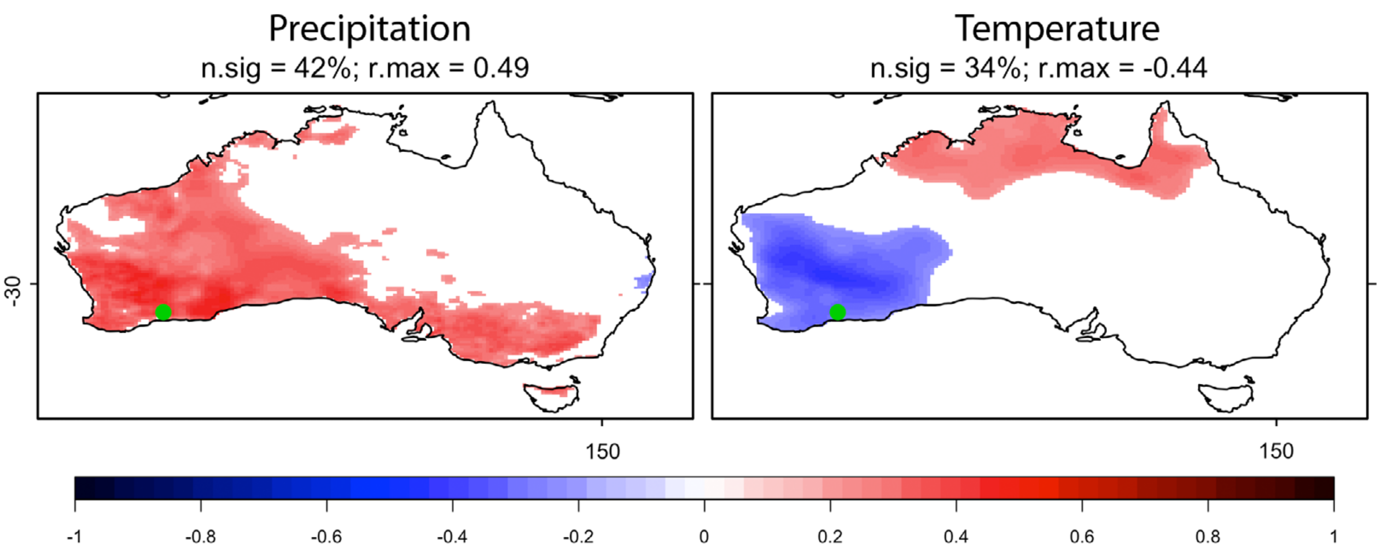

Figure 1. Spatial field correlation of the Cullen and Grierson (2009) Western Australian *Callitris columellaris* tree ring record with the Australian Bureau of Meteorology 0.050 x0.050 (5kmx5km) Australian Water Availability Project (AWAP) temperature grid for winter half year (June–November) temperature (right) and rainfall (left). Correlations calculated over the 1911–2005 period. Green circle indicates record location.

Meteorologist Ailie Gallant then outlined the potential and limitations of using observational gridded datasets available in Australasia. We learned that the high spatial coherence of temperature over Australia (which takes up the majority of the Australasian domain) means that less than ten observational stations can capture over 80% of variance in mean temperature over the region, providing they are randomly and evenly distributed. This is perhaps unsurprising given that continental Australia is predominately a very flat, arid continent.

The rest of the day was spent discussing how we reassess the climate sensitivity of the existing Australian database, perhaps exploiting the clear co-variations observed between rainfall and temperature in many part of the region. This involved examining a series of spatial field correlation maps for the records identified through the compilation of the Aus2K metadatabase (see example in Figure 1).

Day 2 of the workshop focused on a range of relevant multi proxy analyses that have been published for North America, Asia, South America, Europe (Cook *et al.*, 2004; Cook *et al.*, 2010; Neukom *et al.*, 2010a; Neukom *et al.*, 2010b) or are currently in development to achieve the Regional 2K network's objectives (Australia, New Zealand and the Southern Hemisphere).

The group was shown a preliminary 500-year annually-resolved summer temperature reconstruction that has been developed by Joelle Gergis and others at the University of Melbourne. The group discussed the issue of proxy selection and the feasibility of developing a continuous, non-geographically biased temperature reconstruction spanning the past millennium. We will now move forward with refinements generated by the group to produce an Aus2K temperature paper to provide our regional contribution to the broader Regional 2K network's consortium paper.

In recognition of the fact that most of the Australasia's palaeoclimate records comprise decadal–multi-decadal sedimentary records, Scott Mooney gave an overview of the availability of the Australian material that spans the last 2000 years. Andrew Lorrey also illustrated a synoptic pressure reconstruction approach using speleothems and low resolution data. These reconstructions will form an important means of independently supporting low frequency trends and variability identified from the high-resolution material.

To round off the second day of presentations, Steven Phipps provided a thought-provoking discussion of the role of modelling in the last 2000 years. He provided an example of evaluating the stability of regional teleconnections and influence of different climate forcings using simulations from the CSIRO Mk3L model.

The workshop wrapped up on a very productive note with the development of a proposed list of 15 papers for consideration in the *Journal of Climate* Aus2K special issue, and a clear direction forward to deliver Australasia's best available science for the Regional 2K global synthesis.

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INTIMATE meetings, both sides of the Tasman

AINSE, Lucas Heights, 7-8th December, 2010 & GNS, Wellington, 17-18th March, 2011.

Jessica Reeves, Helen Bostock

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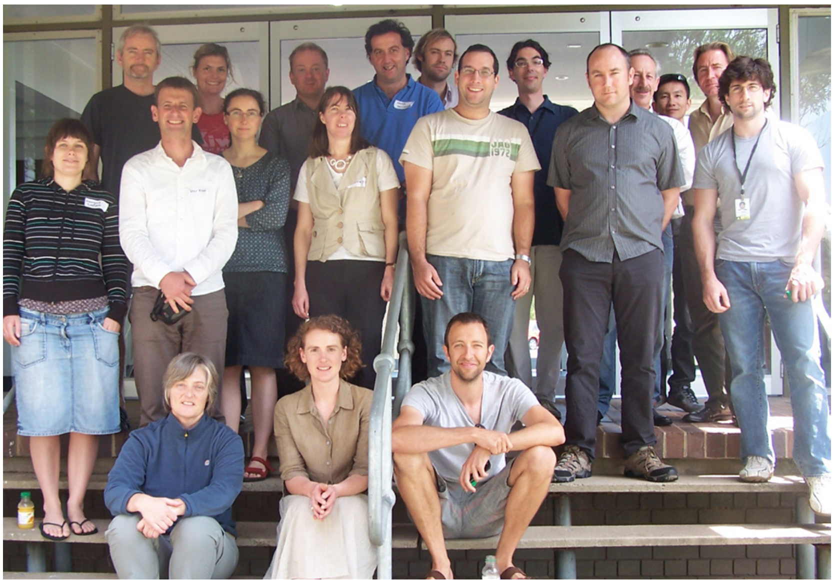

Figure 1. The congregation of the 3rd AINSE OZ-INTIMATE workshop.
Back row (from left): Russell Drysdale, Lynda Petherick, Steven Phipps, Jamie Shulmeister, Josh Larsen, Matt Fischer, David Fink, Toshiyuki Fujioka, John Jansen.
Middle (from left): Katerina Larsen, Peter Almond, Pauline Treble, Justine Kemp, Steve Lewis, Craig Woodward, Zach Swander.
Front row (from left): Linda Ayliffe, Jessica Reeves, Tim Cohen.

Activities of the Australasian-INTIMATE group have been heating up in preparation for INQUA this year. The Australian group (OZ-INTIMATE) came together late 2010 to build on the progress made in the 12 months prior. Following on from this, members of the OZ-group were invited to join NZ-INTIMATE in Wellington in March 2011 for a catch up on advances both sides of the Tasman since the last Australasian-INTIMATE meeting in 2009, and to devise a strategy for future work as we are currently at the end of the 2nd phase of AUS-INTIMATE.

Twenty-two Australian researchers attended the third OZ-INTIMATE workshop, hosted by AINSE. We were also joined by a member of our New Zealand counterpart (NZ-INTIMATE) and overall AUS-INTIMATE project leader, Peter Almond. The primary aim of the workshop was to refine our regional event stratigraphies for presentation at the upcoming INQUA congress in Bern, Switzerland, July 2011.

Following on from the OZ-INTIMATE workshop held at AINSE in 2009, the group divided Australia into regions, to better constrain the climatic phenomena responsible for the observed proxy records. The regions are tropical, temperate, interior and Southern Ocean, with an over-arching palaeoclimate modelling group. Unfortunately the Southern Ocean group was poorly represented at this meeting, as has been a perpetual issue with the OZ-INTIMATE project. The other regions, however, made very constructive progress, which will be presented in the Australasian-INTIMATE session at INQUA and form a series of manuscripts in a special theme of a relevant high-ranking journal (e.g. *Journal of Quaternary Science*).

The structure of this meeting differed from previous events, with a format of 'break-out' groups to discuss the key records from each of the regions, rather than formal presentation of individual records. This proved very successful, with healthy debate within each of the groups. The key objectives of the groups were to ascertain the most appropriate records for inclusion in the climate event stratigraphy, identify the limitations of these records, look for data gaps that may benefit from future research and ensure we had a coherent story to present at INQUA.

The second day of the meeting began with a presentation by Peter Almond on the progress the NZ-INTIMATE group has been making. This included an interactive meta-database, hosted by GNS, that enables proxy-interpretation diagrams for the key climatic parameters of hotter/colder, wetter/drier. This database also allows comparison of records from any time period for which there is data. There was a strong feeling among the OZ-INTIMATE group that we should also contribute to this database. Peter Almond will determine the logistics involved in this in consultation with Marcus Vandergoes at GNS. This would be a strong movement forward for the OZ-INTIMATE group and be an intermediary step toward the formulation of climatic models to describe the responses seen in the records.

One of the key outcomes of this meeting was the identity of the OZ-INTIMATE group; that it is distinct from other research projects, and that it has a clear direction. There was a strong desire to 'brand' output as being associated with OZ-INTIMATE and to use this group to apply for future funding of research projects (e.g. ARC). The first successful OZ-INTIMATE ARC-Discovery grant was recently awarded to INTIMATEs Jamie Shulmeister, Tim Cohen, Craig Woodward, Kat Fitzsimmons and Justine Kemp to investigate the Last Glacial Maximum in eastern Australia.

The strong identity of Australasian-INTIMATE is also evident by the strong response of abstract submissions to the Aus-INTIMATE session at INQUA (23 abstracts), including 10 members of the OZ-INTIMATE research group. We look forward to show-casing our progress at INQUA and will also be holding a workshop, immediately following the Aus-INTIMATE session. We thank AINSE for supporting the endeavours of OZ-INTIMATE and enabling the group to meet regularly to facilitate these crucial discussions.

FThe momentum of the OZ-INTIMATE group has significantly increased and has benefited from "buy-in" from the Australian palaeo-climate community. This year will see a consolidation of this progress in terms of publications, applications for funding for data gaps and the beginnings of data-synthesis and model comparison. The next AINSE workshop will be held 14-15th December, 2011.

INTIMATE matters were again discussed in the refined auditorium of GNS Science Avalon, NZ on March 17-18th. This was the first combined Australasian-INTIMATE meeting since the Past Climates meeting in May, 2009. Along with 14 pre-eminent kiwi Quaternarists, Steven Phipps, Lynda Petherick and Jessica Reeves attended to present the OZ-side, supported by funds from INQUA.

After an initial introduction, the NZ-INTIMATES presented updates on their records. David Barrell gave an overview of the extensive glacial morphology mapping and exposure dating that has been undertaken over the past 5 years. Paul Williams presented on the accumulation of well dated, high resolution speleothem $\delta^{18}O$ records from the South Island, which extend back to 35 ka. The speleothem $\delta^{13}C$ records were also given a spin by Drew Lorrey, to determine local precipitation. Louise Callard presented on her PhD research on a precipitation fed moraine lake in the east of the South Island, using macrophyte pollen. The record extends back beyond the LGM. Matt Ryan's marine pollen record from off the west coast of the South Island extends back over 200 ka. He is correlating this with the nearby onshore Okarito pollen record for his MSc. Marcus Vandergoes provided an update on the work to refine the age of the infamous Kawakawa tephra, although the debate is still open for comment. Finally Drew Lorrey presented on the work he has been doing integrating the NZ records for the 21 ka time slice with model simulations from PMIP. This is a great step forward for the NZ-INTIMATEs and has shown both where there is good correlation with different records and proxies, and regions where further work is required.

The next session saw an update of progress from the Australians. Tim Cohen and Jessica Reeves were invited to Wellington in May 2009 and charged with the task of re-invigorating OZ-INTIMATE, which had lost momentum since its initial promising beginnings in 2004. Now was the time to prove that we were back in action. As mentioned above, OZ-INTIMATE has broken the continent into four regions. Jessica Reeves gave an overview on the progress made to date and the strategy for moving forward. She then presented on the current compilation and correlation of tropical records, defined as the area north of the influence of the westerlies. Lynda Petherick gave an overview of the temperate region, based primarily on pollen and charcoal from lakes and the new high resolution work from the Murray Canyons. Current gaps include the lack of records from Western Australia, a low representation of marine records and the possibility of including archaeological records. Jessica then presented a compilation of the interior records, prepared by Kat Fitzsimmons and Tim Cohen. Steven Phipps closed the Australian contribution with a talk on the potential and issues with the use of models in palaeo-climate work, with a word of caution that modelling should be incorporated into the development of a project from the start, and properly resourced, in order to be effective.

The rest of the workshop was devoted to where we as Australasian-INTIMATE go next. OZ-INTIMATE aim to deliver regional synthesis for presentation at INQUA and publication thereafter, at which point comparison with the NZ-INTIMATE CES can be made. An obvious starting point would be the OZ-temperate zone with the NZ compilation. Traditionally the INTIMATE timeframe was 30-8 ka BP, although the Australians have opted to push through to present, at similar resolution, and Holocene NZ records have been compiled in Lorrey et al., 2008. The NZ group also have a stronger foothold in the Southern Ocean and this would best be tackled as a joint effort.

The two Australasian-INTIMATE sessions at INQUA will be a good show-case for the work achieved to date. We will also be holding a lunchtime workshop immediately following the second session to discuss the future of Aus-INTIMATE. The next local Aus-INTIMATE meeting will be at the AQUA conference at Lake Tekapo in February 2012.

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Pre-industrial sea-surface temperature reconstructions in the Australian region; Part 1 eastern Australia

RV Southern Surveyor Transit voyage SS2011-T01
Depart Hobart May 5, 2011 – arrival Brisbane May 12, 2011

Patrick De Deckker and 10 colleagues from ANU [1Postdoc, 3 PhD, 2 Honours,1 Undergrad] , Bordeaux [1 staff] and Indiana State University [1 staff, 1 PhD]

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The following is a brief report on a transit cruise undertaken in May, 2011 on the Southern Surveyor. The scientific objectives of the project, funded by the ARC, are to reconstruct past sea-surface temperatures in the Tasman Sea across a large temperature gradient for comparison with the northern hemisphere record spanning the last millennium. In addition, to collect calcareous nanoplankton to identify levels of calcification and for comparison with sub-fossil material to be extracted from short cores. Also, to examine the nature of magnetic minerals in undisturbed and uncompressed sediments. Finally, to sample air during the voyage for the determination of its microbial composition under clean conditions.

This project aimed at generating high-resolution records of sea-surface temperature [SST] changes that have occurred in the oceans surrounding Australia. Part 1 [this voyage] covers the Tasman Sea, whereas part 2 will cover the ocean south of Australia [going from Fremantle to Hobart in November 2011]. A variety of innovative proxies will be employed on the samples we have collected and used for comparison with lake records on mainland Australia. Our objectives were to obtain short cores along the Australian coast line [at approximately 1,000 m water depth] across a temperatue gradient. The innovation is to use organic biomarkers to reconstruct past SST.

Additional small projects were conducted during this cruise. These were:

1. to collect material from some of the cores for an extensive study of magnetic minerals in marine sediments;
2. to filter air at the front of the vessel during the entirety of the cruise, and those samples will be treated in the laboratory at ANU, and should be used to determine the DNA;
3. to examine the nature of the sea floor and its microbiota [to determine if they all occur at the sediment water interface or below]; and
4. to obtain samples from the cores for dating purposes using radionuclides. All these supplement our research into calibrating past environmental records; lastly
5. to collect plankton samples and filter waters at the same collection sites for calcareous nanoplankton and water samples for chemical analysis [eg trace elements and $\delta^{18}O$].

Results

The main objective was partly fulfilled as we obtained some cores, but did not manage to obtain any along the middle of our N-S transect. The reason being that we encountered bad weather that either prevented us from deploying the corer, or when the latter could be deployed, rough conditions such as big waves caused the corer to trigger itself before reaching the sea floor. In addition, due to the nature of the sea floor, we never obtained long [>50cm] cores. Nevertheless, it is not until we date the bottom of those cores that we will know if our material spans 1,000 years of deposition.

With respect to the secondary objectives, we obtained suitable material for the determination of the composition of magnetic material, although it would have been good had we obtained more cores. In addition, our air filtering gear worked well and we obtained sufficient material for analysis. There were a few occasions when due to the bad weather conditions at sea that it was not possible to go on the upper deck to replace the filters. We gathered quite a good amount of surface samples for identifying the nature of the microbiota on the sea floor, but had we obtained more cores, we would have been more pleased. We did manage to obtain sufficient water samples using the CTD equipment for radiocarbon dating. Finally, we also obtained sufficient plankton and nanoplankton samples across a large temperature gradient. This could be achieved despite the poor weather conditions at times.

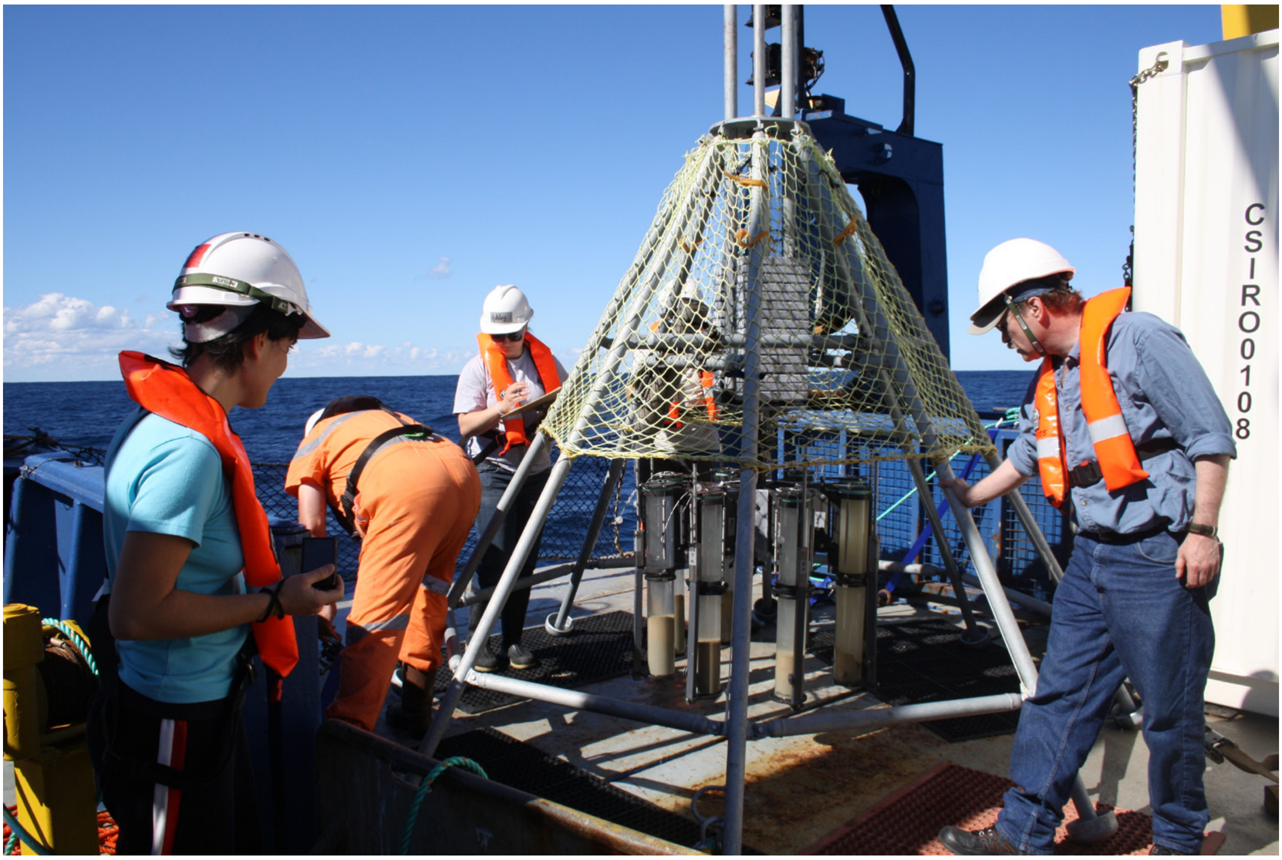

Figure 1. View of the multicorer back on the rear deck of the *RV Southern Surveyor* showing most of the 8 tubes that have sediments in their lower half, and water from the sediment/water interface. The corer weights approx. 800 kilos.The cores were subsequently sliced at 0.5 to 1 cm intervals

2011 ARC LIEF and Linkage Project Funding success for Quaternary Science

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The ARC LIEF results for 2011 and Linkage 2010 Round 2, for funding in 2011 show great success for the Quaternary sciences. The equipment provided by the LIEF grants will ensure some great science is to come in the near future and the Linkage success is a terrific boon for our archaeologists. The successful proposals are listed below encompassing Quaternary research including archaeology. Well done to all those who were successful.

A mass spectrometer to analyse carbonate isotope records of Australia's climate, soil and groundwater history

Administering University: The University of New South Wales

Investigators: Prof Andrew Baker, Dr Russell N Drysdale, Dr Silvia Frisia, Dr Pauline C Treble, Prof Richard I Acworth, Dr Quan Hua, Dr Andrew I Herries, Dr Katrin J Meissner, Dr David Fink

Funding awarded: $370,000

Partner/Collaborating Organisation(s): Australian Nuclear Science and Technology Organisation, The University of Melbourne, The University of Newcastle

Project Summary

Water is a critical resource in Australia, yet there is a fundamental lack of knowledge about the causes and timing of groundwater recharge in the past. This facility will allow researchers to better understand climate and groundwater interactions through high resolution isotope analysis of deposits, such as cave stalagmites and marine corals.

Sonic drilling to provide contamination-free core sampling of rock and unconsolidated sediment

Administering University: University of Wollongong

Investigators: Prof Gerald C Nanson, A/Prof Brian G Jones, Prof Allan R Chivas, Prof Colin D Woodroffe, Dr Kirstie A Fryirs, Prof Colin V Murray-Wallace, Prof John R Dodson, Dr Timothy J Cohen, Prof Sandra P Harrison, Dr Rachel A Nanson, Em/Prof Martin A Williams, A/Prof Alan S Collins, Dr Kathryn J Amos, Dr Paul Hesse, Dr Dioni I Cendón, Dr Timothy J Pietsch, Dr Andrew P Brooks, A/Prof Ian D Goodwin, Prof Jonathon M Olley

Funding awarded: $150,000

Partner/Collaborating Organisation(s): Australian Nuclear Science and Technology Organisation, Griffith University, Macquarie University, The University of Adelaide

Project Summary

Australia is the world's driest inhabited continent. Understanding environmental and climatic changes, from the temperate period when humans arrived about 50,000 years ago to the present state of widespread aridity, is crucial for modelling future climate change. This facility will provide new generation drilling equipment which is necessary to obtain accurate records.

Mobile isotope monitoring for environmental studies

Administering University: James Cook University

Investigators: Prof Michael I Bird, A/Prof Lindsay B Hutley, Dr Sarah O Tweed, Dr Andrew K Krockenberger, A/Prof Samantha A Setterfield, Prof Jonathan F Nott, Dr Paul N Nelson

Funding awarded: $150,000

Partner/Collaborating Organisation(s): Charles Darwin University

Project Summary

This facility will enable a quantum leap in Australia's capacity to undertake real-time, field based studies of environmental processes using the natural isotope tracers of carbon, oxygen and hydrogen. It will enable the researchers to address a range of fundamental research questions in climate change, water resources, ecology and human impact in tropical Australia.

From prehistory to history: landscape and cultural change on the South Alligator River, Kakadu National Park

Administering University :The Australian National University

Investigators: Dr Celia J Brockwell, Dr Janelle G Stevenson

Funding awarded: 2011 $30,000.00; 2012 $66,000.00; 2013 $66,000.00; 2014 $30,000.00

Partner/Collaborating Organisation(s): Kakadu National Park

Project Summary

This project explores the archaeology, history and palaeoecology of the Kakadu floodplains to better understand social and environmental changes that have taken place in this landscape from the mid-Holocene to historical times. The outcome will be a contextualised understanding of potential climate change impacts against a history of past change.

Alive with the Dreaming! Songlines of the Western Desert

Administering University :The Australian National University

Investigators: Prof Howard Morphy, Dr Michael A Smith, Dr Libby Robin, Dr June Ross, Ms Margo Neale

Funding awarded: 2011 $100,000.00; 2012 $200,000.00; 2013 $221,500.00; 2014 $205,000.00; 2015 $83,500.00

Partner/Collaborating Organisation(s): Kanyirninpa Jukurrpa, Ananguku Arts and Culture Aboriginal Corporation, Archaeological & Heritage Management Solutions, Department of Sustainability, Environment, Water, Population and Communities, NPY Women's Council, National Museum of Australia, The Palya Fund

Project Summary

Songlines that map the Australian continent are of iconic significance in the national cultural heritage of Indigenous and non-Indigenous Australians. The vision of Western Desert elders and artists is to share with the wider community an understanding of the scale, spiritual and environmental significance of the Tjukurpa Songlines of Australia.

Rescuing Carl Strehlow's Indigenous cultural heritage legacy: the neglected German tradition of Arandic ethnography

Administering University :The Australian National University

Investigators: Prof Nicolas Peterson, Mr Michael Cawthorn, Mrs Helen Wilmot, Dr John K Henderson, Dr Anna-Maria B Kenny (APDI)

Funding awarded: 2011 $44,500.00; 2012 $86,500.00; 2013 $86,000.00; 2014 $44,000.00

Partner/Collaborating Organisation(s): Central Land Council, Strehlow Research Centre

Project Summary

In collaboration with Arrernte and Luritja speakers, this project will result in the translation of Carl Strehlow's 10,000 word German dictionary and other major, unavailable cultural heritage materials and at the same time incorporate the work of the neglected tradition of German humanistic anthropology into scholarship on Central Australia.

The Australian historic shipwreck protection project: the in situ preservation and reburial of a colonial trader - Clarence (1850)

Administering University :The Australian National University

Investigators: Prof Peter M Veth, A/Prof Mark Staniforth, Dr Ian D MacLeod, Ms Vicki L Richards, Mr Anthony J Barham

Funding awarded: 2011 $150,000.00; 2012 $210,000.00; 2013 $100,000.00; 2014 $40,000.00

Partner/Collaborating Organisation(s): Australian National Maritime Museum, Department of Sustainability, Environment, Water, Population and Communities, Department of the Chief Minister , NSW Department of Planning, Norfolk Island Museum, Parks and Wildlife Service, Tasmania, QLD Department of Environment and Resource Management, The Australian Institute for Maritime Acrhaeology, Victoria Department of Planning and Community Development, Western Australian Museum

Project Summary

The project will use cutting-edge technology to study and preserve an early colonial shipwreck at risk and develop a world-class strategy for the reburial and preservation of endangered historic shipwrecks. The project will help develop new national policy and technical guidelines for site managers of historic shipwrecks and offer new insights into colonial shipbuilding.

Cultures of Coast and Sea: maritime environmental, cultural and ethnographic histories of north-east Australia, 1770-2010

Administering University : The University of Sydney

Investigators: Prof Iain D McCalman, Dr Stephanie C Anderson, Dr Jude P Philp, Dr Michael B Davis (APDI), Dr Nigel P Erskine, Mr Michael Crayford.

Funding awarded: 2011 $126,418.50; 2012 $246,162.50; 2013 $218,699.50; 2014 $98,955.50

Partner/Collaborating Organisation(s): Australian National Maritime Museum, Queensland Museum, Silentworld Foundation

Project Summary

Using new cross-disciplinary approaches and methods, this collaboration between university scholars, museum curators and a philanthropic foundation will study the impact of maritime and marine environmental and cultural change on the peoples and habitats of the Great Barrier Reef and the Torres Strait from the eighteenth century to the present.

Archaeology of rock art in Jawoyn country, western Arnhem Land

Administering University: Monash University

Investigators: Dr Bruno David, Dr Ian J McNiven, Dr Christopher J Clarkson, Prof Jean-Michel Geneste, Prof Jean-Jacques Delannoy, Dr Hugues Plisson

Funding awarded: 2011 $50,000.00; 2012 $125,000.00; 2013 $150,000.00; 2014 $125,000.00; 2015 $50,000.00
Partner/Collaborating Organisation(s): Jawoyn Association Aboriginal Corporation

Project Summary

This project will systematically study the rock art of Jawoyn country, Arnhem Land. It aims to reveal the age and associated archaeological contexts of some of Australia's most popular rock art traditions, feeding the results back to both academic circles and the nation's high exposure domestic and international tourism market.

Droughts and Flooding Rains: A fine-resolution reconstruction of climatic variability in western Victoria, Australia, over the last 1500 years

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The purpose of this study was to reconstruct climatic change of the last two millennia in western Victoria using fossil diatoms as the primary proxy. Due to their short life span and sensitivity to changing water chemistry, diatoms are ideal for reconstructing short term changes in suitable environments. The primary aim of the project was to redress a paucity of highly-resolved climate studies from the Australian mainland and represents one of the first sub-decadally resolved studies of its kind in this regard. Sediments from two crater lakes were examined from the volcanic province of western Victoria. The study region is influenced by *El Niño*-Southern Oscillation (ENSO), the Indian Ocean Dipole and the Southern Annular Mode and recently experienced the most severe and prolonged drought since instrumental records began (Murphy and Timbal, 2008; Ummenhofer *et al*., 2009).

The two study lakes – Lake Elingamite and Lake Surprise – have differing morphology and catchment history and lie approximately 100 km apart. Lake Elingamite is a broad, currently shallow (maximum depth = 3.4 m), oligosaline (3470 µS/cm) maar lake which shows evidence of significant catchment and lake disturbance since European settlement in the region. A 178 cm core was retrieved from this lake, representing a *ca.* 1500 year record. Lake Surprise is one of only two "true crater lakes" in the western Victorian volcanic province (Timms, 1975). It is fresh (220 µS/cm) with a maximum depth of 12 m and has a more complex morphometry than Lake Elingamite. It is located within a National Park and does not have the same degree of catchment disturbance as Lake Elingamite. Two cores were retrieved from Lake Surprise, a frozen spade core of the most recent sediments and a hammer-driven piston core of the older sediments. The combination of both cores provide a 344 cm record of the last *ca.* 1425 years. Cores from both lakes were sampled contiguously for fossil diatom analysis.

In order to quantitatively reconstruct palaeo-conductivity fluctuations from the study sites, a diatom-conductivity transfer function was developed with an intentionally short conductivity gradient, using only sites with a conductivity < 22,000 µS/cm in the modern calibration set (min: 81 µS/cm; max: 21,540 µS/cm; SD: 5592.7 µS/cm). The resulting model is robust, with a jack-knifed r^2 of 0.89 and an RMSEP of 0.238 log µS/cm (equating to 9.8% of gradient length), which compares favourably to other diatomconductivity or salinity transfer functions. At a sample-specific level, reconstruction confidence was tested by squared-chord distance using the modern analogue technique tool.

The Lake Surprise diatom-inferred (DI) conductivity record shows a good coherence with the Palmer Drought Severity Index developed for south-eastern Australia for the 20th Century (Ummenhofer *et al*., 2009), confirming the lake's climatic sensitivity. Comparisons between DI conductivity and instrumental climate data were not possible for Lake Elingamite due to the degree of recent lake and catchment disturbance. Importantly, the climate signal evident in the full Lake Surprise record is replicated in the Lake Elingamite record, indicating that the lakes are reflecting a common, regional scale, climate forcing.

Lake Surprise proved to be the more sensitive of the lakes and, in places where the DI reconstruction has poor modern analogues, the interpretation is supported by the Lake Elingamite record. Results show a strong centennial-scale agreement with a reconstruction of *El Niño* events from Ecuador (Moy *et al.*, 2002), confirming the influence of ENSO on the climate of the study region. At decadal-scale, the DI conductivity record provides a history of drought frequency, intensity and duration enabling the recent drought to be viewed in an historical perspective for the first time. Results demonstrate that, while the recent drought was unusual in terms of its severity and duration, it is not unprecedented. At centennial-scale, evidence is presented of extended periods of dry and wet climates, including a prolonged humid period prior to European settlement in the study region.

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An Assessment of Landscape Change Over 40,000 Years in Central Victoria

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A combination of climatic and anthropogenic influences produced the landscape instability seen in central Victoria in the past 40,000 years, with fire playing a major role in destabilising the sediment of the slopes. Once destabilised, the sediment is transported via the fluvial system through several periods of aggradation and degradation in a connected pathway from the hill slopes to the alluvial fans. Recent destabilisation of the landscape due to land use change has removed the sediment from streams and created the gullies to expose the sediment deposited in the past.

The removal of vegetation by a fire destabilises the sediment of the slopes, allowing the removal of the top soil during subsequent rainfall events. The fine particle top soil and burnt organic matter is the first to be removed from the slopes and deposited into the nearby streams as valley fill, while higher intensity rainfall events are needed to transport the larger particles that form poorly sorted, matrix- and grain-supported valley fills above the fine sediment to create the pyroalluvium and pyrocolluvium deposits found in the sediment profiles.

Charcoal ages from 10 gully sites show that there were several localised fire events over central Victoria, with two distinct clusters around 40,000 years BP and 2,000-3,000 years BP. These fire events created sediment yields ranging between 2.0×10^4 t ha^{-1} to 1.7×10^2 t ha^{-1}, while the thickness of the stripped sediment from the surrounding hill slopes ranges between 0.01-1.28m. This sediment was deposited in the local streams choking them and forming valley fills, probably during periods of lower precipitation.

The alluvial fans are dominated by silt-sized particles, transported by sheet flow from the slopes of central Victoria to the low gradient depositional plains on the edges of the Victorian highlands. These sediments were probably derived partly from weathered bedrock and valley fill sediments associated with the erosion of the hill slopes after a fire. The silt-sized particles were originally deposited as dust mantles by aeolian processes during periods of cooler, drier climates when weakened hydrological cycles caused the destabilisation of the arid inland regions of Australia.

Applying palaeolimnological techniques to sub-tropical east Australian estuaries

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This thesis examines the application of paleolimnological techniques, pioneered and developed predominately in northern hemisphere freshwater environments, to sub-tropical east Australian estuaries. The aim of this research was to determine how successfully these techniques - in particular those related to coring, dating, diatom analysis and stable isotope analysis – can be either applied or adapted to the estuarine environment to reconstruct nutrient levels in the absence of monitoring data. This will allow pre-impact environmental conditions of estuaries to be determined, which in turn will aid future management decisions.

Fifty-two estuaries from a spatially large geographic area were initially sampled, to create a dataset that consisted of surface sediment diatoms, and associated water chemistry data from point water samples. The sampling strategy of extracting point samples from estuaries was the only feasible option due to budgetary, spatial and time constraints. Principal Components Analysis (PCA) identified that a relationship between point sampling water chemistry and pre-determined classifications of estuarine health does exist (OzCoasts ratings, and ANZECC trigger values). Hence, a point-water sampling strategy can have merit as sampling method in sub-tropical east Australian estuaries, particularly when assessing total nutrient levels.

The application of the statistical methodologies PCA, Canonical Correspondence Analysis (CCA), and variance partitioning, to the water chemistry and surface sediment diatom data determined that total phosphorus (TP) exhibited significant influence on diatom distribution in the fifty-two estuaries, although this signal may be confounded with total nitrogen. Two transfer functions techniques, Weighted Averaging (WA), and Weighted Averaging Partial Least Squares (WAPLS), were used to create inference models for TP on numerous groupings of estuaries. The group that had all estuaries removed that had below detection limit levels of bio-available nutrients (PO_4, NH_4, NO_2, NO_x) in their point water samples gave the strongest transfer function scores (r^2jack = 0.69, RMSEP = 0.027 log^{10} mg TP l).

Five cores were extracted from depositional areas within three sub-tropical estuaries of differing environmental health; the Richmond River, NSW; the Burrum River, QLD; and Moreton Bay, QLD. These cores were put through a process of elimination involving loss-on-ignition testing and paleomagnetic profiling, to ensure that the cores of best integrity for paleolimnological analyses were selected. These cores were analysed using a combination of ^{210}Pb and AMS ^{14}C methods. Core chronologies were constructed for the riverine Richmond River and Burrum River. However, the open embayment Moreton Bay ^{210}Pb results indicated background unsupported ^{210}Pb levels, with ^{14}C results also inconclusive, demonstrating sediment deposition from mixed sources.

Results from diatom and δ^{13}C and δ^{15}N stable isotope analyses indicated that the total phosphorus levels in the Richmond River have fluctuated since 1920, and are most likely a function of climate. In the Burrum River, diatom assemblages, and the upper and lower limits for δ^{13}C and δ^{15}N stable isotopes, have shown very little variation over the past 5000 years. These minimal changes to water quality over the time period indicate that the Burrum River has value as a suitable reference site for benchmarking impacted sub-tropical estuaries. In the Moreton Bay core, zero diatom preservation was observed, probably due to the salinity and temperatures characteristic of sub-tropical open embayment estuaries. Reconstructions using geochemical and isotopic signals were mixed, but did indicate that Moreton Bay has been receiving sediment loads from different catchment sources for the past 10 000 years.

This thesis has demonstrated that paleolimnological techniques can be applied and adapted successfully in sub-tropical riverine estuaries. The inferences for the Richmond River can be used by environmental managers to influence decision making relating to nutrient levels in the Richmond River. In the Burrum River, paleolimnological techniques were applied successfully to identify the site as having benchmarking value. This research has also demonstrated the difficulties that can be encountered when applying paleolimnological techniques to more dynamic open embayment estuaries, such as Moreton Bay. Future studies attempting to reconstruct environmental histories of estuaries using paleolimnological techniques should incorporate river-influenced locations rather than marine-dominated sites, to provide increased probabilities for diatom preservation and definitive geochemical signals.

Past Climate Variability and Wetland Development of Eighteen Mile Swamp on North Stradbroke Island, South East Queensland: A Palaeolimnological Account

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Eighteen Mile Swamp is a groundwater fed shallow freshwater coastal wetland stretching almost the entire length of the eastern side of North Stradbroke Island, South East Queensland. Based on the chronology of this project and previous research, the Swamp is believed to have formed in the last millennium, developing rapidly from a marine estuary to a freshwater acidic system. Little research has been conducted on how this wetland formed and how it has been affected by climate variability and drought events. This study uses a diatom-based palaeolimnological approach to determine the timing and nature of Eighteen Mile Swamp's formation and evolution and the effect of climate variability on its ecosystem. A 220 cm sediment core representing approximately the last 650 years BP was taken from a central position of a pool approximately half way down the Swamp's length. Diatom assemblages and in particular, pH reconstructions were used, along with sediment analysis, to reconstruct the wetland's history. Radiocarbon dating (^{14}C) and diatom assemblages suggest Eighteen Mile Swamp became a freshwater acidic system approximately 420 years BP. Correspondence analysis and pH reconstruction were used to infer climate variability. Climate variability appears to have had only a small impact on Eighteen Mile Swamp, with the past 120 years BP being the most affected period of the wetland's history. A period of diatom dissolution approximately 290-120 years BP closely correlates with the Little Ice Age and warmer temperatures in the region. Drought events could not confidently be identified in the current study.

Climatic and oceanographic history of the SW Pacific from clay composition and particle size of the Canterbury Drifts

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Marine sedimentary records provide valuable information for reconstructing ancient environmental and climatic change, and by doing so, also contribute knowledge critical for better understanding future climate change. Records from mid-latitude locations, such as New Zealand (Southern Hemisphere), are particularly important for paleoenvironmental research because they provide information on potential climatic teleconnections between equatorial and polar regions. In reality, however, paleoclimatic and paleoceanographic research on mid-latitude records has received limited attention, particularly in the Southern Hemisphere.

This thesis focuses on Pliocene-Pleistocene drift deposits in the Canterbury Basin, also known as the Canterbury Drifts, SE New Zealand. The Canterbury Drifts are recognised as important paleoclimate and paleoceanographic archives of the SW Pacific because they record intrinsic signals of variability in South Island climatic conditions (glacial erosion), of tectonic uplift of the Southern Alps (western South Island), and of the

flow of intermediate depth water masses and associated currents that originate from Antarctica (i.e. Sub-Antarctic Mode Water, Antarctic Intermediate Water, Antarctic Circumpolar Current). Despite previous research on the Canterbury Drifts, crucial aspects of their history remain unknown, including details of sediment source and supply dynamics relative to climatic, oceanographic and/or tectonic processes, and how SW Pacific climatic and oceanographic conditions have responded to Milankovitch cycles and high latitude conditions. The aim of this thesis was to address these issues by using clay mineralogy, clay geochemistry (trace elements and Nd, Sr isotopes), and particle size analysis of Canterbury Drift deposits recovered from Ocean Drilling Program (ODP) Site 1119.

The principal objectives of this thesis were to identify:

1. Changes in South Island weathering regimes and detrital sediment supply relative to Plio-Pleistocene climatic conditions.
2. Change in on-land source for shelf sediments relative to environmental conditions, including distinct tectonic events during Plio-Pleistocene drift sedimentation.
3. Connectivity between the Southern Alps ice cap and Antarctic temperatures prior to MIS 11, and Milankovitch (orbital) cycles in Late Pleistocene drift sediments.

Plio-Pleistocene changes in South Island weathering regimes and detrital sediment supply are identified from the clay mineralogy of Site 1119 sediments. The abrupt replacement of smectite with higher chlorite and illite contents at ~3.5 Ma is coincident with the global Early-Late Pliocene transition and reflects the onset of a glacially modulated physical weathering regime, which accompanied abrupt global cooling at that time. Chlorite and illite remain abundant through the Late Plio-Pleistocene, consistent with persistent glacial erosion and continually cooling climate. A glacial control on physical weathering is also seen at high resolution (~4 ka resolution sampling between ~650-260 ka) as increased chlorite and illite deposition during cold glacial phases. Changes in clay mineralogy of ODP Site 1119 therefore reflect changes in onland weathering regimes associated with global climate events.

The high-resolution record (back to at least MIS 16) from this study also shows close ties between the behaviour of the Southern Alps ice cap and Antarctic atmospheric temperatures. Periods of reduced Antarctic temperature appear concurrent with increased glacial erosion on the South Island and increased supply of detrital sediments (chlorite, illite, Th, Rare Earth Elements) directly to Site 1119 during periods of lowered sea level. Cold phases were also a time of reduced Southland Current flow as determined by the fine mean sortable silt and low sand content proxies. Conversely, warm Antarctic temperatures (interglacial and glacial-interglacial transitions) are concurrent with reduced glaciation on the South Island, reduced detrital sediment supply to Site 1119 and faster Southland Current flow. Previous evidence of a connection between SW Pacific climate and Antarctic conditions has been strengthened in this study by using numerous proxies and by providing spectral evidence. Spectral analysis of the clay and particle size data indicates high latitude influence on New Zealand climate and oceanography during the Plio-Pleistocene and highlights complex heat distribution in the Southern Hemisphere.

Rare earth elements (REEs) in Site 1119 sediments identify a dominant Torlesse Terrane provenance during the Plio-Pleistocene. Trace element ratios (Th/Sc, Nd/Sc, Rb/Ba) could not confidently identify sediment source and question the conventional use of immobile elements to fingerprint sediment source. Neodymium and Sr isotope data demonstrate intervals of distinct provenance change, alternating between a central Torlesse Terrane source and more a more volcaniclastic-rich sediment input from terranes further south. Specific shifts in the geochemical record between 2.7-2.3 Ma and 0.7-0.6 Ma coincide with previously recorded Australian-Pacific plate rotation events, and suggest distinct episodes of tectonic control on sediment supply to the Canterbury Basin. Identification of tectonic control on drift sedimentation highlights the importance of considering tectonic activity when interpreting paleoclimatic signatures in basin environments.

This research demonstrates that paleoenvironmental studies of mid-latitude sedimentary records, such as the Canterbury Drifts, are integral to piecing together changes in global climatic and oceanographic conditions through time. Understanding how the Earth's climate has changed in the past, and what has driven these changes, in-turn provides valuable insight into the prediction of, and potential effects of, future climate change.

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