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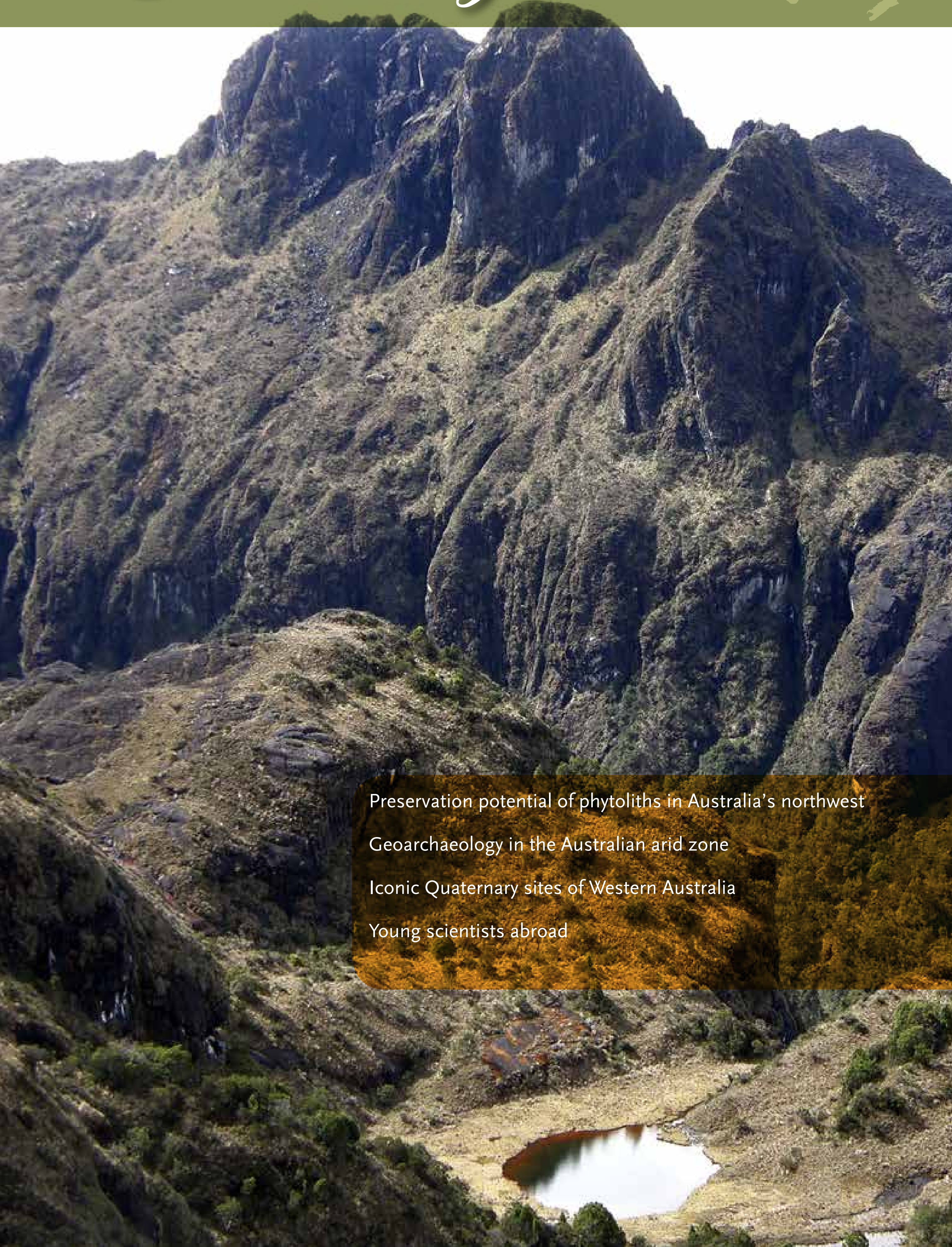
Quaternary AUSTRALASIA



Preservation potential of phytoliths in Australia's northwest

Geoarchaeology in the Australian arid zone

Iconic Quaternary sites of Western Australia

Young scientists abroad

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Inside front cover photo:
Collection of sub-surface artefacts from 1 m grid squares on Site H299, an artefact scatter in a shallow blowout on a longitudinal dune at Olympic Dam. The dunes here are widely spaced and the swales have small pans and patches of gibber.
(Photo Marjorie Sullivan, HEH).

Front cover photo:
Brass Tarn (Tegepunkwa), 3940 m alt, was exposed by ice retreat on Mt Wilhelm, PNG about 12800 years ago. Its 9 m of sediment contain at least 8 volcanic ashes and a record of treeline change.
(Photo Geoff Hope July 2010.)

EDITORIAL

Dear Fellow Quaternarists,

A recent issue of *Science* magazine focussed on the changing nature of scientific communication through time. One omnipresent theme permeated these opinion articles: communication and genuine exchange of ideas remains the most important tool for scientific progress, even if the mode evolves into the twenty-first century. This is certainly the case for Quaternarists working in Australasia, particularly in an increasingly global scientific community, and given the tyranny of physical distance of this region from the more densely populated research environments of Europe, North America, and Asia. In this regard, we've been doing pretty well for ourselves! This issue sees reports by early career researchers who travelled as far afield as India and Scotland, among other locales, in the quest of furthering international collaboration and scientific exchange.

Despite expanding our horizons, it is equally important to retain our local focus. In this issue, Ingrid Ward provides us with a useful overview of the history of Quaternary research and iconic sites in Western Australia, a region which frequently suffers from scientific neglect relative to the more intensively investigated southeast of the continent and New Zealand. Marjorie Sullivan and Philip Hughes discuss the results of intensive geoarchaeological investigations in the Olympic Dam

desert area of South Australia, demonstrating the utility of intensive and systematic survey within spatially constrained areas for understanding human-environment interactions. Lynley Wallis focuses on the Kimberley region of northwest Australia in an investigation of phytolith assemblage preservation across a range of sedimentary contexts, an approach which can be extrapolated to other environments, and which provides useful information for the preservation potential of this proxy within the Quaternary record.

We also pay tribute to archaeologist, Quaternarist and visionary, Professor Mike Morwood, who passed away in July this year.

Finally, we would like to thank our former Co-Editor, Jasmyn Lynch, for her excellent and thorough efforts with the last few issues of Quaternary Australasia, and to welcome our new Co-Editor, Pia Atahan, who takes on the job with this issue.

Yours Quaternarily,
Kathryn Fitzsimmons and Pia Atahan *Editors*

PRESIDENT'S PEN

And so the time has come, my friends, to pass the mantle. By the time the next QA goes to press, AQUA will most likely have a new President (hopefully a very feisty woman from across the Tasman). So I would like to take this as an opportunity to reflect.

I was asked to consider becoming AQUA president two years back, when I was co-editor of this fine publication. Craig Sloss was Vice President at the time, and so next in line, but decided to abdicate in view of his many and various international leadership roles. One comment he made was: "we have all of these keen female ECRs coming through and they need a role model – why don't you do it." Believe me, if you were aware of the appalling juggling act I make of parenting and a career, you would find this notion as amusing as I do – but I took his point.

Being a female scientist and approaching your career prime coincident with your peak child-bearing age is a serious challenge and, at least in Australia, can be quite a barrier. These are things we are not supposed to talk about – as everything is equal...except that it is not, quite.

There is no right answer of how to deal with this. I was lucky – I had a part-time job in a University whilst both of my children were very young, but it was a very task-oriented position, so not too challenging. As my brain began to rot, I put my hands up for positions back with my real colleagues – my fellow Quaternarists. This is how I became involved in AQUA and INTIMATE. To have that connection to people who understood where I came from and what I cared about was critical at that time. And I thank you all for the opportunities that presented themselves. I also benefited with close collaborations from senior colleagues – and I think there is much to be gained from this, with mutual benefit.

Stay connected – in whatever your capacity, is my take home story. We have a great community that can be very supportive. I hope we get to celebrate this when we next meet at the AQUA conference in Mildura in July.

Many thanks,
Jessica Reeves
AQUA President

NEWS

ONLINE AQUA MEMBERSHIP

Memberships are well and truly due and you can pay these easily online at: www.regonline.com.au/aqua_membership. There is also a link on the membership page of the new AQUA website. It is easy, so please get yourself signed up and encourage your colleagues, students and friends. This is a great time to sign new people up, as anyone that joins AQUA now will automatically have their membership extended right through to 28 February 2015. If, in the rare case you do have an issue with the online system, please contact our treasurer, Steven Phipps (treasurer@aqua.org.au).

AQUA FACEBOOK PAGE

Join us on the social network and share up-to-date news related to Quaternary Science and AQUA activities www.facebook.com/groups/43580401738

Feel free to upload links here to your latest outputs or other Quaternary-related news.

MEET A MEMBER OF THE AQUA EXECUTIVE COMMITTEE

KAT FITZSIMMONS: EDITOR, QUATERNARY AUSTRALASIA

Kat completed her PhD at Australian National University in aeolian geomorphology and luminescence dating, focussing on the history of aridity of the central Australian arid zone. Since then she has expanded her interests to work on the interactions between humans and their environment, collaborating with archaeologists in the loess steppes of eastern Europe and central Asia, and the desert regions of Australia, northern and southern Africa. She currently leads the luminescence dating group in the Department of Human Evolution, Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany.

A NEW EDITORIAL TEAM

This issue sees the stepping down of Co-Editor Jasmyn Lynch (University of Canberra) from the role. We would like to welcome new Co-Editor Pia Atahan (ANSTO) to the AQUA Executive, forming a new editorial team with Kat Fitzsimmons. Welcome, Pia!

AQUA 2014 CONFERENCE – BACK TO THE CORE!

AQUA 2014 CONFERENCE

Yes, next year sees the 30th anniversary celebration of AQUA by returning to where it all began – Mildura. With a public lecture at the Grand Hotel and a fieldtrip to the Willandra Lakes, this conference will see AQUA return to its homeland.

The conference will take place 29 June – 4 July, with a pre-conference fieldtrip to Lake Victoria and the Murray floodplain west of Mildura and a post-conference trip to the Willandra Lakes – both an archeological and geomorphological heartland for us all. Other possible pre-conference fieldtrips will be running from major cities. This will also be a CELL-50K and SHAPE meeting and we are hoping to run sessions on archeology of the Willandra and the use of Quaternary in management.

It is shaping up to be a great meeting and we hope to see you all there. Updates will be posted on the web www.aqua.org.au and through aqualist.


Australasian Quaternary Association Inc.
AQUA
Join us in celebrating the 30th anniversary of AQUA by heading back to where it all began...
AQUA Biennial Conference
29th June to 4th July 2014
The Setts Conference Centre
Mildura, Victoria
Conference fieldtrips include the Willandra Lakes (Mungo) World Heritage Area, as well as pre- and post-conference trips to other iconic Quaternary sites.
A free public lecture will be held at the Grand Hotel in Mildura, in association with the conference. Speakers include Prof Jim Bowler and Prof Peter Gell.
We encourage people from all fields of Quaternary research to attend, including archaeology and management.
For up to date information and registration details, check out AQUA's website: www.aqua.org.au under the "conferences" tab or email Jessica Reeves: president@aqua.org.au

A comparative study of phytolith assemblages in modern sediments from the Kimberley, Western Australia

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ABSTRACT

This paper presents the results of a study of phytolith assemblages in modern sediments from the Kimberley region of Western Australia. Phytoliths from 29 from savannah grassland, rocky talus slope, swamp, river margin, sand-dune, pindan and vine thicket sedimentary contexts were quantified and then compared using multivariate statistical techniques to determine whether they produced meaningfully different phytolith assemblages. Results indicate that contemporary vegetation communities are not necessarily accurately reflected in their associated sedimentary phytolith assemblage. Nevertheless, some distinctive phytolith types were identified that can serve as useful indicator types for particular ecological settings, particularly when considered in combination with non-phytolith microfossils. These findings suggest archaeological and palaeoenvironmental researchers attempting to reconstruct past Australia environments on the basis of palaeo-phytolith assemblages should exercise due caution.

KEYWORDS

phytoliths, Kimberley, modern analogue, palaeoenvironment, archaeology

INTRODUCTION

Since Rovner's (1971) seminal paper, phytolith analysis has increasingly become commonplace in archaeological and palaeoenvironmental studies. A fundamental precursor to such studies is a detailed understanding of phytolith production in modern contexts, with researchers enthusiastically exploring phytolith production in modern flora (e.g., Mulholland, 1989; Piperno and Pearsall, 1998; Lu and Liu, 2003; Wallis, 2003; Mercader *et al.*, 2004; Blinnikov, 2005; Tsartsidou *et al.*, 2007; Barboni and Bremond, 2009; Morris *et al.*, 2009). However, it is one matter to demonstrate that modern vegetation produces a range of distinctive phytolith types, it is quite another to assume uncritically that all such phytoliths will be equally well represented in sedimentary contexts. Thus, the study of phytolith assemblages in modern sediments is equally as important as those in modern flora.

The isolation and definition of phytolith spectra that correspond to known vegetation communities and climatic conditions allows for the identification of these characteristics in fossil phytolith assemblages, providing uniformitarian principals are adopted. Such modern analogue studies have been undertaken in the Americas (e.g., Blinnikov, 2005; Fearn, 1998; Fernandez Honaine *et al.*, 2009; Iriarte and Paz, 2009; Piperno, 1988:151–167), New Zealand (e.g., Kondo *et al.*, 1994; Prebble *et al.*, 2002), Africa (e.g., Runge, 1999; Albert *et al.*, 2006; Barboni *et al.*, 2007) and Europe (e.g., Bremond *et al.*, 2004; Bobrova and Bobrov, 1997; Delhon *et al.*, 2003; Gol'yeva, 1997; Kamanina, 1997). Most of the aforementioned studies were successful in using phytolith assemblages to distinguish different vegetation communities though, interestingly, often single morphotypes played an inordinately important role.

Despite international studies demonstrating close relationships between phytolith assemblages in extant vegetation and associated sediments, the few studies undertaken in Australia to date have been somewhat more ambiguous. Hart (1988) examined the phytolith assemblage of a swamp sediment near Oxford Falls (17 km north of Sydney) and found it in no way resembled that which might be predicted on the basis of the extant vegetation, failing to identify the dominant vegetation—*Gahnia sieberana* and *Gleichenia dicarpa*—in the phytolith assemblage. Conversely, sphere aggregates, a phytolith type that was abundant in the sediment, did not occur in either of the co-dominant plant species. Hart (1992) also examined soils and litter in the Pillaga region (ca 300 km northwest of Sydney) and again encountered difficulties in establishing a positive relationship between the phytoliths produced by the modern vegetation and those found in the associated sediments. Topsoil assemblages recovered from broom plain, mallee and forest communities were "not sufficiently similar, in the case of the broom plains, or different, in the case of the mallee, forest and broom plain, to be used to distinguish between vegetation communities" (Hart 1992:114–115).

The aim of the current study was to investigate phytolith accumulation in sediments of the southwest Kimberley and its' relationship to modern vegetation communities. While the leaves of approximately 300 modern plants were also examined for their phytolith content; results relating to this aspect of the study have been presented elsewhere (Wallis, 2000, 2003) and so are not repeated here, though they were used as a basis for determining the distinctiveness of certain morphotypes, and interpreting the sediment results.

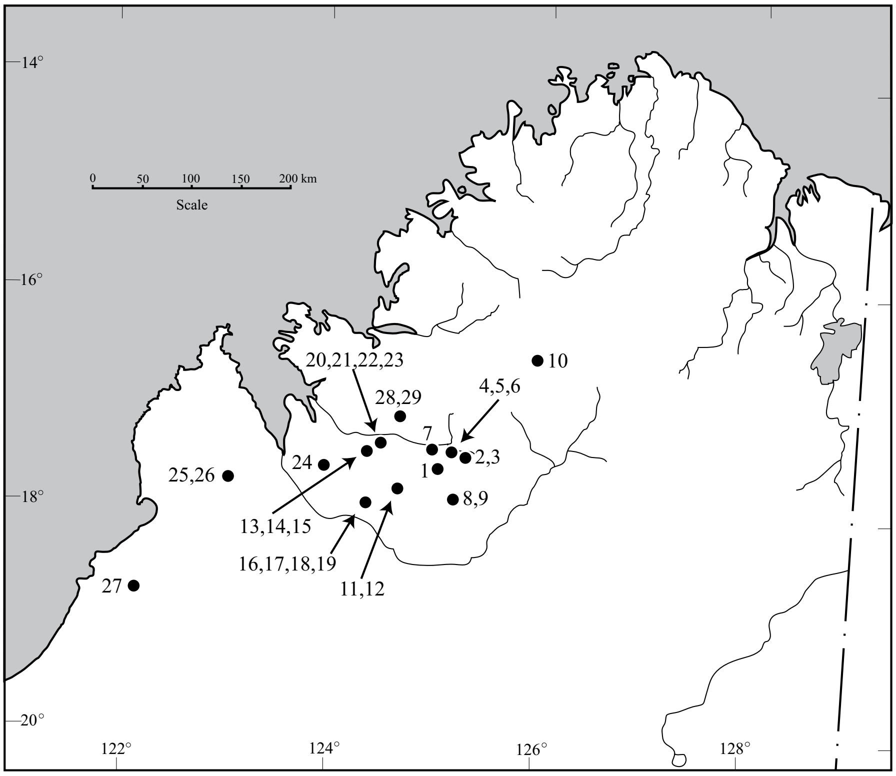

Figure 1. Map showing the locations of collected surface sediment samples from the southwest Kimberley, Western Australia. Numbers on the figure are cross-referenced to sample codes in Table 1.

1 = Savannah grassland. 2 = Carpenter's Gap, Napier Range. 3 = Savannah plain between Napier and King Leopold Ranges. 4 and 5 = Napier Range talus slope. 6 = Vine thicket. 7 = Lennard River, Windjana Gorge. 8 and 9 = Savannah grassland. 10 = Barnett River Gorge. 11 and 12 = Blina Swamp. 13, 14 and 15 = Savannah grassland, Gibb River Road. 16, 17, 18 and 19 = LeLievre and Lanlacatta Swamps. 20, 21, 22 and 23 = Richard's Pool and Black Swamp. 24 = Pindan, Gibb River Road. 25 and 26 = Pindan, Great Northern Highway. 27 = Pindan, Dampier Downs Station. 28 and 29 = Vine thicket.

METHODS

Twenty-nine sediment samples from across the southwest Kimberley, grouped into the following seven broad categories, were examined: (1) savannah grassland; (2) the rocky talus slopes of the Napier Range; (3) river margins; (4) swamps; (5) sand-dunes; (6) pindan; and (7) vine thicket. Details of each sample are provided in Table 1 and their locations shown on Figure 1.

Five pinch samples (each of ~10-20 g) randomly collected from the upper 0–5 cm within a 50 x 50 m area at each location were combined into a composite sample (so as to minimise the immediate vegetation bias at each location). pH was determined in the field using a field soil pH test kit. Sediment colour was described by reference to a Munsell soil colour chart, following overnight oven drying.

Phytoliths were extracted from these samples using a heavy liquid extraction process, following methods fully described in Wallis (2000). Sediments were initially sieved through a 2 mm mesh to remove pebbles and macroscopic organic debris. Clay-sized particles were then removed using gravity settling out in distilled, deionised water in a 30 cm graduated cylinder over an 8 hour time period, thereby ensuring that all phytoliths were retained. The number of settling out steps required varied depending on the nature of individual samples. Organics were then removed using hydrogen peroxide, followed by the removal of carbonates using a weak solution of hydrochloric acid and then the separation of phytoliths via flotation in sodium polytungstate (specific gravity 2.3).

A crude measure of phytolith abundance was determined by calculating an approximate percentage by dry weight value before and after processing. It is acknowledged that this method was not entirely accurate, since in some cases the remaining 'phytolith' fraction also contained small quantities of other inorganic particles; however, without any efficient means through which to remove these extraneous inorganic particles it was not possible to improve this measure.

Phytolith residues were mounted for viewing with an Olympus BH2 stereo-microscope. Slide scanning was carried out at 250x magnification (20x objective; 12.5x eyepieces) and percentages of individual phytolith types present were calculated by scanning transects until 1000 phytoliths had been counted. Resultant data were plotted using the pollen software package C2 (Juggins, 2007).

The absence of a universally applicable key for the description, identification and classification of phytoliths has hindered phytolith studies to date, and

Table 1. Summary information about surface sediment samples.

SAMPLE TYPE	SAMPLE NUMBER	LOCATION AND DESCRIPTION	PH	MUNSELL	DOMINANT PLANT SPECIES PRESENT IN THE AREA
Savannah Grassland	1	Black soil plain to the south of the Napier Range	8.5	10YR 4/2 dark grayish brown	*Acacia suberosa, Astrebla elymoides, Chrysopogon latifolius, Dicanthium fecundum, Dolichandrone heterophylla, Enneapogon purpurascens, Lysiphyllum cunninghamii, Sesbania cannabina, Sorghum plumosum*
Savannah Grassland	2	Rocky limestone soil at Carpenter's Gap, Napier Range	8	5YR 4/4 reddish brown	*Adansonia gregorii, Aristida* spp., *Buchnera asperata, Eragrostis exigua, Cochlospermum fraserii, Crotalaria* sp., *Enneapogon purpurescens, Gomphrena canescens, Ptilotus corymbosus, Stemodia lythrifolia, Triodia* spp., *Pletrachne* spp., *Polycarpa longiflora*
Savannah Grassland	3	Plain between Napier and King Leopold Ranges	9.5	10YR 5/3 brown	*Adansonia gregorii, Buchnera asperata, Cajanus reticulates, Chrysopogon latifolius, Cochlospermum fraserii, Corchorus sidoides, Cullen* sp., *Cymbopogon bombycinus, Enneapogon purpurescens, Eriachne obtuse, Grevillea pyramidalis, Hakea* sp., *Hypoestes floribunda, Indigofera colutea, Sorghum plumosum, Stemodia viscose, Terminalia* spp., *Trichodesma zeylanicum*
Talus Slope	4	In front of Carpenter's Gap 1 rockshelter, northeast margin of Napier Range	9	5YR 4/4 reddish brown	*Aerva javanica, Dicliptera armata, Phyllanthus* sp., *Stemodia* sp., as for Samples 5 and 6
Talus Slope	5	Northeast margin of Napier Range in vicinity of Carpenter's Gap 1 rockshelter	8.5	5YR 3/3 dark reddish brown	*Adansonia gregorii, Atalaya variifolia, Cochlospermum fraserii, Corchorus sidoides, Ficus platypoda, Fluegga virosa, Grevillea pyramidalis, Harrisonia brownie, Melhania oblongiflora, Triodia* spp.
Vine Thicket	6	Northwest of Carpenter's Gap 1 rockshelter, northeast margin Napier Range	9	10 YR 5/4 yellowish brown	*Celtis philippensis, Diospyros maritime, Ficus* spp., *Stemodia* sp., *Passiflora foetida, Terminalia* spp.
Riverbank	7	Sandy floodbank of Lennard River, Windjana Gorge National Park	7	7.5YR 5/4 brown	*Achyranthes aspera, Arundinella nepalensis, Bothriochloa bladhii, Cenchrus ciliaris, Cyperus javanica, Eragrostis exigua, Ficus* spp., *Heteropogon contortus, Imperata cylindrical, Leptochloa neesii, Mnesithea rottboellioides, Physalis minima, Stylidium flumenense*
Savannah Grassland	8	Black soil plain to the south of the Napier Range, Fairfield Station	8.5	10YR 3/2 very dark grayish brown	*Acacia suberosa, Chrysopogon latifolius, Cymbopogon bombycinus, Hibiscus panduriformis, Iseilema vaginiflorum, Leptochloa neesii, Lysiphyllum cunninghamii, Pteriocaulan serrulatum, Stemodia tephropelina, Streptoglossa odora*
Savannah Grassland	9	Plain abutting the southern margin of the Napier Range, near Tunnel Creek, Fairfield Station	8	7.5YR 3/4 dark brown	*Cymbopogon bombycinus, Dichrostachys spicata, Heteropogon contortus, Hibiscus pentaphylla, Indigofera linifolia, Iseilema vaginiflorum, Leptochloa neesii, Polymeria lanata, Rhyncosia rhomboidea, Senna planitiicola, Solanum beaugleholei, Sorghum plumosum*
Riverbank	10	Sandy floodbank of Barnett River Gorge	6	10YR 3/2 very dark grayish brown	*Acacia tumida, Adansonia gregorii, Bossiaeae bossiaeoides, Brachychiton viscidulus, Calytrix brownie, C. Exstipulata, Distichostemon hispidulus, Drosera burmanii, Eriocaulan cinereum, Germainia truncatiglumis, Grevillea pteridifolia, Hibiscus fryxcelli, Pandanus aquaticus, Senna venusta, Terminalia* spp., *Trachymene didiscoides, Triumpheta bradshawii*
Sand-Dune	11	Adjacent to Blina Swamp, Blina Station	7	7.5YR 5/4 brown	*Abutilon* sp., *Acacia tumida, Adansonia gregorii, Calotis breviseta, Crotalaria cunninghamii, Crotalaria* sp., *Senna notablis, Solanum lucani, Sorghum plumosum*
Swamp	12	Blina Swamp, Blina Station	7	7.5YR 6/4 light brown	*Cyperus* sp., *Drosera indica, Melaleuca nervosa, Schoenoplectus dissachanthus*

SAMPLE TYPE	SAMPLE NUMBER	LOCATION AND DESCRIPTION	PH	MUNSELL	DOMINANT PLANT SPECIES PRESENT IN THE AREA
Savannah Grassland	13	Black soil plain, Gibb River Road	7.5	2.5YR 5/2 grayish brown	*Astrebla elymoides, Chrysopogon latifolius, Eucalyptus grandiflora, E. Microtheca, E. tectifica, Lysiphyllum cunninghamii, Terminalia platyphylla*
Savannah Grassland	14	Black soil plain, Gibb River Road	7	10YR 4/2 dark grayish brown	
Savannah Grassland	15	Black soil plain, Gibb River Road	7.5	10YR 5/2 grayish brown	
Swamp	16	LeLievre Swamp, Camballin Station	6.5	10YR 5/4 yellowish brown	*Arundinella nepalensis, Cyperus* sp.*, Drosera indica, Eragrostis exigua, Schoenoplectus dissachanthus*
Sand-Dune	17	Adjacent to Lanlacatta Swamp, Camballin Station	7	5YR 4/6 yellowish red	*Adansonia gregorii, Byblis liniflora, Cleome tetrandra, Crotalaria cunninghamii, Drosera derbeyensis, Eleocharis dulcis, Eriachne glauca, Ipomoea muelleri, Marsilea* sp.*, Pletrachne pungens, Ptilotus lanatus, Solanum lucani, Stylidium shizanthum, Trianthema pilosa, Utricularia muelleri, Velleia panduriformis*
Sand-Dune	18	Adjacent to Lanlacatta Swamp, Camballin Station	7	5YR 4/6 yellowish red	
Sand-Dune	19	Adjacent to Lanlacatta Swamp, Camballin Station	7	5YR 4/6 yellowish red	
Swamp	20	Richards Pool, Kimberley Downs Station	5	10YR 5/4 yellowish brown	*Caldesia oligococca, Nymphoides* spp.*, Pseudoraphis spinescens, Schoenoplectus praelongatus*
Swamp	21	Richards Pool, Kimberley Downs Station, 5 m from waters edge	5.5	10YR 5/3 brown	
Swamp	22	Richards Pool, Kimberley Downs Station, 10 m from waters edge	6.5	5Y 3/3 olive	
Savannah Grassland	23	60 m from waters edge, Black Swamp, Kimberley Downs Station	6	10YR 6/3 pale brown	*Acacia farnesiana, A. Suberosa, Caldesia oligococca, Chrysopogon latifolius, Nymphaea violaceae, Nymphoides* spp.*, Pennisetum basedowii, Pseudoraphis spinescens, Schoenoplectus praelongatus*
Pindan	24	Gibb River Road	7	5YR 5/4 reddish brown	*Acacia* spp.*, Atalaya hemiglauca, Chrysopogon* sp.*, Dolichandrone heterophylla, Eragrostis eripoda, Eriachne* spp.*, Eucalyptus* spp.*, Grevillea* spp.*, Hakea* spp.*, Pletrachne pungens, Terminalia canescens*
Pindan	25	Great Northern Hwy between Broom and Derby	6.5	5YR 4/6 yellowish red	
Pindan	26	Great Northern Hwy between Broom and Derby	6.5	5YR 4/6 yellowish red	
Pindan	27	Dampier Downs Station	7	2.5YR 4.6 red	
Vine Thicket	28	Southwest margin of Napier Range, Napier Downs Station	8.5	5YR 5/3 reddish brown	*Celtis philippensis, Diospyros maritime, Ficus* sp.*, Terminalia* spp.
Vine Thicket	29	Northeast margin of Napier Range, Napier Downs Station	8	5YR 3/3 reddish brown	

Table 2. Description of phytolith morphotypes utilised.

PHYTOLITH TYPE	DESCRIPTION
Unilobate	A three-dimensional body found in members of the Poaceae, resembling half a bilobate (i.e. a lobe with a small projection).
Bilobate	A three-dimensional body formed by two lobes of approximately equal size joined by a straight edged shank. Described by others as a 'dumb-bell'.
Long shanked bilobate	A variation of the bilobate. A three-dimensional body formed by two lobes of approximately equal size, joined by a straight edged shank whose length is at least equal to or greater than the length of the lobe. Typically found in members of the *Aristida* genus.
Saddle	A three-dimensional body that appears like an ovoid with waisted margins
Rondel	A three-dimensional body formed by a single lobe typically less than 10 microns in diameter, with concave upper and lower surfaces.
Polylobate	A three-dimensional body formed by three or more connected lobes.
Cross	A three-dimensional body formed by four lobes connected at right angles to form a 'cross' like body.
Long angular quadrilateral	A compact three-dimensional body whose four margins are concave; length more than twice height
Short angular quadrilateral	A compact three-dimensional body whose four margins are concave; length approximately equal to height
Stomata	Stomatal complex comprising a pair of guard cells and subsidiary cells located around a stomatal pore
Cuneiform bulliform other (Parallepipedal bulliform cell)	A three-dimensional quadrilateral body. Often a silicified bulliform cell that lacks a 'classic' bulliform morphology, having instead of more quadrilateral appearance.
Trichome	A three-dimensional body with one end tapering to an apex that is typically located off centre, making the body asymmetrical (in contrast to bodies described as 'elongated conical' types, whose body is symmetrical).
Elongated conical	A three-dimensional body tapering to an apex; height typically at least twice the width of the base of the body; surface of the cone is smooth.
Cyperaceae	A three-dimensional body comprising a typically square basal cross-section with a single central echinate node rising from the base; sometimes additional satellite nodes are present. The entire body is often smaller than 20 microns in any direction. Often individual bodies are observed linked to each other forming long chains.
Elongate long cell	Three-dimensional elongated body whose two longest margins are essentially straight; body length is at least twice that of width.
Elongate sinuous long cell	Three-dimensional elongated body whose two longest margins are undulating; body length is at least twice that of the width. Distinguished from elongated quadrilateral plate with sinuous edges by the three-dimensional nature of the body.
Elongate echinate long cell	Three-dimensional elongated body whose two longest margins are characterised by the occurrence of spiny protuberances; body length is at least twice that of width.
Elongate mixed long cell	Three-dimensional elongated body whose two longest margins are characterised by a mixture of straight, spiny and sinuous segments; body length is at least twice that of width.
Elongate ornamented long cell	Three-dimensional elongated body with striate (i.e. raised linear marks) or verrucate (i.e. irregularly shaped, wart-like projections) ornamentation running around or across the body; body length is at least twice that of the width.
Elongate columellate long cell	Three-dimensional elongated body whose two longest margins are characterised by the occurrence of pillar-like protuberances longer than they are broad; body length is at least twice that of width.

PHYTOLITH TYPE	DESCRIPTION
Flat with tuberculate nodes	Two-dimensional flat body which appears to be comprised of adjoining rectangular cells when viewed from above, that have tuber like processes extending from the surface.
Flat irregular	Two-dimensional flat body with an irregular arrangement when viewed from above; derived from epidermal cells.
Flat elongated quadrilateral	Two-dimensional flat body which appears to be comprised of adjoining rectangular cells when viewed from above; derived from epidermal cells.
Flat sinuous	Two-dimensional flat body which appears to be comprised of adjoining, generally rectangular cells when viewed from above. The long margins of the interlocking rectangular cells are gently undulating.
Flat highly sinuous	Two-dimensional flat body which appears to be comprised of adjoining, generally rectangular cells when viewed from above. The long margins of the interlocking rectangular cells are strongly undulating.
Globular psilate	Three-dimensional body whose shape is essentially spherical when viewed in any orientation. The surface of the body is smooth.
Globular echinate	Three-dimensional body whose shape is essentially spherical when viewed in any orientation. The surface of the body is covered in echinate ('prickle') projections.
Globular verrucate	Three-dimensional body whose shape is essentially spherical when viewed in any orientation. The surface of the body is covered in irregular wart-like projections.
Acacia	An irregularly shaped three-dimensional body with verrucate ornamentation.
Irregular blocky with fine echinate nodes	A three-dimensional irregular, through typically somewhat quadrilateral in overall morphology having a combination of sharp and smoothed margins whose surface is covered in fine echinate nodes. Typically observed in vine thicket sediment samples though its plant derivation is unknown as yet.
Elongated conical	A three-dimensional conical body tapering to an apex; height typically at least twice the width of the base of the body; surface of the cone is smooth. Overall the body is typically symmetrical with the apex being centrally located above a circular base.

researchers have tended to construct individual keys for their specific local study area (e.g. Brown 1984 for grasses of the Central United States), resulting in a multitude of keys and non-standardised terminology. Progress has been made in addressing the latter issue in the form of guidelines established by the International Committee on Phytolith Nomenclature (ICPN) (Madella *et al*. 2005; see also Bowdery *et al*. 1998); this terminology was used to describe the phytolith morphotypes in this study. Developing a single classificatory key that can be used by all researchers in all contexts, however, is only partially alleviated by the ICPN guidelines.

Bowdery (1996, 1998) constructed an Australian-based classification scheme based on her studies of phytoliths recovered from central Australian flora and sediments. Her scheme is generally intuitive, simple and easy-to-use and, as such, served as the basis for distinguishing broad categories of phytoliths in the present study (Table 2). Some aspects of her scheme were thought to add an increased level of complexity, without necessarily contributing any additional interpretive information and consequently her additional sub-divisions of morphological categories were not adopted. For example, Bowdery sub-divided bilobate categories on the basis of the shape of the end lobes, i.e. whether they were flat, concave, rounded or a combination thereof, despite such distinctions not corresponding to different species, genera or sub-tribes (Wallis 2000).

As well as phytolith counts, the numbers of burnt phytoliths were recorded (cf. Parr, 2006), along with number of carbonised particles and starch grains, the latter deriving predominantly from tuberous plants (Torrence and Barton 2006). Phytolith analysts also typically record the presence of diatoms and sponge spicules whilst counting as these microfossils are potentially powerful palaeoecological indicators. For example, Piperno (1988:202–210) examined an 11,300 year old sediment core from Panama that recorded a shift in environments from moist tropical rainforest, through to mangrove and then freshwater swamp. The mangrove (marine swamp) phase is apparent in the biogenic silica assemblage by the appearance of abundant sponge spicules and marine diatoms. The development of freshwater swamp conditions is indicated by the continued presence of sponge spicules and a marked change in the diatom types present. In an Australian context Bowdery (1996:216, 226, 230) reported the presence of sponge spicule fragments in sediments from the Puritjarra rockshelter, the Strezlecki dunefields and Allen's Cave (N145) in the arid zone of central Australia, though frustratingly their significance to the assemblages was only mentioned in passing.

Owing to the complexity of the phytolith count data, multivariate statistical analyses were undertaken to allow for easier interpretation of the data. Ordination using principal components analysis (PCA) reduces the dimensionality of complex assemblage data, enabling the most salient features of each sample to be quantified and expressed spatially as graphs (Digby and Kempton, 1987). Ergo, points located close to one another on a graph will have similar phytolith assemblages, whereas points distantly separated in space will contain different phytolith assemblages. The pollen plotting and analysis software package PSIMPOLL (Bennett, 1997) was used to perform the multivariate statistical analyses and produce ordination graphs.

RESULTS

Phytolith percentages by weight

The percentage by weight values of the phytolith fraction of each sample are presented in Table 3 and Figure 2. These range between a low of 0.02% for samples 19 and 26 (from sand-dune and pindan contexts, respectively), and a high of 10.70% for swamp sample 20. Although these data should not be over-interpreted, some trends are apparent. The sand-dune and pindan samples routinely contain the lowest percentages of phytoliths, possibly because material in the typical size range of phytoliths (5-50 µm) has been winnowed from these characteristically sandy sediments. Surprisingly, percentage values for the savannah grassland samples are relatively low, despite their associated vegetation communities being dominated by abundant phytolith producing plants (Wallis 2001). Interestingly, the vine thicket samples consistently contained the highest percentages by weight of phytoliths, around 5%.

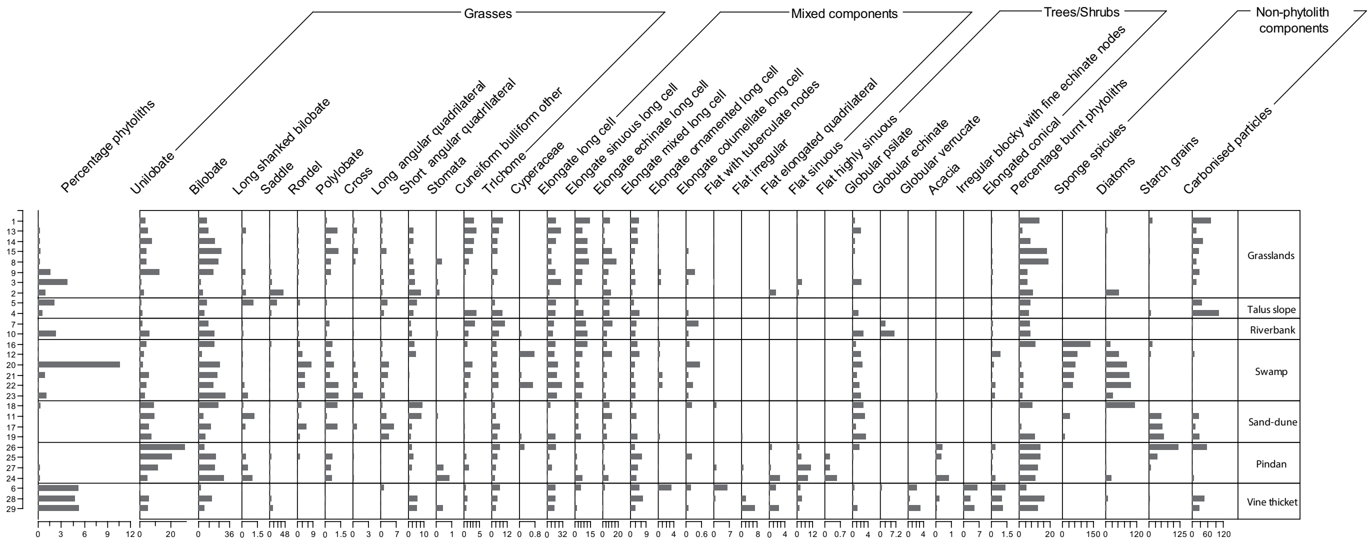

Figure 2. Diagram showing phytolith and non-phytolith microfossil assemblages in modern surface sediment samples. Note that not all categories of phytolith morphotypes are included in this summary diagram.

Table 3. Percentage by weight of phytolith fraction in surface sediment samples.

SAMPLE CODE	CATEGORY	PERCENTAGE PHYTOLITHS
1	Grassland	0.06
13	Grassland	0.30
14	Grassland	0.28
15	Grassland	0.40
8	Grassland	0.30
9	Grassland	1.72
3	Grassland	3.92
2	Grassland	1.10
5	Talus Slope	2.28
4	Talus Slope	0.66
7	Riverbank	0.14
10	Riverbank	2.46
16	Swamp	0.20
12	Swamp	0.16
20	Swamp	10.70
21	Swamp	0.96
22	Swamp	0.22
23	Swamp	1.12
18	Sand-Dune	0.44
11	Sand-Dune	0.04
17	Sand-Dune	0.04
19	Sand-Dune	0.02
26	Pindan	0.02
25	Pindan	0.14
27	Pindan	0.28
24	Pindan	0.34
6	Vine Thicket	5.30
28	Vine Thicket	4.88
29	Vine Thicket	5.38

Savannah grassland sediments

There is nothing especially distinctive about the nine savannah grassland assemblages. The extant vegetation in these locations is predominantly grass with occasional scattered trees and/or shrubs. As such, it was predicted that their phytolith assemblages should be almost exclusively comprised of grass types such as short cells (eg bilobates, rondels etc.) and elongates. While these samples do contain large proportions of grass morphotypes, when compared to other samples it is apparent that these proportions are not especially high; in fact, samples 1 and 3 contain some of the lowest observed frequencies of grass types. Only one sample stands out amongst this group of samples by virtue of a very high frequency of saddles (sample 2), collected from the Napier Range, reflecting the dominance of spinifex in the locale.

Napier Range talus slope sediments

The two samples from the Napier Range talus slopes also lack distinction in their phytolith assemblages. They both have high frequencies of saddles, reflecting the localised abundance of spinifex, but contain no other distinctive types. These samples also have high carbonised particle counts and medium levels of burnt phytoliths, although not so much so that they are demonstrably different from other samples.

Riverine sediments

Despite marked differences in their associated vegetation, the two river margin samples are not especially unique when compared to other samples, though they do display the lowest frequencies of saddles, reflecting the lack of spinifex in the immediate environment. The other phytolith type in these samples worthy of discussion are globular echinate forms derived from members of the Palmae (Piperno, 1988; Wallis, 2003). Although there are palms not far from Barnett River Gorge, there are none in the immediate vicinity of the Lennard River, and hence their presence in the latter sample was unexpected. However, water transportation will have played as much a role in the formation of these assemblages as would have *in situ* decay. As such, their source location will be much wider that for other samples, and it is thus possible that the globular echinate phytoliths derive from the upstream catchment where palms are relatively common. The occurrences of diatoms and sponge spicules in the river samples are negligible, even though an abundance of these microfossils was anticipated.

Swamp sediments

The five swamp samples, whose associated vegetation communities are dominated by Cyperaceae and *Melaleuca* spp., generally lack distinctive phytolith assemblages. The flat rectangular phytoliths with distinct ornamentation which are so abundant and distinctive in modern Cyperaceae specimens (Wallis, 2003) do not survive well in sedimentary contexts, mirroring the findings of Hart (1988). Nevertheless, when the presence of non-phytolith microfossils are also considered, however, these samples are markedly different, with very high levels of sponge spicules and diatoms compared to other samples.

Sand-dune sediments

The four samples collected from sand-dune substrates dominated by *Acacia* spp. and Fabaceae shrubs, and various grasses, also have mundane phytolith assemblages. Whilst Fabaceae members typically produce abundant elongated cones (Wallis, 2003), these do not survive in associated sediments, in line with

Piperno's (1988:163) findings. Some sponge spicules occur in each sample, a phenomenon best explained as reflecting the close proximity of the dunes to swamp habitats. Starch is another microfossil type that is abundant in the sand-dune samples.

Pindan sediments

There is a comparatively high level of diversity amongst the pindan. Pindan vegetation communities are highly distinctive, being dominated by a dense medium storey of *Acacia* spp. Both Wallis (2003) and Hart (1992) have demonstrated the production of varying quantities of irregularly shaped, ornamented phytoliths occurs in some Australian members of the Mimosaceae family, and it was therefore hypothesised that pindan sediments should contain high levels of these phytoliths. However, while some such phytoliths were observed in the pindan samples, they are in extremely low quantities that do not reflect the importance of these plants in the extant vegetation. In fact, their values are so low that it is somewhat difficult to even consider them an indicator of *Acacia*-dominated vegetation communities.

Two of the pindan samples have very high frequencies of unilobates. The principal pindan grass species are *Pletrachne schinzii,Chrysopogon palladus, Sorghum sti poideum* and *Heteropogon contortus* (Kenneally *et al*., 1996:33). In the Kimberley flora, unilobates have been shown to occur most frequently in members of the *Aristida* genus, though they also occur in limited quantities in some members of the *Enneapogon*, *Pletrachne, Chrysopogon,Heteropogon* and *Sorghum* (Wallis, 2000). Given this, the high quantities of unilobates in the pindan samples is probably reflective of the principal grass species in the extant vegetation, although not of *Aristida*, as might be the initial expectation. Large quantities of starch grains also occur in two of the four pindan samples.

Vine thicket sediments

The three vine thicket samples are differentiated from all others by the presence of two distinctive phytolith types: (1) globular verrucate forms derived from members of the Ulmaceae family (Wallis, 2003); and (2) blocky irregular bodies with fine echinate ornamentation whose plant origins are yet to be determined. Additionally, one of the samples also contains reasonable quantities of flat sinuous phytoliths with tuberculate nodes whose plant origins are again as yet unknown. There is little else unique about the vine thicket phytolith assemblage or other microfossils, despite their highly characteristic vegetation communities.

Multivariate analyses

While multiple PCAs with different combinations of phytolith types included or excluded, and also different transformations of the data, were run, similar results were routinely achieved. The PCAs presented below include the initial PCA incorporating all phytolith types with no transformation of the data, and another two that illustrate the differentiation (or lack thereof) of the 29 samples.

PCA 1

PCA 1 incorporated all phytolith types (n=42) for the 29 samples, with no transformation of the data. The resultant eigenvalues show the first and second axes explain 57% of the variation in the dataset (Table 4). Inclusion of the third axis results in explanation of 72% of the variability. When the sample scores are plotted on the first three axes it confirms the general lack of distinction amongst different groups of samples, with considerable overlap (Fig. 3). As shown, there is some separation of three of the four pindan samples on the third axis, caused by high levels of unilobates in these samples, although the clustering is not particularly pronounced.

PCA 2

A second PCA was undertaken using the same dataset with a square root transformation of the data in order to reduce the influence of over-represented types, such as the bilobates, which had primarily been causing the (limited) variance in the previous analysis. In PCA 2 the first and second axes explain 43% of the variability and addition of the third axis raises the cumulative variance explained to 56% (Table 5). As shown in Figure 4, this analysis reveals some clustering of both the pindan and vine thicket samples, although there is still little distinction between the remaining river, swamp, savannah and rocky talus slope samples, which all overlap considerably. Even within the savannah samples there is little cohesion, despite these samples representing relatively similar vegetation groups. A number of phytolith types are responsible for the separation of the pindan and vine thicket samples, these being saddles, flat phytoliths, blocky irregular forms with fine echinate nodes, and globular verrucate forms. The separation of the vine thicket samples on the third axis is also being caused primarily by the blocky irregular ornamented bodies.

PCA 3

In order to achieve further separation between samples a third PCA was undertaken in which the data were again transformed using a square root function, with the six types with the strongest eigenvectors (on the first and second axes) identified in PCA 2 omitted (i.e. bilobates, saddles, elongate sinuous long cells, rondels and short angular quadrilaterals). The first and second axes account

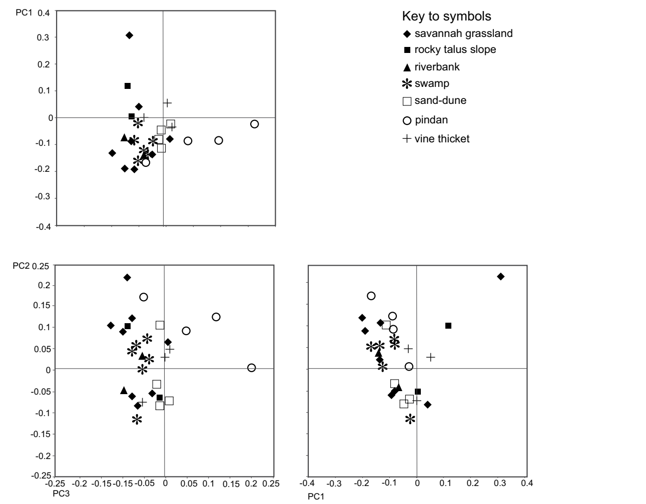

Figure 3. PCA 1: Ordination graphs showing variation amongst modern surface sediment samples (including all variables with no transformation of data).

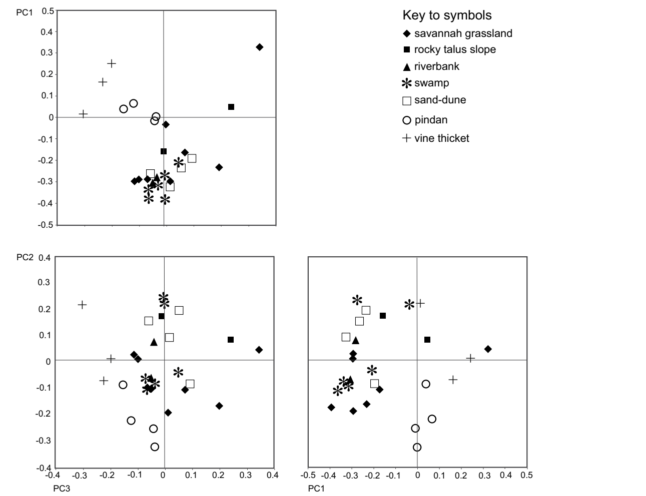

Figure 4. PCA 2: Ordination graphs showing variation amongst modern surface sediment samples (including all variables with a square root transformation).

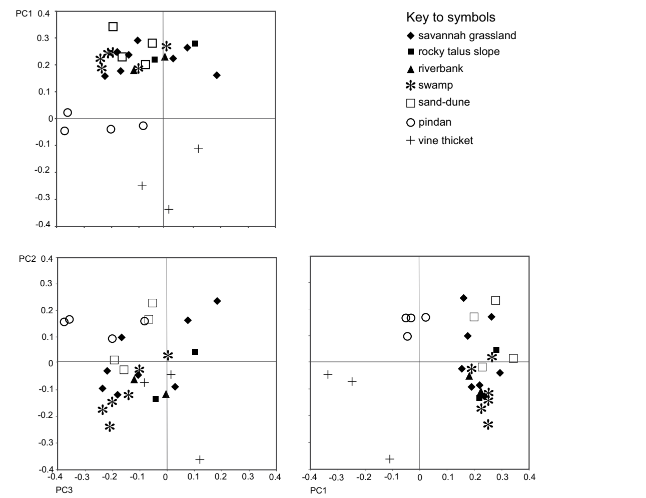

Figure 5. PCA3: Ordination graphs showing variation amongst modern surface sediment samples (exclusion of six over-represented phytolith types with a square root transformation of data).

Table 4. Eigenvalues from PCA 1. * = Interpretable axis.

AXIS	VALUE	PROPORTION EXPLAINED	CUMULATIVE PROPORTION
PC1	0.010548	0.342376*	0.342376
PC2	0.007059	0.229119*	0.571495
PC3	0.004578	0.148608*	0.720104
PC4	0.003024	0.098139*	0.818243
PC5	0.001803	0.058520*	0.876763
PC6	0.001212	0.039331	0.916094

Table 5. Eigenvalues from PCA 2. * = Interpretable axis.

AXIS	VALUE	PROPORTION EXPLAINED	CUMULATIVE PROPORTION
PC1	0.037647	0.273369*	0.273369
PC2	0.022016	0.159868*	0.433236
PC3	0.017306	0.125666*	0.558902
PC4	0.013563	0.098489*	0.657391
PC5	0.009188	0.066719*	0.724110
PC6	0.006337	0.046014	0.770124

Table 6. Eigenvalues from PCA 3. * = Interpretable axis.

AXIS	VALUE	PROPORTION EXPLAINED	CUMULATIVE PROPORTION
PC1	0.027478	0.215073*	0.215073
PC2	0.020853	0.163224*	0.378297
PC3	0.018087	0.141569*	0.519866
PC4	0.012161	0.095186*	0.615052
PC5	0.008773	0.068670*	0.683722
PC6	0.006155	0.048177	0.731899

for 38% of the variation and addition of the third axis raises the cumulative total to 52% in PCA 3 (Table 6), with the pindan and vine thicket samples very clearly separated from the other samples on the first axis (Figure 5). The vine thicket samples are distinguished by the presence of blocky irregular bodies, globular verrucate forms and flat forms with tuberculate nodes, although within the three samples there is not a strong degree of clustering. The pindan samples form a tight cluster separate from all other samples, driven largely by the presence of unilobates.

DISCUSSION

Results indicate that four categories of phytolith types are present in the examined sediments:

1. Redundant types that are common to abundant in most samples and whose frequencies do not differ greatly between samples (e.g. bilobate, some elongates and trichomes);
2. Distinctive types that occur extremely rarely (e.g. long shanked bilobate, cross, cuneiform bulliform other and conical forms);
3. Distinctive types that are generally present in all samples in low quantities, but that can occur in very high frequencies in particular samples (e.g., saddle and unilobate forms); and,
4. Distinctive types with restricted distributions (e.g. globular echinate and verrucate forms, and blocky irregular bodies with fine echinate nodes).

The abundance of redundant phytolith types in most samples generally precludes their being useful in distinguishing between samples, while the very rare occurrences of the second group of phytolith types also limit their usefulness. However, the latter two groups are helpful in identifying differences between samples. In addition, the non-phytolith microfossil data have also proven to be a valuable source of ecological information and are included in the discussion below.

Unilobates occur to some degree in all samples, but are particularly abundant in pindan samples 25 and 26, while saddles are the overwhelmingly dominant grass type in samples 2 and 5 from the Napier Range. Based on data from Wallis (2000), the saddles included in this category are almost certainly derived from spinifex (*Triodia* spp.), which is the dominant plant type on the limestone soils associated with the range.

Globular echinate phytoliths derive from members of the Palmae (Wallis, 2003). They are only present in any quantity in the two samples collected from river contexts. Palms do not occur in the immediate vicinity of these sample locations and it is likely that these phytoliths have been introduced by water movement from upstream where palms are a common element of the vegetation.

Globular verrucate forms are a distinctive morphotype found in the Ulmaceae family (Wallis, 2003). They occur in very low frequencies in the three vine thicket samples and are absent from all other samples. Members of the Ulmaceae are common in vine thickets and their affiliation with vine thicket sediments is therefore not unexpected. Blocky irregular bodies with fine echinate nodes are a type whose species of origin are, as yet, undetermined, and that also occur in all three vine thicket samples. Given their absence from all other samples, it seems likely that this type is derived from an as yet unexamined member of the vine thicket community and hence can tentatively be considered an indicator of this vegetation community.

Flat sinuous phytoliths with tuberculate nodes are another morphotype whose plant origins are unknown. It occurs in some abundance in one of the vine thicket samples (sample 6) though not the other vine thicket samples, which may be a reflection of the smaller size and decreased diversity of the latter patches compared to that associated with sample 6. It also occurs rarely in other isolated samples (e.g., samples 18 and 27).

Unsurprisingly, in this study diatom fragments occurred in consistently high quantities in all five swamp samples. Additionally, they are found in one grassland sample (sample 2), a sample from a sand-dune swale near Lanlacatta Swamp and another sample from a grassland near Black Swamp (sample 23). The high frequencies of diatoms in the samples near swamps are self-explanatory, given that moist conditions are generally the preferred habitat for these organisms. The abundance of diatoms in the sand-dune swale can be explained by the fact that water accumulates in pools in the swale depressions following rainfall events, thereby providing suitable conditions for diatom communities to exist. Three other sand-dune samples, collected from the tops of dune ridges where water does not pool in this manner, contain only minimal quantities of diatom fragments. The abundance of diatoms in sample 23 is explained by this site's proximity to Black Swamp and the fact that the collection site itself experiences periods of waterlogging during the wet season, thereby providing a suitable habitat for diatom communities. There is no obvious explanation for the high occurrence of diatoms in grassland sample 2, though it is possible that the exposure of limestone in this location also provides areas where water can pool after rainfall events and therefore provides microhabitats suited to diatom growth. Diatoms occurred in minimal quantities in all other samples where their appearance is possibly a consequence of windborne transportation from diatom-rich areas. While diatoms might have been expected in abundance in the two samples collected from riverbanks, they were in fact negligible in this samples, probably as a result of their physical fragility.On the basis of these observations, the presence of diatoms can generally be considered indicative of the immediate, or very nearby, presence of standing bodies of water that may, or may not, persist throughout the dry season. There is evidence for their probable transportation by wind across the landscape, albeit at very low frequencies.

The scenario described for diatom occurrence in sediment samples is essentially replicated by that of sponge spicules, which are abundant in all of the swamp sediments. Sponge spicules are also relatively common in the sand-dune sediment collected immediately adjacent to Blina Swamp (sample 28), and additionally are a minor presence in the three remaining sand-dune samples collected in the vicinity of Lanlacatta Swamp. Their presence in such samples is probably due to localised wind transportation from the adjacent swamps. Sponge spicules were either absent or very rare in all other samples, including those associated with the river contexts. The evidence suggests sponge spicules will be abundant in samples collected in or very near slow-running or standing bodies of freshwater that may, or may not, be maintained throughout the dry season. Low quantities of spicules might be expected in locations relatively close to such bodies of water, where the potential for wind transportation over short distances is high. Other locations can be expected to contain extremely limited quantities of these microfossils, with the potential for wind transportation over long distances being apparently low.

Starch grains are present in abundance in three of the four sand-dune and two of the four pindan samples examined, but only rarely in other samples. While starch grains occur in the leaves and seeds of plants (Ridge, 1991:96), they are especially common in root storage organs such as tubers, bulbs and corms (Pate and Dixon, 1982; Torrence and Barton, 2006). Of 14 species of plants recorded in the southwest Kimberley as having edible tubers (Kenneally *et al.*, 1996:18), the preferred habitat of at least nine of these is sandy soil and/or pindan; such plants are not often found in the clay-rich black soil plains. A high level of starch in sediment samples might therefore be taken as being indicative of a sandy substrate.

There are two sources of information on burning in the sediment samples: the presence of carbonised particles (CP) and the percentage of burnt phytoliths (cf. Parr, 2006). Interestingly, there does not appear to be a high degree of correlation between the two. Generally, CP are relatively common in the savannah grassland and Napier Range talus slope samples, and are least common in the river and swamp samples. The remaining groups of samples show a mixture of both high and low CP levels. Burnt phytoliths never account for more than 20% of any sample examined, including those with particularly high CP counts. The savannah grassland samples display a mixture of both high and low percentages of burnt phytoliths, as do the sand-dune and vine thicket samples. The Napier Range talus slope and riverbank samples fall in the medium range of the spectrum. The swamp samples contain consistently low quantities of burnt phytoliths, whilst the pindan samples contain consistently high quantities. It is typically the savannah grasslands that experience regular firing in the Kimberley (Beard, 1969:38) and, on this basis, it logically follows that their sediments should retain evidence of such events, and possibly the highest quantities of burnt phytoliths. As demonstrated, this is not strictly the case, with high CP counts in some, but not all, of the savannah samples and a similar patterning in the percentages of burnt phytoliths. The problems with using CP as an indicator of fire events are well attested to (e.g., Clark, 1983) and may be a contributing factor to the inconsistent results.

Fire is seen by botanists and ecologists as a controlling factor of the pindan communities, where there exists a fire-regeneration cycle of five to seven years (Kenneally *et al.*, 1996:33). It follows, therefore, that the pindan samples should also contain high levels of both CP and burnt phytoliths as indicators of this fire regime. While all four pindan samples do contain comparatively high levels of burnt phytoliths (although not distinctively so), large numbers of CP were only observed in sample 26.

Vine thickets in the Kimberley commonly occur in fire shadows along gorges and thus typically remain unaffected by fire (Clayton-Green and Beard, 1985; Russell-Smith and Dunlop, 1987). The discovery that sediments associated with vine thicket samples 28 and 29 contained high levels of both CP and burnt phytoliths was therefore unexpected. Why this should be the case is not entirely clear. These two patches of vine thicket were very small and their assemblages may therefore contain greater proportions of material derived from the nearby talus slopes and savannah plains than actual vine thicket species, in which case evidence for burning should be high. That the third patch of vine thicket, (sample 6), was much larger in extent and contains very little evidence for burning, offers some support for this possibility. The otherwise general lack of distinction of the vine thicket assemblages may be due in part to the small size of the vine thicket patches, which results in the incursion of phytoliths from the surrounding savannah grasslands overriding the vine thicket signal, or due to their very recent establishment in these locations.

That the swamp and river samples generally contain very few burnt phytoliths and small quantities of CP is, superficially, not surprising since these locations themselves rarely experience fire. However, it is common for swamp sediments to trap at least carbonised particles (e.g. Clark 1983), thus their absence in these samples is unexpected and may relate to the particular sedimentation/accumulation processes occurring locally. In any case, overall the evidence for burning in samples, be it from the presence of burnt phytoliths or CP, is somewhat erratic and meaningful patterning is not easily discerned. Such data has been shown to be of little interpretive value in helping distinguish between different categories of samples.

CONCLUSIONS

Phytoliths in sediments from a variety of ecological settings in the southwest Kimberley, Australia were extracted and examined. While similar studies from elsewhere in the world have oftentimes allowed researchers to clearly differentiate sedimentary phytolith assemblages associated with different vegetation communities, the Kimberley results are not so straightforward, mirroring the findings of Hart (1988, 1992) from southeast Australia. Descriptive and multivariate statistical analyses reveal there is a high level of homogeneity amongst the samples based singularly on their phytolith assemblages, though in some cases the presence of other microfossil types such as starch grains, diatoms and sponge spicules were useful as a means of differentiation. It is possible there is too much vegetation similarity and physical proximity between the sampled vegetation communities to adequately distinguish between their phytolith assemblages, despite this factor not seemingly having led to similar results elsewhere (e.g. Twiss *et al.*, 1969; Kurmann, 1985; Twiss, 1992; Fearn, 1998). As the greater diversity of the Australian flora is demonstrably not reflected in a corresponding increase in the diversity of phytolith types produced (Wallis, 2000, 2003), attempts to characterise vegetation communities on the basis of their overall phytolith assemblage is not straightforward. The discordance between vegetation communities and their associated soil/sedimentary phytolith assemblages suggests issues of production rates in modern plants (cf. Hart 1988, 1992), along with phytolith taphonomy and preservation matters, are particularly important in the formation of phytolith assemblages, and, as such, need to be investigated in order to more accurately interpret fossil assemblages.

It is encouraging to observe, however, that samples from the distinctive vegetation communities of pindan and vine thicket do show some distinctive differences to the other samples, which lends support to the idea that communities with much greater floristic differences than those examined in this study may produce more distinct assemblages. It would be useful to conduct similar investigations using samples collected from more floristically diverse areas, such as the arid zone deserts and the wet tropics to explore this possibility.

In closing, in the Kimberley distinctive phytolith morphotypes, in conjunction with other microfossil types, serve as more useful indicators of particular ecological settings than do full suites of phytoliths in sedimentary phytolith assemblages. This has important implications for the future analysis of phytolith assemblages from archaeological and palaeoenvironmental contexts in this region.

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Quaternary geoarchaeology in the Olympic Dam desert area – a program overview

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ABSTRACT

The stony and sandridge desert near Olympic Dam in South Australia is generating interesting archaeological and palaeoenvironmental results and offers opportunity for additional research in several fields. BHP Billiton has supported a research-based salvage program to mitigate the impacts of a proposed mine expansion. The program covers archaeological investigations within a landscape context and has revealed interesting Quaternary geoarchaeological information. This note outlines the scope and general findings of the program and suggests there is a range of possible Quaternary research that could follow from the information gained in the salvage phase.

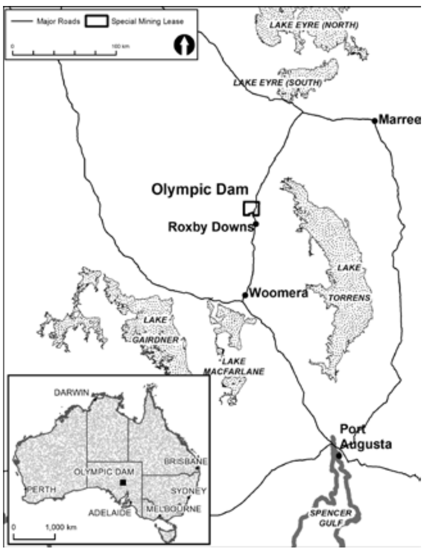

Figure 1. Olympic Dam study area location map (prepared by BHP Billiton Base Metals).

BACKGROUND

This is not a research report, but a note to outline briefly what has become a major program of geoarchaeological research in arid northern South Australia, and to inform the Australasian Quaternary community of the program and the associated research resource. Traditionally environmental scientists and mining companies are not regarded as sharing many common interests, but this is a situation in which the requirements for environmental management overlapped with timely Quaternary research interests, and one that is yielding a rich research resource base.

BHP Billiton deserves acknowledgement for supporting wide-ranging archaeological research when probably they could have met their legal obligations by commissioning less than has been done. As part of mitigation of environmental impacts of their proposed expansion of the Olympic Dam mine, they commissioned Huonbrook Environment & Heritage P/L(HEH) – working with archaeologists from the Australian National University and Sydney University, and dating specialists from the Institute for Photonics and Advanced Sensing at the University of Adelaide – to undertake an archaeological survey, salvage and research program over seven years, with encouragement to publish the findings (see Hughes *et al.*, 2011).

PROGRAM SETTING

The stony and sandridge desert near Olympic Dam in South Australia is not (yet?) an iconic Quaternary site but the ability to look at its extensive archaeological resources in a context of Quaternary landscape change, means it is generating interesting archaeological and palaeoenvironmental results and offers opportunity for additional research in several fields.

Following early surveys an environmentally-based predictive model (Hughes and Hiscock, 2005) using terrain patterns based on landform types and geology was demonstrated to be robust in predicting the locations and frequency of 'campsites', which are strongly associated with sand dunes to 'camp' on, sources of water, ease of moving across the landscape and the availability of different rock types for making stone artefacts. In 2009 BHP Billiton submitted an Environmental Impact Statement for the proposed expansion of its existing mine (ARUP/ENSR, 2009). The Olympic Dam Agreement between BHP Billiton and the Barngarla, Kokotha and Kuyani native title claimant groups specified a range of archaeological investigations to mitigate the impact of the expansion. This included a complete survey of the whole 600 km2 application area (not all of which will be impacted) and subsequent salvage work to be determined on the basis of that survey. Using hand-held GIS-enabled computers with recording forms, HEH undertook the survey during 2007, 2008 and 2009, with the team members spaced on average 15m apart walking a total of about 40,000 km, and recorded data on ~16,000 archaeological sites. A detailed description of the survey methods and protocols used, and the results obtained, is included in Hughes *et al.*, (2012).

After the survey phase BHP Billiton agreed to support a research-based salvage program and advised relevant government agencies of that decision. The salvage program was designed to run for four years from mid 2010, so the research would not be compromised by mine development, and the program covered ~160 sites selected for their special scientific values.

The Olympic Dam area is representative of the pattern of prehistoric land use in arid northeast South Australia (and wider afield). The sandridges on which many of the sites occur are of quartz sand with low radiation signals, so are excellent for optical dating, mainly using single-grain Optically Stimulated Luminescence (OSL). Stone artefact layers provide evidence of exposed sand surfaces, act as markers of dune stratigraphy, and facilitate the interpretation of dune evolution.

PROGRESS SUMMARY AND ADVICE ON INFORMATION NOT YET PUBLISHED

- A report to BHP Billiton on the survey phase has been presented to government agencies and the three Aboriginal communities, and while not published, is available (Hughes *et al.*, 2012). This covers patterns of archaeological site occurrence and content in a landscape context, and details of methodologies, protocols and background findings.
- Surface and shallow subsurface excavations have been completed at all salvage sites.
- A PhD project on chert and quartzite knapping floors is at the final write-up stage, with those sites analysed. A PhD project on hearths which will include research on food residues and on dating of hearthstones, commenced in 2012.
- The archaeological material collected for scientific study, now and in the future, is about half a million artefacts (they fill two large shipping containers). The salvage sites have been catalogued and packed to museum standards.
- It is proposed to move the research collection to the South Australian Museum once a management agreement has been reached with the three Aboriginal communities, for long-term curation and for research access.
- Separate 'display collections' have been managed by the Aboriginal archaeological assistants involved in the program, and displays are established at the mine site, in Roxby Downs and in Port Augusta.
- Artefact measurements and analyses have commenced on selected sites. These analyses are designed to i) measure the magnitude and nature of assemblage variation across the landscape and to understand that variation in terms of behavioural ecology of desert land use, ii) comprehend the technology and economics of raw material supply and artefact production in different parts of the landscape, and iii) identify the changes in those archaeological patterns and human behaviours over time.
- More detailed patterns of site locations and characteristics have been analysed further using ArcGIS.
- To date the sediments that demonstrate particular aspects of dune development or that contain distinct occupation layers, more than 70 samples have been optically dated.
- There are Holocene optical dates on sediments associated with artefact layers eroding from dunes and a few of terminal Pleistocene ages on deeper layers. Human occupation of the desert area appears always to have been episodic. Periods of use in the Pleistocene correspond generally with wetter climatic periods. At least three separate periods of occupation can be identified from the late Holocene by which time people had adapted to the desert environment.
- Optical dating indicates that dune formation extends back to ~150ka and demonstrates that the dunes have re-formed on the same basic locations and alignments through past erosional and rebuilding phases.
- Members of the salvage program team are continuing to pursue several specific geoarchaeological research questions. A summary of the findings will be included in the overall salvage report to BHP Billiton which will be completed in 2014, and will form the basis of further publications, BUT our project scientific investigations (including material published recently, submitted for publication, and ongoing investigations which include PhD, Masters, and Honours projects) will certainly not exhaust the potential for a range of archaeological and wider-ranging Quaternary research.
- The collections and related data are accessible now and it is proposed that they will be available now at Olympic Dam and later through the South Australian Museum for student projects or other forms of research in the future.

TOP – Figure 2. Collection of sub-surface artefacts from 1 m grid squares on Site H299, an artefact scatter in a shallow blowout on a longitudinal dune at Olympic Dam. The dunes here are widely spaced and the swales have small pans and patches of gibber. (Photograph HEH).

MIDDLE – Figure 3. Piece-plotting and collection of artefacts from multiple knapping areas adjacent to large silcrete blocks that were quarried on Site H347, an extensive pan between two widely spaced dunes at Olympic Dam. Peter Hiscock in the foreground. (Photograph Jo Thredgold, HEH).

BOTTOM – Figure 4. On some dune sites, especially those with buried artefact layers, such as this site (H366) a small tracked excavator was used after the hand excavations, to dig to about 4m into the dunes. Sand samples for optical dating were taken from the exposed profiles. (Photograph HEH).

THE SALVAGE COLLECTION OFFERS SCOPE FOR FURTHER OR DIFFERENT RESEARCH

If any Quaternary scientists are interested in accessing material from the program, or in undertaking any specific research that might build on the basic geoarchaeological information that the program has provided, any of the research coordinators named here would be able to provide advice, specifically:

- On landscape information and site-landscape links: Drs Philip Hughes and Marjorie Sullivan, HEH, as above.
- On stone artefacts and related analyses: Professor Peter Hiscock and Tom Austen Brown Professor of Australian Archaeology, Department of Archaeology, School of Philosophical and Historical Inquiry, Faculty of Arts and Social Sciences, University of Sydney.
- On dating/issues relating to chronology: Adjunct Professor Nigel Spooner, Institute for Photonics and Advanced Sensing, School of Chemistry and Physics, University of Adelaide, and Defence Science and Technology Organisation, Edinburgh SA
- On access to the artefact collections and catalogues now, HEH or Peter Hiscock, and after they are moved to SAM: Dr Keryn Walshe, Researcher in Archaeology, South Australian Museum, Adelaide.

We hope to return to Olympic Dam in 2014 or 2015 to carry out further limited excavations at a few of the geoarchaeologically most important sites we have worked on. If people have interesting ideas on additional samples/ data we should collect during these excavations we would be keen to hear from them. For example, we have not tested the potential of the dune sands to contain microfossils such as phytoliths, nor have we examined in detail their mineralogy or geochemistry. We have not examined artefact residues. We are interested in learning more about the rates of down-wasting of the gibber plains on which the dunefields have formed and a program of cosmogenic dating of some of the outcrops of large almost unweathered silcrete and quartzite boulders on these plains could inform this. There may also be potential for trialing TL dating of gibber rocks.

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The contribution of Quaternary scientists to developing iconic sites in Western Australia

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INTRODUCTION

In the recent issue of Quaternary Australasia, a number of iconic sites for Australia were put forward (Fitzsimmons, 2012). These sites were considered to 'have played an important role in helping us understand the major landmarks, both geographically and within the history of our science.' (Fitzsimmons, 2012:14). However, it is not just the sites that are important but also the Quaternary scientists who have helped us understand particular regions from these landmark sites.

The original article presented only the iconic site of Devil's Lair in the west of the continent. The geographic and probable research bias towards southeastern states was acknowledged (Fitzsimmons, 2012:14). This paper augments the list of sites for Western Australia (WA) to give a broader perspective to what was started earlier. In the spirit of the original article, an attempt has been made to narrow the list to around 20 sites (Figure 1) and I equally hope that it provokes further healthy debate amongst the Quaternary community.

KIMBERLEY

The global geoheritage significance of the Kimberley coast, as a large scale tropical ria coast with a local archipelago (the Buccaneer Archipelago) and a distinct suite of coastal sediments, is comprehensively outlined by Brocx and Semeniuk (2011a). A conservation document for the Kimberley marine environment specifically identifies nine iconic places along the Kimberley coast, of which King Sound and the Fitzroy River delta were marked out for their Quaternary geology (http://issuu.com/kimberley.wilderness/docs/the_kimberley_coast__nine_iconic_places).

Extending from the mouth of the Fitzroy River on the rocky west Kimberley coast, **King Sound** (Figure 1) formed when rising sea levels flooded the coastline at the end of the last Ice Age around 12,000 years ago (Semeniuk, 1980). The Fitzroy River delta has the largest tidal range (maximum tidal range 11.5 m) of any tide-dominated delta in the world (Brocx and Semeniuk, 2011b). These high tides have allowed unique and complex Holocene intertidal facies to develop against a sharp contact of relict (Pleistocene) desert dunes (Jennings, 1975; Semeniuk, 1980; 1982), which provides important information on deltaic sedimentation and geomorphic change, post-glacial sea-level rise, Pleistocene aridity and climate change (Semeniuk and Brocx, 2011b and references therein). For the human element, King Sound also preserves fossilised human footprints (Burke, 2011) providing the only evidence of early human tracks on Australia's west coast and a possible link with Southeast Asia when global sea levels were lower.

The Kimberley is also well known for its iconic Gwion-Gwion and Wandjina rock art, set against the striking backdrop of King Leopold and Oscar Napier Ranges. In particular, **Carpenter's Gap** (O'Connor, 1995) and **Riwi** (Balme, 2000) not only demonstrate the earliest 'art' in Australia's cultural history and the earliest evidence of ornamentation (Dentalium beads) but also economic networks over distances of 500 km and continuous occupation and over the last 40 ka. Palaeoecological studies at Carpenters Gap (McConnell, 1998; Frawley and O'Connor, 2010; Wallis, 2001) also provide rare evidence of plant procurement strategies used by Aboriginal people from the Pleistocene, through the Last Glacial Maximum (LGM), a period when many occupation sites were abandoned across Australia, and into the Holocene, while also contributing to our understanding of the impacts of climate change on flora. Justifiably this range has been the focus for the Lifeways of First Australians project (http://www.kimberleyfoundation.org.au/lifeways-of-first-australians).

Inland from the Oscar Napier Range is the **Gregory (Mulan) Lakes** (Figure 1). The Gregory Lakes are a series of terminal freshwater lakes on the semi-arid, northern margins of the **Great Sandy Desert** in northwestern Australia. Fed by monsoon streams, interdigitating fluvial and lacustrine sediments in these lakes provide a record of palaeomonsoon variability over the last 300 ka (Bowler *et al.*, 2001; Wyrwoll and Miller, 2001; Veth *et al.*, 2009; Fitzsimmons *et al.*, 2012). The activity of desert dune systems within the Lake Gregory

Figure 1. Map showing the location of iconic sites and other key sites for Western Australia.

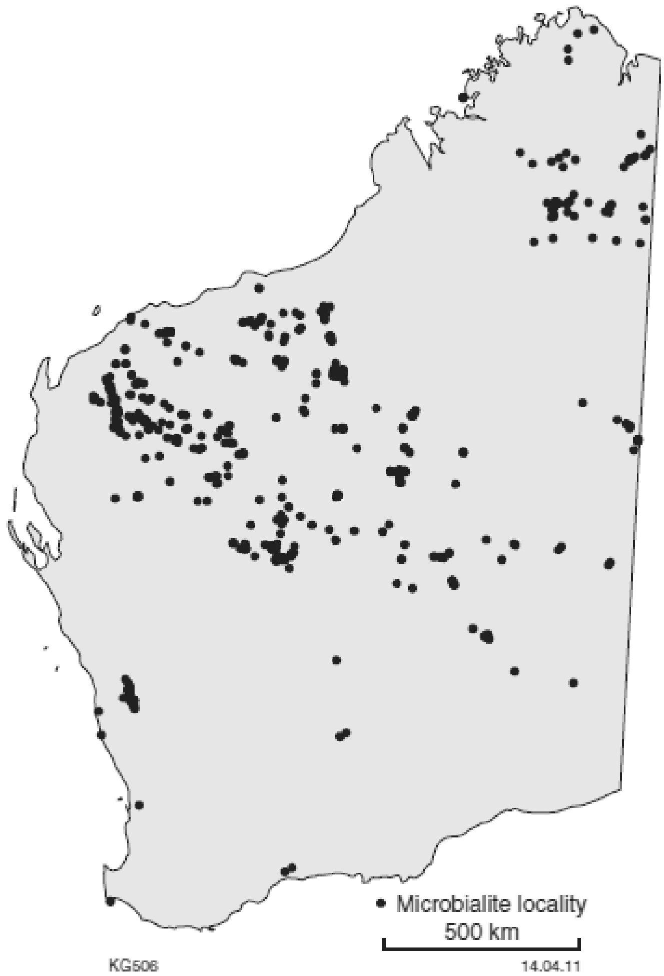

Figure 2. Location of fossil stromatolites across Western Australia. Source: Department of Mines and Petroleum, 2013.

catchment provide additional data to support the fluvial and lacustrine records for periods of increased aridity between ~35 – 11.5 ka (Fitzsimmons *et al.*, 2012) and again from 5 ka (Wyrwoll and Miller, 2001; Fitzsimmons *et al.*, 2012). Whilst these records may reflect local aridity or hydrology (although local may ultimately reflect regional trends, e.g. see Wyrwoll *et al.*, 1992), they nevertheless provide an important Late Quaternary palaeoclimatic record for the arid (Hesse *et al.*, 2004; Fitzsimmons *et al.*, 2013) and tropical (Reeves *et al.*, 2013b) regions of Australia where data are rare or non-existent.

From the human element, Lake Gregory represents the WA equivalent of Lake Mungo. The freshwater lake ecosystem was a focal point for Late Pleistocene hunter-gatherers as early as 45 – 50 ka years ago (Veth *et al.*, 2009). **Puntutjarpa** is another critical site for understanding the adaptive lifeways of desert foragers in the Western Desert from the terminal Pleistocene (Gould, 1977; c.f. Veth, 1995; Smith, 2005). One point of difference, as pointed out by Veth *et al.* (2009), is that Lake Gregory is still active and therefore still able to tell us more about lake responses in relation to changing climates.

The characteristic dunefields of WA's **Great Sandy Desert** may be singled out not only for their contribution to the regional palaeoclimatic records, as outlined above (see also Wyrwoll *et al.*, 1986; 1992a, b), but also to the movement of desert people in response to the changing palaeoenvironmental conditions in the late Pleistocene (Veth *et al.*, 2009). As indicated by Fitzsimmons (2012), it is the desert dunefields that attain iconic status in the arid heartland for their contribution both to palaeoclimate and geochronology.

PILBARA REGION

The iconic Pilbara in northwestern Australia is another ancient and important region of biodiversity, endemism and refugia (Pepper *et al.*, 2008). Like the Oscar-Napier Range, the Hamersley Range has a number (> 17) of Pleistocene-age rock shelter including several > 30 ka (e.g. Maynard, 1980; Marwick, 2002; Slack *et al.*, 2009; Hughes *et al.*, 2011). However, in terms of helping to reveal early occupation and human resource use of the Late Pleistocene landscape, **Mandu Mandu** in Cape Range (Figure 1) has perhaps been more significant. Evidence from Mandu Mandu and nearby rock shelters and shell middens on the Cape Range Peninsula indicate that Aboriginal people have lived and exploited the **Ningaloo** coast for over 30,000 years (Morse, 1988; 1993; Przywolnik, 2008). The word 'Ningaloo' itself is an Aboriginal word that means a 'promontory' of high land jutting into the sea.

The **Montebello Is.** and **Barrow Is.** complex (Veth, 1994; 2007) similarly provide an exceptional record of indigenous occupation dating back about 45 ka and evidence for continued use of coastal resources until ~7.4 ka (Veth 2007). An emerging picture from these islands and the nearby **Dampier Archipelago** provides a record of peoples' responses to changes in sea level (McDonald and Veth, 2009; McDonald, 2011; Mulvaney, 2013) and of the submerged landscape itself (Ward *et al.*, in press). This story of sea-level change is uniquely depicted in the iconic rock art of the region and in particular the Burrup Peninsula (Mulvaney, 2013), a site that has achieved outstanding heritage status and which has also been put forward for World Heritage Status (McDonald and Veth, 2009; McDonald, 2011). All of these island groups have enormous potential for reconstructing human and environmental histories for northwestern Australia from its earliest occupation.

Adding to our understanding of late Quaternary palaeoenvironment and palaeoclimate in this region are the pollen (van der Kaars and De Deckker, 2002; 2003; van der Kaars *et al.*, 2006) and benthic foraminifera records (Murgese and De Deckker, 2007) from over 38 marine cores taken along the WA coastline. Of these, one core **FR10/95-GC17** may be singled out. Gravity core FR10/95-GC17 was collected 60 km west of Cape Range Peninsula from a water depth of 1093 m (Murgese and De Deckker, 2007) (Figure 1). With a continuous record spanning the past 45 ka, it is one of the most intensively studied deep-sea cores from the Australian region, with past investigations including changes in mineralogy (De Deckker, 2001; Gingele *et al.*, 2001; M. Sloan in Olley *et al.*, 2004), pollen (van der Kaars and De Deckker, 2002), and other marine microfossils (Martinez *et al.*, 1999; Takahashi and Okada, 2000; Murgese, 2003), in addition being used to demonstrate the viability of optical dating for deep-sea sediments to the last 500,000 years (Olley *et al.*, 2004). Marine core FR10/95-CG17 lies within the northwestern aeolian dust pathway, and both the dust and pollen records reveal a shift to drier vegetation during and following the LGM, returning to wetter vegetation after 14 ka, mirroring the record from Lake Gregory (Wyrwoll and Miller, 2001; Hesse *et al.*, 2004). Marine core FR10/95-CG17 has been critical in providing information for understanding palaeoclimate both on the regional and hemispheric scale.

If the Great Barrier Reef is marked out as an icon of Australian ecology and tourism (Fitzsimmons, 2012) then arguably so can the World Heritage site of **Ningaloo reef**. Ningaloo Reef is Australia's largest fringing coral reef, extending along 280 km of coastline. It supports a huge diversity of 'iconic marine species' (DEWHA, 2010: 68) including whale sharks, migratory humpback whales and a number of endangered and vulnerable marine creatures. As outlined by DEWHA (2010), the outstanding value of the Ningaloo coast derives from its functionally integrated reef and karst system lying along an arid coastline and its rich record of past life and landscapes.

The reef ecosystems here record a rich archive of past climate variability over the past 200 years (Kuhnert *et al.*, 1999; 2000). The well-defined fossil reef terraces extend further to the Plio–Pleistocene (Veeh *et al.*, 1979; Kendrick *et al.*, 1991). The terrace deposits at Ningaloo are one of several representative sites for the Last Interglacial (MIS 5e) sea level highstand (O'Leary *et al.*, 2013). Located half-way along the WA coastline, the Ningaloo terraces are also central to the unanswered question of a tectonically stable coastline (see also Wyrwoll *et al.*, 1995; O'Leary *et al.*, 2013 and references therein), which has both continental and global connotations.

GASCOYNE (CARNARVON COAST)

Notable along the Carnarvon Coast, is the World Heritage site of **Shark Bay** (Figure 1). From a geologic and geomorphic perspective, the region hosts Quaternary coastal, near-coastal, and marine landforms, and a wealth of geological, geomorphic, sedimentologic and tectonic features (Logan & Cebulski, 1970; Playford 1990; Brocx and Semeniuk, 2007).

Shark Bay was formed in the last two million years from a combination of sea-level change and sediment deposition, beginning with the **Peron Sandstone** (forming the Peron Peninsula) and subsequently the Tamala Limestone (forming the **Zuytdorp Cliffs** and Dirk Hartog Is.) (Logan *et al.*, 1970; Playford, 1990). Both the Peron Sandstone and the Tamala Limestone at Zuytdorp Cliffs are highlighted by Brocx and Semeniuk (2010) as classic (type) sites for stratigraphy.

The present shallow water environment developed during the last ice age, when the land was flooded and sediments trapped by seagrass meadows created underwater barriers, resulted in the hypersaline lakes and marine lagoons in which are now found living stromatolites (Logan *et al.*, 1974). **Hamelin Pool** and **Lake Clifton** in the South West (Moore, 1993) (Figure 1) are two of only four places on Earth (the other two in the Bahamas) where living marine stromatolites occur. WA is a world leader in stromatolite biostratigraphy, with one of the most continuous and best-studied records of fossil stromatolites recorded across nearly 46 % of the state and representing most periods of geological time (Figure 2, from DMP 2013).

MID WEST

Adding to our understanding of sea-level change are the coral records from the **Houtman Abrohlos Islands** (Fairbridge, 1948; 1961; Collins *et al.*, 1993; 2004; 2006; Eisenhauer *et al.*. 1993; Zhu *et al.*, 1993; O'Leary *et al.*, 2013). These records have been instrumental in resolving both the timing (~127 – 119 ka) and level (+ 3 – 4 m) of the Last Interglacial (MIS 5e) (O'Leary *et al.*, 2013) and mid-Holocene sea level highstands (~6.4 ka, + 1 – 2 m) (Eisenhauer *et al.*, 1993; Lewis *et al.*, 2012). These records not only provide important regional comparisons with other parts of the WA coast where data is generally scarce (Lewis *et al.*, 2012 and references therein) but also as an important reference point for global sea level (Eisenhauer *et al.*, 1993; O'Leary *et al.*, 2013).

Another iconic site within the Houtman Abrolhos Islands is the **Batavia wreck** site. The wreck of the Batavia was found in 1963, 300 years after it was wrecked on Morning Reef (Leys, 2006). The wreck of the Batavia and others like her prompted the Dutch East India trading company to make accurate charts of the coastline and ultimately helped put Australia on the world map.

Inland, the heritage record for the mid-west region is little known or largely forgotten. **Wilgie Mia** ochre mine in the Weld Range is the largest, deepest and probably oldest underground Aboriginal ochre mine in Australia (Winton *et al.*, 2010). Evidence indicates that the Wilgie Mia has been a source for red ochre traded over large distances, perhaps as far as Western Queensland (Woodward, 1914; Clarke, 1976; Crawford, 1980), contributing to our understanding of prehistoric links across the continent.

Within the same region as Wilgie Mia are the sites of **Ballinu Spring** and **Billibalong Spring** (Figure 1). Although there are numerous sites containing megafaunal remains in WA (Dortch, 1984; Grün *et al.*, 2008; Turney *et al.*, 2001; Prideaux *et al.*, 2010), it was the discovery of a diprotodontid (Zygomaturus trilobus) mandible in the cemented sediments at Ballinu Spring that prompted Duncan Merilees (1968) to first set up the hypothesis of 'Man the Destroyer'. Subsequent discoveries of Zygomaturus at Billibalong Spring (Balme, 1979; Bordes *et al.*, 1983) and further south at Greenough River (Wyrwoll and Dortch, 1978) in similar sediments supported the conclusion that Homo sapiens and at least one species of megafauna were contemporaneous in southern WA. It is almost surprising that this iconic site has been so forgotten in current debates of Pleistocene mammalian extinction, ruled out because of the dynamic nature of the alluvial depositional environment and the absence of articulated remains (Roberts *et al.*, 2001). Although it is likely that the fossil and artefact material are not in primary context within these alluvial sediments, the chronology of the embedded fossil and archaeological material still has great potential to yield unique information regarding the human and faunal antiquity of the Murchison region, and to also contribute to the debate on megafaunal extinction in Australia.

SOUTH WEST

Devil's Lair was the only WA site identified in Fitzsimmons (2012) list of iconic sites for its record of human antiquity. It also preserves an important record of megafauna (Balme *et al.*, 1978) and is a key site for ancient DNA research (Oskam *et al.* 2010; see also http://media.murdoch.edu.au/murdoch-researchers-to-probe-ancient-dna-at-devil%E2%80%99s-lair). Another important archaeological site is **Rottnest Is.** (Figure 1). Although few in number (6), the fossiliferous chert artefacts found in Tamala Limestone paleosols on Rottnest Is. (Dortch and Hesp, 1994), along with a further three found on Garden Island (Dortch, 1991) and one at Point Peron (Dotch and Dortch, 2012) indicates wide ranging human movements on this part of the emergent continental shelf during the Late Pleistocene and Early Holocene. These finds also highlight the archaeological potential of the Tamala Limestone coastal cliffs and all along the Indian Ocean coast (Dortch and Morse, 1984; Dortch and Hesp, 1994).

The Tamala Limestone is not only important from a regional archaeological perspective but also from a geological one, particular in regard to Quaternary sea-level change (Teichert, 1950; Fairbridge, 1954; 1961). Raised and submerged notches in the Tamala Limestone cliffs at **Shark Bay** (Fairbridge, 1950), **Rottnest Is.** (Fairbridge and Teichert, 1953) and the **Abrolhos Is.** (Fairbridge, 1948) were used in Fairbridge's (1961) sea-level compilation for global eustatic sea-level change (Lewis *et al.* 2013). A more recent study uses emergent shoreline data from Fairbridge Bluff on **Rottnest Is.** as central evidence for global ice sheet collapse at the end of the Last Interglacial (MIS 5e), ~118,000 years ago (O'Leary *et al.*, 2013).

Phil Playford (1983; 1988) subsequently revised Fairbridge's (1961) interpretations arguing that whilst the Pleistocene sea-level changes that ultimately severed Rottnest Is. from the mainland could be attributed to global eustatic events, the Holocene highstands evident on the island could not. However, despite important work on this issue (e.g. Lambeck and Nakada, 1990; 1992; Semeniuk and Searle, 1986; Playford, 1988) it remains uncertain whether the changes in relative sea-level evidenced on Rottnest Is. are local or regional. Quaternary sea-level change remains a recurrent theme along the WA coast but the sea-level database for the west of the continent remains relatively poor in comparison to the east (Lewis *et al.* 2012), which makes sites like Rottnest Is. all the more significant.

A number of other geoheritage sites have also been identified in the South West including the Swan Coastal Plain (Semeniuk and Semeniuk, 2001), the Leschenault Peninsula and its leeward estuarine lagoon (Brocx and Semeniuk, 2011c), and the Walpole-Nornalup Inlet (Semeniuk *et al.*, 2011). Indeed for every region outlined above, numerous additional sites could have been added to those outlined, indicating that WA is far from short of Quaternary iconic landmarks (Brocx and Semeniuk, 2007; 2010; Pillans, 2007; Newsome *et al.*, 2012).

CONCLUSION

It is clear from this brief overview that WA has a wide range of iconic Quaternary archaeological, geomorphic and geoheritage sites, extending from the continental shelf to the arid interior. Some of these have not only contributed to a greater scientific understanding of the region and continent, but in some cases also to global change (Brocx and Semeniuk, 2007; 2010).

Quaternary scientists such as Rhodes Fairbridge, Phil Playford, Brian Logan, Vic Semeniuk, Karl-Heinz Wyrwoll and Charlie Dortch were instrumental in providing the founding research for many of these sites. Current and future Quaternary scientists will no doubt reveal more from the islands of the Pilbara, the archaeological sites in the West, and the less researched parts such as the Goldfields-Esperance region. As stated by Sandra Bowdler (1987:8): 'those vast distances contain vast untapped resources and there are undoubtedly many exciting (and iconic) discoveries just waiting to be made.'

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COST INTIMATE Spring Meeting

28-30 APRIL 2013, BLAIR ATHOLL, SCOTLAND

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The annual Spring meeting of the COST INTIMATE (European Cooperation in Science and Technology Integration of Marine, Atmospheric and Terrestrial Records) was held in April at Blair Atholl Castle, Scotland. Over 100 delegates (42 female, 58 male; of whom 36 were early career researchers) representing institutes across Europe attended the meeting, which aimed to discuss, update and collate records of palaeoenvironmental variability in the North Atlantic region for the period 80,000-6,000 years BP. I was fortunate to receive funding from the Australian Academy of Science to attend the meeting. My role was to present the current state of "palaeo" research in Australia and New Zealand. This included the recent work completed by the OZ-INTIMATE group (led by Jess Reeves and Tim Cohen) and the upcoming SHAPE (Southern Hemisphere PalaeoEnvironments) project (led by Drew Lorrey and Stephen Phipps).

Talks were held in the magnificent dining room of Blair Atholl Castle, where we were looked down on by hundreds of stags' heads, hunted over hundreds of years by the local gentry. After an introduction by organisers Simon Blockley (Royal Holloway, University of London) and Sune Olander Rasmussen (University of Copenhagen), each of the four INTMATE Working Groups presented progress reports. The remainder of the meeting was a mixture of individual Quaternary

TOP – Figure 1. Blair Atholl Castle.

MIDDLE – Figure 2. The dining room during the meeting.

ABOVE LEFT – Figure 3. Stags' heads watching over us.

ABOVE RIGHT Figure 4. Quaternary scientists' version of highland dancing.

LEFT – Figure 5. Delicious local cuisine.


Figure 6. The River Tilt, from two perspectives.

talks and specifically themed breakout sessions. Twenty-six oral presentations and 29 posters were delivered, covering the full spectrum of marine, terrestrial and ice-core records.

Towards the end of the meeting, we discussed scientific planning and strategy for the remainder of the COST INTIMATE lifetime. We agreed for the focus to be on upcoming meetings for collaboration between researchers. In addition, proposals for two special editions (Quaternary Science Reviews and Quaternary International) were presented. A key outcome of this part of the meeting was the identification of the poor relationship between Quaternary scientists and the public. Increased interaction and better communication between the two groups, particularly with respect to the dissemination of scientific findings (and their significance), was identified as needing to be urgently addressed.

Meals each night were served in the local pub, which provided superb local cuisine including some rather tasty haggis, venison, cock-a-leekie soup and, of course, the local brews.

The conference dinner itself was held in the castle. As we approached the entrance we were greeted by a Scotsman in traditional kit playing the bagpipes. The evening started with pre-drinks in one of the beautiful private rooms of the castle, after which we were led in precession by the piper downstairs to the dining room. After dinner, the outstanding career of retiring scientist John Lowe was recognised and celebrated with speeches and toasts of whiskey. Following this, the tables were cleared from the dining room, to provide room for traditional Scottish dancing to a live highland band. There are few things more hilarious than 90-odd Quaternary scientists (at varying degrees of inebriation) trying to learn highland dancing. At one stage the lead singer, who was (trying) to teach us the steps, completely broke down, saying “I don’t even know what you guys are trying to do”. A personal highlight for me was when my partner flung a bit too hard, and ended up sliding across the wooden floor on his stomach about 5 m, stopping only when he ploughed head-first into a table. Not a reflection of my own dancing skills of course.

All in all, it was a very interesting (and entertaining) meeting. The Europeans are fortunate to have predominantly continuous records (e.g. unlike the arid interior of Australia) and the advantage of the close proximity of the Greenland ice core records. As such, the North Atlantic INTIMATE group don’t face the same sorts of challenges that we face in Australasia. However, there are certain features of the work presented from Europe which are extremely relevant to our own region. For example, the age control and temporal resolution of the records presented was simply staggering, and is something we need to consider before drawing too long a bow in comparisons between our own records. Although the Europeans have had somewhat of a head start in terms of sheer numbers and funding, I think that the Quaternary community of Australasia can look to aspects of the research of our Northern Hemisphere counterparts as a benchmark for our own future directions.

Conference on Australasian Vertebrate Evolution, Palaeontology and Systematics (CAVEPS)

14TH MEETING, FLINDERS UNIVERSITY, ADELAIDE, SOUTH AUSTRALIA

30 SEPTEMBER TO 4 OCTOBER 2013

Main report: Elen Shute,School of Biological Sciences,Flinders University,Adelaide,South Australia 5042
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Kangaroo Island field trip: R. Esmée Webb,School of Natural Sciences,Edith Cowan University,Joondalup,Western Australia 6027

This year marks the 60th anniversary of R.A. Stirton's first expedition to central Australia in search of Tertiary fossil mammals. The 1953 University of California/South Australian Museum expedition, and those that followed it, laid the foundations of Australian vertebrate palaeontology into the modern era, and so this anniversary formed an appropriate backdrop to the 14th biennial CAVEPS meeting.

PRE-CONFERENCE FIELD TRIP: KANGAROO ISLAND (R. E. WEBB)

The pre-conference fieldtrip to Kangaroo Island began at the ridiculously early hour of 6 am on Friday 27 September, 04.30 for those from Perth, when participants assembled in Glenelg for a bus trip across the Fleurieu Peninsula to Cape Jervis and the ferry to Penneshaw. The crossing was smooth, but the channel is dangerous; the water is very cold, the current very strong. Stop 1 was an exposure of Cambrian trilobites at Emu Bay. We were allowed to keep any fossils we found in the spoil dump (Figure 1A). We then drove to Flinders Chase National Park, had lunch and set up camp while it was still light. While dinner was being prepared by Carey, an excellent cook who devised meals that catered for some very 'fussy feeders', Jeannette Hope (Figure 1B) took the interested to see where she had excavated at Black Creek Swamp (Hope *et al.*, 1977; Wells *et al.*, 2006).

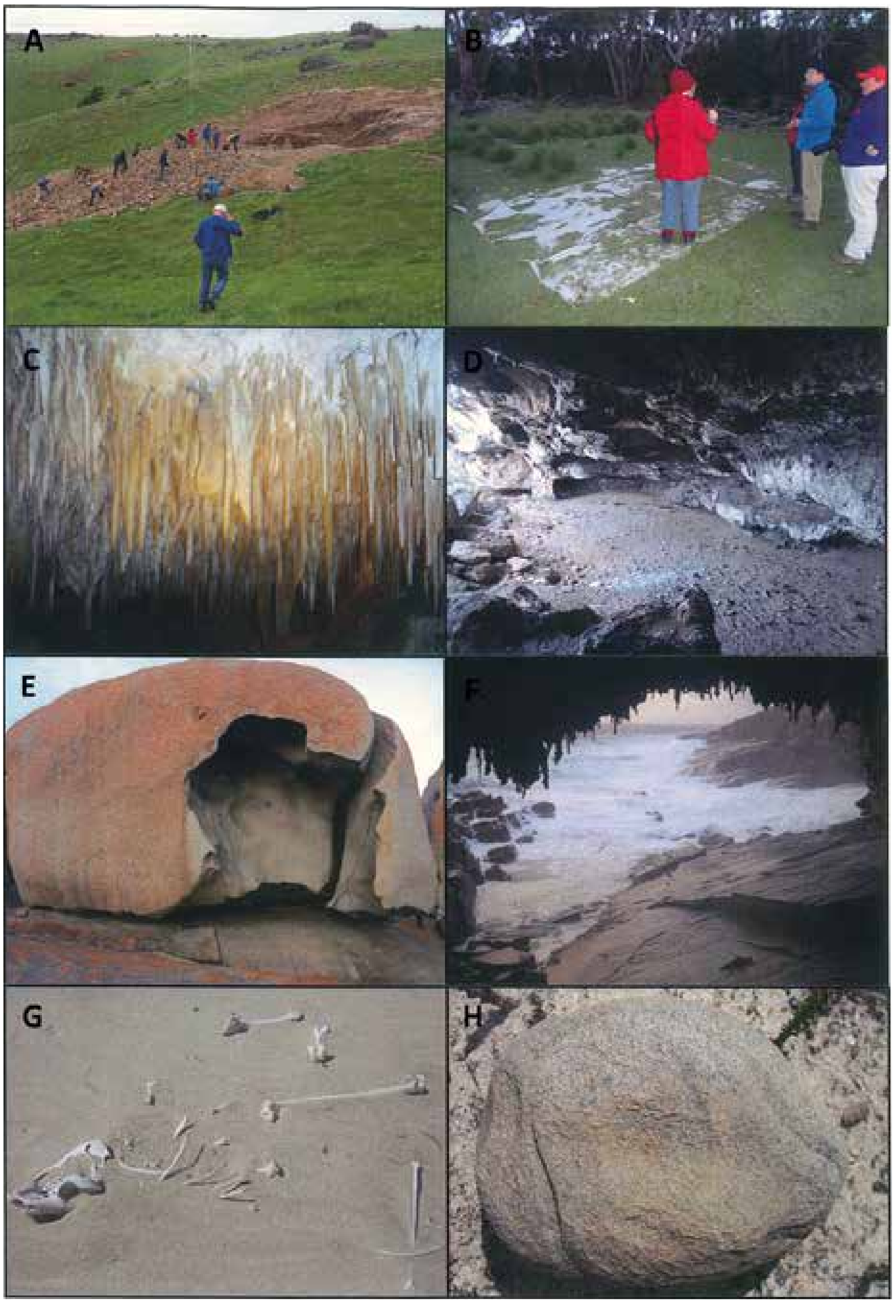

Figure 1: A. Scavenging for trilobites at Emu Bay; **B.** Jeannette Hope explaining her work at Black Creek Swamp; **C.** Stalactites in Kelly Hill Cave; **D.** Cape de Couëdic rockshelter; **E.** Remarkable Rocks; **F.** Admiral's Arch, with seals; **G-H.** Disintegrating *Macropus eugenii* skeleton and pitted hammerstone/ pounder at Bale's Bay.

Next day, we toured the stalagmites and stalactites formed in Tertiary karst at Kelly Hill Caves (Figure 1C). Non-claustrophobes visited Matt McDowell's (Flinders) investigations into Late Quaternary fossil accumulations in underground cave fills (McDowell *et al.*, 2013). After an excellent lunch back at camp, we headed off to Cap de Couëdic where Draper (1987, 1999) had excavated a very large rockshelter (Figure 1D) on the edge of near-vertical cliffs. Keryn Walshe (SA Museum) hopes to reinvestigate this site to answer some questions Draper did not consider. Seals manage to clamber up the cliffs to pup, and live, in this cave. We then became tourists and visited Remarkable Rocks (Figure 1E), 'elegant concavities' that originally formed by subsurface erosion (Twidale and Campbell, 2005: 75-76) and Admiral's Arch, a sea cave favoured by seals (Figure 1F), where we saw, and heard, a baby who was not happy that his mum had gone fishing without him! Unlike similar formations in southern Western Australia, none of the tafone at Remarkable Rocks is decorated, possibly because people had abandoned the island due to rising sea levels long before pigmented artwork became common throughout Australia around 4000 BP (McDonald and Veth, 2006). We got back to camp after dark to an excellent and very convivial dinner; Carey had clearly been cooking all day. Some partied on into the early hours!

On Sunday, those interested trekked off across trackless sand dunes to a site at Bale's Bay where Tammar Wallaby (*Macropus eugenii*) bones are continually eroding out of the fine sands. Walshe (in press) believes wallabies were skinned there first by Aboriginal people, then by sealers. We collected every visible bone, apart from a disarticulated skeleton (Figure 1G), which is being left for taphonomic analysis. I noted a pitted pebble pounder or hammerstone (Figure 1H), that might have been used to shell nuts, but very few other stone artefacts; perhaps because, while there is a soak nearby, the area is otherwise waterless. The non-archaeozoologists visited Seal Bay. Finally, we all visited the Raptor Domain where some people got 'up-close and personal' with a variety of diurnal and nocturnal raptors. Injured birds are brought to the sanctuary, healed and eventually released back into the wild, but I still felt, uncomfortably, that they were being exploited for tourism; whereas, our foreign visitors were delighted. After all the exercise and sea air, most people dozed on the coach back to the ferry. The crossing was quite rough, with a strong cross wind.

THE CAVEPS CONFERENCE, FLINDERS UNIVERSITY (E. SHUTE)

The conference proper began on Monday 30th, with a day of workshops on dating techniques, fossil preparation and casting, phylogenetics, and scientific drawing. These small-group tutorials provided delegates with the opportunity to learn first-hand from leaders in their respective fields. The drawing workshop – run by Peter Murray, Peter Trusler and Janet Matthews – was particularly popular with attendees, with seemingly everyone ending the day with a drawing of high enough quality to stick up on the fridge at home. The day was rounded off with drinks and canapés in the Pacific Cultures Gallery at the South Australian Museum, where Gavin Prideaux officially welcomed the nearly 180 delegates to Adelaide, many of whom had travelled from interstate,

LEFT – Figure 1: Delegates gather in Anchor Court between talks

TOP – Figure 2: Emu Bay shale, Kangaroo Island

TOP – Figure 3: Fossiliferous outcrop at Lake Palankarinna

LEFT TOP – Figure 4: Prospecting in Cooper Creek

LEFT MIDDLE – Figure 5: Carey's Boil-in-the-bag omelettes

ABOVE – Figure 7: Trevor Worthy with his uncanny *Genyornis* find

LEFT BOTTOM – Figure 8: Before there were vertebrates: Brian McGowran points out the Golden Spike that marks the base of the Ediacaran Period

BELOW – Figure 6: Black-winged Stilts, Cooper Creek

and with participants also coming from as far afield as the USA, New Zealand, and China.

The following four days of the conference saw the presentation of 100 talks across a diverse range of topics, from the history of palaeontology to molecular phylogeny and ancient DNA analysis, demonstrating the breadth and depth of research in our field today.

The first symposium grounded us in the history of Stirton's legacy, with the plenary address given by Tom Rich. He concluded by urging younger researchers to step away from their computers, and to take up the exploratory spirit demonstrated by Stirton and his co-workers in the 1950s and '60s, by planning and carrying out fossil prospecting in new Australian locations. By way of inspiration, this era of exploration, its scientific legacy, and the character of 'Stirt' himself, was brought to life by various speakers with close ties to him and his work.

The audience was especially delighted to welcome to the stage Paul Lawson, a veteran of Stirton's expeditions, who at the age of 95 provided a lively and humorous account of time spent in the field 60 years ago at Lake Callabonna, where field research continues today. A poster session presentation by Sam Arman and Travis Park traced the academic phylogeny of CAVEPS delegates, demonstrating that around 25% of attendees could trace their pedigree back through a direct line to Stirton, further highlighting the impact of his foundation work through to the present.

Much temporal, taxonomic and geographical ground was covered in the following days of the conference. Talks addressed vertebrate subjects as diverse as Silurian jawed fish from China, Triassic Lepidosaurs from Germany, Miocene penguins from Australia, and Pleistocene

Homo floresiensis remains from Indonesia. Symposia keynote addresses were delivered by Johannes Müller on bridging the divide between genetic and fossil evidence in squamate evolution, and by Lee Lyman on the application of palaeozoology in modern conservation. Many more talks were given, by established professionals and students alike.

Evenings, meanwhile, saw the opportunity for socialising over local wines, beers, and cheese, with a lively and good-humoured poster presentation one evening, and an epic fund-raiser auction on another. Chief auctioneer Paul Scofield whipped up some competitive bidding on more than 100 quality items kindly donated by conference-goers and local businesses, and more than $4000 was raised for the charity Teachers Without Borders. The conference dinner on Thursday night was held at the Stamford Grand Hotel at Glenelg, and the undoubted highlight was witnessing a ballroom full of palaeontologists doing words and actions to 'Dinosaur Stampede', performed live by Professor Flint and the Flintettes. A few brave souls partied on into the night, and most even made it back to Flinders for the final day of talks on Friday. The final day also saw the awarding of the Riversleigh Medal to Peter Murray for his many and varied contributions to Australian palaeontology.

For most the conference ended there, but for the party of 30 who were about to set off on the six-day post-conference field trip to the Lake Eyre basin, the fun had hardly begun. Headed by Rod Wells, Gavin Prideaux and Aaron Camens of Flinders University, the trip paid homage to Stirton's legacy, and retraced some of his steps by visiting important vertebrate fossil localities at Lake Palankarinna and Cooper Creek.

Barring the occasional bogging of our vehicles in sand-dunes and the odd tangential detour across country, progress was remarkably smooth. Conditions were hot and dry, apart from when they were cold and windy with chance of a gale and some loss of tents. No lives were lost, and the only disappearance was of the keys to one of the vehicles in Marree. Plenty of wildlife was sighted, including dingos, dragons, goannas, snakes, camels, waterbirds, emus with chicks, and even Yellow-footed Rock-wallabies in Brachina Gorge. And with the palaeontological penchant for bones and decay, there can have been few convoys in history with equal enthusiasm for stopping for roadkill as for live animals. There were many successful opportunities for fossil prospecting along the way, and the trip was an unmissable chance to learn about some of these localities from veterans of the field such as Rod Wells and Neville Pledge, with their decades of collective research experience in the Lake Eyre basin. Remains of various taxa were found, including fish, turtles, crocodiles, flamingos, and marsupial megafauna. The award for fossil detection sixth sense went to Trevor Worthy, whose uncanny find of one of the best preserved *Genyornis tibiotarsi*, within about twenty seconds of getting out of his vehicle in Cooper Creek, left many of us shaking our heads in disbelief. For locals and overseas visitors alike, the trip was a first class introduction to the vertebrate fossil localities of the Lake Eyre basin, and a fitting tribute to the work of Stirton and his successors.

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International Interaction and Collaboration: A Summary of the Second PAGES Young Scientists Meeting

SECOND PAGES YOUNG SCIENTISTS MEETING: THE PAST—A COMPASS FOR FUTURE EARTH; GOA, INDIA, 10–12 FEBRUARY 2013

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From February 10-12th, 2013, 79 early-career scientists from 27 different countries converged on the International Centre in Goa, India for the second PAGES Young Scientists Meeting (YSM). The meeting served as an opportunity to share research while providing the next generation of palaeoscientists with relevant professional development.

In addition to global diversity, participants covered a broad spectrum of palaeoscience research, spanning a range of PAGES foci and cross-cutting themes including:

- Climate Forcings
- Regional Climate Dynamics
- Global Earth-System Dynamics
- Human-Climate-Ecosystem Interactions
- Chronology
- Proxy Development, Calibration and Validation
- Modelling

These themes allowed climate modellers, glaciologists, oceanographers, and others to share a stage and engage in dynamic scientific dialogue. Workshops and panel discussions augmented the oral and poster presentations. Professional development workshops covered a wide range of topics including data sharing and management, the art of peer-review, and effective science communication. Experienced mentors who shared their expertise included Gavin Schmidt (NASA Goddard Institute for Space Studies), David Anderson (Institute of Arctic and Alpine Research and National Climatic Data Center), Alicia Newton (Editor for *Nature Geoscience*), Denis-Didier Rousseau (Co-Editor-in-Chief of Climate of the Past) and Chris Turney (Asian and Australasian Regional Editor for the *Journal of Quaternary Science*).

Participant-led breakout sessions focused on issues and challenges facing the international palaeoscience community. These discussions identified key issues for both early-career and senior scientists. The need for improved knowledge transfer between proxy-based scientists and data modellers was identified in the discussion about educational requirements for future palaeoscientists, while a direct need for improved non-technical communication skills was called for to aid communication with the public. Better articulation of the importance of palaeoscience and scientific uncertainty to policy makers and funding agencies is also vital for the success of future research programmes. A ten-year outlook on the priorities and key research questions called for the development of more high-resolution proxy reconstructions, as well as improved model-based predictions and estimations of environmental change. Earth science data-sharing capabilities were also identified as a key priority for our community.

Detailed summaries from the breakout sessions can be found in the Young Scientists Meeting Section of the August issue of PAGES News (http://igbp-scor.pages.unibe.ch/download/docs/pages-news-21-2/PAGESnews_2013(2)_LoRes.pdf#page=45).

In addition to sharing sophisticated science and addressing difficult questions about future directions, the participants managed to have fun during communal meals, lunch breaks in the pool, and an amazing welcome dinner full of delicious Goan cuisine. This balance of work and play ultimately fostered new collaborations and improved international dialogue and awareness. We hope that more meetings of this type and calibre can be held in the near future.

Thank-you to all of the meeting sponsors including: The Ministry of Earth Sciences, Government of India; United States National Science Foundation; the Swiss National Science Foundation; Asia-Pacific Network for Global Change Research; System for Analysis, Research and Training; IGBP, Brazil Regional Office; National Oceanic and Atmosphere Administration, USA; National Institute of Ocean Technology, India; Indian National Centre for Ocean Information Services, India; Indian Institute of Tropical Meteorology, India, Oeschger Centre for Climate Change Research, University of Bern Switzerland; and the International Association of Sedimentologists.

Additional YSM meeting summaries can also be found in:

Bogus, K., Bouimetarhan I., and Richey, J., 2013. Early-Career Scientists Discuss Research and Future Directions for the Paleoclimate Field. Eos, Transactions American Geophysical Union, 94(26), 233-233.

Saraswat, R. and Jensen, B., 2013. A brief report on the 2nd PAGES Young Scientists Meeting in Goa, India. PAGES News, 21 (2). 89-89.

LEFT – Figure 1. One of the many beautiful courtyards at the International Centre Goa.

ABOVE – Figure 2. The beach near the conference venue.

BOTTOM – Figure 3. YSM participants enjoying the outdoor poster session at the Open Science Meeting.

(Photos: Heidi Roop)

IPS 2012, the 12th International Paleolimnology Symposium

21-24 AUGUST 2012, GLASGOW, UK

Phuong Doan

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In August 2012, I had the privilege of attending and presenting at the 12th International Paleolimnology Symposium in Glasgow, UK, organised under the International Palaeolimnology Association (IPA). This meeting, held every 3 years, brought together 320 scientists from more than 30 countries under the conference theme "advancing the science of palaeolimnology". There were 16 special oral and poster sessions, four plenary presentations and a ceremony to present Outstanding Service and Lifetime Achievement Awards.

Opening the conference was the first plenary presentation, presented by Prof. Rick Battarbee (Environmental Change Research Centre, UCL), who highlighted the relatively long history of palaeolimnology in the UK during the "pioneering days". The three plenary presentations that followed were by: Dr Marie Elodie Perga (Alpine Centre for Research on Trophic Networks and Lake Ecosystems (INRA)), Prof. Tom Johnson Large (Lakes Observatory, University of Minnesota, Duluth) and Prof. John Anderson (Department of Geography, Loughborough University).

Among the 16 sessions, the highlighted themes, which provided the most updated reviews and studies in the disciplines of palaeolimnology and palaeoecology undertaken worldwide, were:

- Quantitative environmental reconstructions in palaeolimnology – progress, current status, and future needs (KN: John Birks)
- Applied palaeolimnology to evidence-based lake conservation (KN: Carl Sayer)
- Advances in the development of lake chronologies (KN: Christopher Bronk-Ramsey)
- Biomarkers in palaeolimnology: Progress and problems (KN: Josef Werne)
- Regional integration of recent lake sediments for management of landscapes, ecosystems and ecosystem services PAGES Focus 4 (KN: Peter Gell)
- Past climates of the Southern Hemisphere (KN: Svante Björck)

Examples of Australian work were presented by Peter Gell, Keely Mills, Phuong Doan (University of Ballarat); John Tibby, Cameron Barr (University of Adelaide); Michael Reid (University of New England); Mark Burrows (Australian National University) and Kathryn Taffs (Southern Cross University). As a keynote speaker of PAGES Focus 4 session, Prof. Peter Gell presented the topic "*Sailing through the perfect storm: wetland condition assessment for wetland management; south-east Australia*". The talk provided an emerging synthesis of paleolimnological records across the region which contextualise the present climate regime and identify the historical range of variability, and also resilience, of wetlands. Keely Mills presented evidence for pre-European drought in the south-eastern Australia from diatom records. John Tibby focussed on Holocene carbon isotopic reconstruction from Swallow Lagoon, North Stradbroke Island, which provided inferred variations in precipitation in the subtropical Pacific. Cameron Barr highlighted the climatic variability in southeastern Australia over the past 1500 years inferred from the high-resolution fossil diatom records of two crater lakes. Mark Burrow reconstructed the humification record for the peat sequence in Quincan Crater from pollen, $\delta^{13}C$, grain size analysis, magnetic susceptibility and charcoal over the last 4,000 years.

My talk was given on the first day of the conference in the session theme 15 "Palaeo-productivity, the Elusive Grail – Integrating the effects of nutrient and DOC loading on lakes over millennial timescales", which was led by Prof. Daniel Engstrom from University of Minnesota, USA. My talk addressed the possibilities of using sedimentary pigments to track changes in lake productivity in Australian lakes. Tracking the response of lakes to past climate change and anthropogenic impacts through changes in aquatic community structure provides a baseline from which we can understand how aquatic ecosystems may respond to future pressures. I presented the first Southern Hemisphere record of fossil pigment from a saline volcanic lake Tower Hill, Victoria. This record reveals a non-linear mechanism in lake productivity and algal community in response to periods of droughts in the past (last 5500 years), as well as in the recent Australian Millennial Drought (1996-2009). This mechanism serves as a key reference from a saline system for comparing those in freshwater systems for future studies in the region.

Being at this conference provided me an outstanding opportunity to discuss and receive feedback on my research results from leading experts from the northern hemisphere (e.g. Prof. Peter Leavitt, Dr Suzanne McGowan) in the area sedimentary pigment research. Unfortunately there are few available in Australia. Through a variety of conversations both at and outside the conference venue, my confidence was increased in laboratory protocols and method development for sedimentary pigment analysis. Although my oral presentation received very positive feedback, the poster session was also a great opportunity for researchers with a non-English background like me to open up detailed conversations seeking feedback from desired experts, as well exchange information among colleagues, which was otherwise restricted after an oral presentation. My personal reflection was added by a palaeolimnological study about Late Holocene environmental change in the northern mountains of Vietnam, my home country, presented by Dr Marie Weide (California State University, Long Beach, USA). This inspired me to pursue opportunities to continue palaeolimnogical research in my homeland, work which has not yet been explored by regional scientists.

To sum up, the IPS 2012 was a great success, not only as platform for stimulating research directions and networks for participants, but also from the perspective of a research student. It helped me locate how my current journey fits into the "bigger picture" of palaeolimnology, that I would not have achieved if not for being there. This valuable opportunity of attending and presenting at this remarkable conference would not be happened without the continuous support from my supervisors Prof. Peter Gell and Dr Keely Mills from the University of Ballarat (Australia) and advisor Dr Suzanne MC Gowan from The University of Nottingham (UK).

The next symposium will be held in Lanzhou, China in 2015. For Symposium details, see: http://paleolim.org/ips2012/

TOP LEFT John Birks receiving his IPA Lifetime Achievement Award from Rick Battarbee and John Smol

MIDDLE LEFT & ABOVE TOP IPS2012 group assembles for photo

LEFT Curt Stager and friends provide a rendition of "When McArthur Farted and Saved the Town from Drought" (John Tibby and Cameron Baar representing the Australian team!!!)

ABOVE LEFT IPS2012 Dinner and Ceilidh

ABOVE RIGHT Phuong Doan (The University of Ballarat and Marie Weide (California State University, Long Beach, USA) in front of the poster "Late Holocene environmental change in Lac Ba Be, Vietnam".

Asia Oceania Geosciences Society Meeting, Brisbane, June 2013

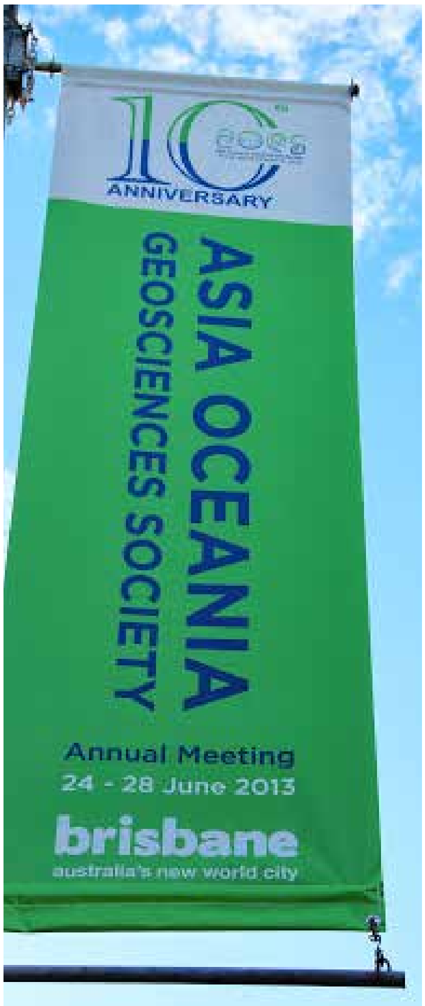
Claire Krause and Nick Scroxton

The Australian National University

The Asia Oceania Geosciences Society (AOGS) Meeting was held in its 10th Anniversary year for the first time in the southern hemisphere, running from the 24th to the 28th of June in Brisbane. Close to 1300 attendees came from all over Asia, Oceania and from around the World for a week of talks, posters and meetings.

The newly inaugurated interdisciplinary section of the conference, in which Quaternary research sat, was an outstanding success. It was here that the palaeoclimatologists, geoarchaeologists and the palaeo community in general were able to come together and showcase important research.

Monday morning kicked off with a session on the Quaternary evolution of monsoons, chaired by James Shulmeister. This session included a variety of speakers, using different proxies, and even models, to examine monsoon variability over the late Quaternary. Steven Phipps had the honour of being the first palaeoclimate speaker of the conference, demonstrating that proxies and models can in fact work together successfully.



From there, we were delighted with tales from stalagmites, sediment cores and lake records, which all provided accounts of Australasia's rainfall history.

Following this session, the first informal meeting of the new SHAPE (Southern Hemisphere Assessment of PalaeoEnvironments) initiative was held at a local Turkish Restaurant in South Bank. Turnout for the meeting was encouraging, with a large number of people putting up their hands to be involved in the new project, which will foster collaboration between different research groups across the southern hemisphere (and Singapore).

Monday night saw the main conference-organised social event for the week, the welcome reception. This provided an opportunity for networking over a glass of wine and a canapé, while shouting over the background noise to be heard, as is traditional at these events. The entertainment for the night was provided by a local aboriginal dance troop, who delighted the crowd with traditional dance and stories, and were more than happy to pose for the many cameras.

PREVIOUS PAGE - CLOCKWISE FROM TOP:
The welcome reception on Monday night, held in the main hall amongst the trade displays.

Banner for the AOGS Conference as seen around South Bank, Brisbane.

A local aboriginal dance troop performing at the Welcome Reception.

Patrick Nunn receiving an award from AOGS as part of the Distinguished Lecture Series.

Robert Wasson receiving an award from AOGS as part of the Distinguished Lecture Series.

(All photos courtesy of conference organisers.)

Each research section had its own distinguished lecturers, who spoke in a special session at the end of the day. The distinguished lectures for the interdisciplinary geosciences were held on Tuesday evening. Despite the late hour, the turn out to these lectures was excellent. Patrick Nunn presented a brilliant lecture titled, "Lashed by Sharks, Pelted by Demons, Drowned for Apostasy: the Value of Myths that Explain Geohazards in the Asia-Pacific Region," which combined social sciences and natural hazards to recreate hazard histories. Robert Wasson presented an entertaining lecture arguing for a unified geomorphology that enables a more complete understanding of Earth surface processes. Both lecturers were presented with an award from AOGS as part of the distinguished lecture series.

The second Quaternary session, on geoarchaeology, was held on Wednesday afternoon and included a variety of research from different disciplines. This session brought together proxy climate records and records of human occupation from across Australasia. Speakers were thoughtfully introduced by Stacy Oon, and spoke on topics including Northern Australian shell mounds, the extinction of the Flores Hobbit, the newly discovered "Kiacatoo Man", historic earthworks (or "moats") and OSL dating techniques. This session was well attended and facilitated discussions, which carried on throughout the rest of the day.

The conference-organised entertainment for the week was limited, and the poster session bar tab seemingly more limited. This led to a more thorough sampling of the highlights of the South Bank area of Brisbane. The stand-out party of the week, organised by the Earth Observatory of Singapore was a buzz of networking and scientific discussion. EOS invitations became a much sought-after item, with Chris Gouramanis clearly enjoying the attention being keeper of the invitations brought him. The warm Brisbane winter's evening provided excellent conditions for al dente wine and canapés by the Brisbane River. By the end of the night, new friendships and collaborations were made, and Australia had a new (old) Prime Minister.

Thursday provided an opportunity to relax and sample some of the broader disciplines on offer at AOGS. We learnt more about El Niño than one would ever care to know, and caught a great session on ocean acidification.

Those who survived to Friday afternoon were rewarded with an excellent session on late Quaternary environments of temperate Australasia, convened by Patrick Moss. Discussion in this session was lively, particularly regarding the non-linearities in climate feedbacks, and the synthesis of different palaeoproxies across Australia during the LGM. A new proxy (at least to these authors) was introduced in the form of fossilized midge skeletons in lake sediments and proved to be note-worthy, even though our enthusiasm for note-taking was, by then, wearing thin.

Overall, the AOGS conference brought together Quaternarists from across Australia and Oceania to facilitate discussion and brainstorm over a few beers in a tropical location. And really, what more could you ask for.

Taking SHAPE (Southern Hemisphere Assessment of Paleo-Environments)

Helen Bostock and Drew Lorrey *(NIWA)*

This is a shorter version of the highlights from the first SHAPE meeting – the longer version can be downloaded from the AQUA website SHAPE project page (http://aqua.org.au/?page_id=56).

The main aim of SHAPE is to continue the momentum that was started with Australasian-INTIMATE (Integration of Ice, Marine and Terrestrial), but to broaden the scope and compare with records from the rest of the Southern Hemisphere. Thus along with Australian and New Zealand researchers we hope to get input from our South American and South African colleagues. The original INTIMATE timeframe was from 8-30 ka, one of the first aims for SHAPE is to expand and provide good, high resolution climate records from 0-60 ka – thus sitting within the timeframe that is possible to date with radiocarbon. Another goal of SHAPE is to compare the proxy data to the paleo-climate model outputs such as the PMIP3 (Paleoclimate Modelling Intercomparison Project). By comparing the proxy data with the models we hope to understand some of the processes and drivers of past climate. One of the other objectives of INTIMATE, and we hope to continue with SHAPE, is to foster the growth of early career scientists and encourage them to lead some of the initiatives.

Thus with these grand ambitions the first SHAPE meeting was hosted by GNS Science in Lower Hutt, New Zealand on 16-17th September 2013. It took the same format as previous INTIMATE meetings with a day of presentations followed by a day of discussion of what we would like to achieve as a community (along with what we promised to deliver to INQUA to qualify for a small amount of funding for this initiative).

Talks on the first day highlighted the wide range of work being undertaken in a range of environments and using different proxies and models, with several talks given by young career researchers. The day started with an overview of what was learned during Oz-INTIMATE from Jessica Reeves. This was followed by a marine pollen record from offshore the west coast of New Zealand by PhD student Matt Ryan, then some ice core and modelling work being done across the Antarctic Cold Reversal (ACR) by post doc Joel Pedro. Tim Cohen presented some dated shoreline and lake level work from Lake Eyre between 40-60 ka, and suggested that it may have been climate change that caused the demise of the Australian Megafauna (paper submitted). Marine records for MIS 5E from the SW Pacific were presented by Giuseppe Cortese and changes in the position of the Subtropical Front south of New Zealand since the last glacial by Helen Bostock. A very high resolution tropical speleothem record from Sulawesi was presented by PhD student Claire Krause, combined with some modelling to look at potential changes in the hydrological cycle in this region during Heinrich Event 1. The Key note was by Paul Williams who presented a composite of the west coast of the South Island speleothem records for the last 130 ka and how these records relate to the glacial advances in the Southern Alps. This was nicely followed by Peter Almond who summarised our current understanding of the glacial deposits on the east and west of the South Island of New Zealand. In progress project reports were presented by Craig Woodward on the Australian last glacial maximum project from the East of Australia and Gavin Dunbar on the potential varved sediments from Lake Ohau and their hopes to really develop this over the coming years with new Marsden funding to collect longer cores. Poster presentations were given on the Holocene fluvial activity by Ian Fuller and the crew at Massey University. Drew Lorrey showed his recent work on the ancient Kauri records from MIS3, and Andrew Rees some chironomid work from Tasmania. Heidi Roop had more detail on the Lake Ohau sediments.

Day 2 was spent discussing the SHAPE proposal and questions that we need to answer, along with the timeline for undertaking work, and what collaborative deliverables that could potentially be achieved by the next INQUA congress in 2015 in Nagoya, Japan. If we can show some progress towards our objectives by 2015 we hope that there will be support for a second phase of SHAPE until the next INQUA congress in 2019. This will allow some of the more ambitious compilations (hemispheric-scale) to be completed.

One of the high priorities for SHAPE is the comparison of proxy data with models. There are now a wide range of model runs available from PMIP3 and Initial discussions were held around the current model runs that are available to compare with in the PMIP3 (Paleoclimate Modelling Intercomparison Project). Some are timeslice models, while others are transient (e.g. the 0-8 ka).

Another tool that has been developed by Andrew Lorrey and colleagues at NIWA is PICT (Past Interpretation of Climate Tool; pict.niwa.co.nz; Lorrey *et al.*, 2013). This is an online tool that allows the submission and synoptic interpretations to be made from different kinds of proxy data and climate archives. PICT uses a virtual climate station network (VCSN), a gridded product with 5 x 5 km resolution, and runs currently for rain fall and temperature for New Zealand. Once users input their proxy interpretations or reconstructions, PICT derives analogue years and selects corresponding information from reanalysis data to generate ensemble maps (modern synoptic configurations) that show realistic configurations of atmospheric and oceanic conditions that can help to explain why the site (and proxy) responded the way it did. The more data and spatial coverage that is included for a time slice the better the output of the reconstructions, as outliers (presumably from a few proxies) won't play as big a role in the ensemble mean. At present, PICT can realistically be applied to the Holocene, when sea level and climate were more similar to modern conditions. In the future, proxies over longer time scales will need to consider the relative changes in the contribution from insolation and Green House Gas forcings, in addition to circulation changes, to explain local conditions. The tool will be developed further in the next few years and hopefully will expand to include Australia and South America.

Of course a key to any comparison of records with other records and models is good chronology. Thus the latest dating techniques, calibrations and standards were discussed. There will be continued effort on tephrochronology for the New Zealand region as these are key chronological markers in the landscape. We need to improve the dating of the older tephras from 30-60 ka to help compare across different records. The new radiocarbon calibration curve INTCAL13 (Reimer *et al.*, 2013) and SHCAL13 (Hogg *et al.*, 2013) are now out and extend back to 50 ka and will be critical for providing better chronological constraint for older records back to 50 or 60 ka. There are new 10Be calibrations for New Zealand (Putnam *et al.*, 2010), and also for South Africa and Antarctica (which are very similar to New Zealand), it would be good to check the calibration for Australia. For this older time period there magneto-stratigraphy and identifying Beryllium spikes in sediment archives (produced during the Laschamp and other magnetic anomalies) may also be helpful. A new protocol was written during Aus-INTIMATE for the use of optically stimulated luminescence (OSL) by Kat Fitzsimmons.

There is now increasing use of the Bayesian modelling for chronologies, using Oxcal or Bacon (Lowe *et al.*, 2013; Vandergoes *et al.*, 2013), and these methods will also be helpful for the extended time period.

A number of key projects were identified for the next few years with lead names next to these (see list below). If you have anything (records/ideas/modelling) you think you can contribute to these projects then please contact the lead person (or Andrew Lorrey – Andrew.Lorrey@niwa.co.nz). If you have any projects that would also fit under the SHAPE themes then also let us know. There will be a series of virtual meetings discussing some of these projects in early 2014 and the next SHAPE meeting will be at the AQUA conference in Mildura in mid 2014 when we hope preliminary results from many of these projects will be presented.

List of anticipated SHAPE projects* (with named lead)

1. Compilation of records from 30-60 ka – Tim Cohen (Aus)/Drew Lorrey (NZ)
2. ENSO changes through time – Drew Lorrey
3. ACR compilation of models and records – Joel Pedro and Marcus Vandergoes
4. Monsoon speleothem compilation – Claire Krause
5. *Westerlies across LGIT – Michael Shaun-Fletcher, Krystyna Saunders
6. Kawakawa timeslice from 24-26 ka for NZ – Peter Almond
7. 28-32ka timeslice – Looking for a lead?
8. Early Holocene 8-10 ka – Craig Woodward (Aus)/ Drew Lorrey (NZ)
9. Holocene model comparison – Steve Phipps
10. *Tephrochronology across the SHAPE timescale – Kat Holt and David Lowe
11. ^{14}C surface reservoir ages in the SW Pacific – Helen Bostock
12. Temperature gradients across oceans – 21 ka – Tim Barrows
13. *$\delta^{13}C$ deglacial minimum – Helen Bostock

* these are key deliverables promised to INQUA.

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Archaeology in Environment and Technology: Intersections and Transformations

Edited by David Frankel, Jennifer M. Webb and Susan Lawrence

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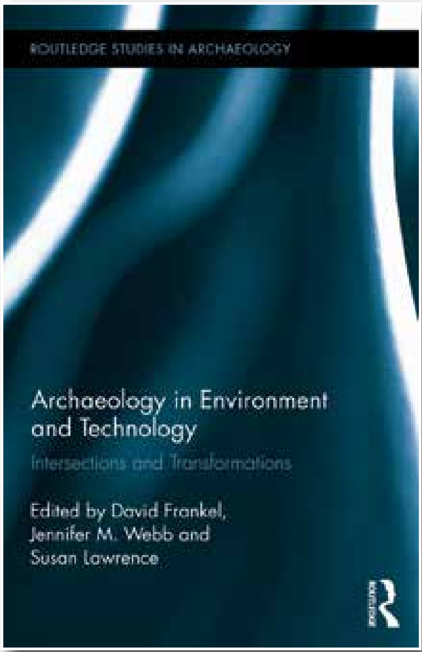

The contributions to this book examine in broad terms the inter-relationships between environment, culture and technology in a wide range of archaeological contexts. It comprises 12 chapters divided amongst three thematic sections, and is mainly a summary of research discussed at a workshop at La Trobe University in Melbourne, Australia, in 2010.

The inferred intention of the book is to distinguish itself from the rich academic tradition of interpreting the analytical spheres of environment, culture, technology, and the assumed unidirectional relationships between them, as focal points from which to initiate research. In contrast, here environment, culture and technology are treated by contributors to this volume broadly as three inseparable analytical "axes". Thus the volume is concerned with interrelationships among these three factors, and in particular how mutual feedback loops between them are shaped and articulated within a series of interesting case studies.

In addition there is concern with the nature of the archaeological record. Relations between context and material on the one hand, and appropriate scales of approach, observation and interpretation on the other, are discussed within a number of contributions. This stems from the authors' awareness that the literature is rife with examples of research that conflates differing scales of data and analyses. This tendency has moulded certain research questions and ultimately yields interpretations that may be explicable, but not necessarily accurate.

The chapters vary along a number of dimensions: in chronological and group focus, perspective, applied methodology, as well as in the material cultures targeted. In a book where the analytical objective is to argue for a new departure, the breadth of subject matter – from the Late Pleistocene Dordogne Valley to Colonial Australia, from World Heritage listing criteria to lithic cortex ratios – would have benefitted from some more constraint.

That said, many contributions criticise previous studies, with good reasons, for approaching the three domains – environment, culture and technology – as discrete analytical elements. This charge is overstated in a number of chapters, although warranted in certain contexts. The ongoing tradition of placing lithic techno-complexes into arbitrary culture-historic categories is a persistent example of euro-centrism that has been demonstrated widely to be unsuitable for applications outside of Europe. Similarly, the riskiness of applying behavioural models developed outside of Australia to the Australian record is articulated and demonstrated with reference to the unique ecology of the continent by Holdaway *et al.* in Part One.

Apart from Holdaway, all the first authors cited are based at Australian institutions. In this light a number of contributions comprise interesting alternative perspectives to European and American schools to which likely readership may be accustomed. This seems fitting given the predominantly antipodean focus of the case studies.

Part One makes up the largest portion of the book, and is primarily concerned with environmental variability and technological responses. These chapters use a variety of technological and geomorphological datasets to investigate how different groups of hunter-gatherers (and one so-called "empire") adapt to environmental constraints.

Stern *et al.* present highly resolved multidisciplinary analyses of human adaptation to environmental change in the Willandra Lakes region. They use lithic variability as their principal behavioural proxy. This work emphasises the value of correlating scales of investigation and interpretation in order to understand a dynamic material record in an evolving contextual framework.

Thomas presents an explanation for the rise and fall of the Ghurid Empire in the medieval period. Thomas's study stands out in Part One in terms of chronological focus and scale of analyses, as well as because it is focused on social and technological change in a period of relative environmental stability in contrast to variability.

Holdaway *et al.* make use of diverse datasets, including modern ecological assessments of the Australian continent as well as specific lithic analysis techniques, to track artifactual movement across a palaeo-landscape. They argue that lithic variability represents sets of hunter-gatherer responses to an unpredictable environment. A minor issue with this chapter is its oversimplification of the heuristic value of optimal foraging theory for interpreting archaeological patterns. There are numerous examples of the application of optimal foraging theory where temporal scales of material context and interpretation are not necessarily conflated. Additionally, a number of sections are fairly long-winded. For example:

"Like the ethnographic studies of modern Aboriginal subsistence that ignore the consequence of historical change, what is missing from archaeological studies is a sense of the implication for Australian ecology of dynamic environmental change that is the key theme in the non-human ecological studies discussed..."

Such passages make for a heavy read.

To follow the arguments presented in the other two studies in Part One is more challenging. Cosgrove *et al.* attempt to isolate patterns in the ways that hunter-gatherers cope with supposedly common problems under extreme environmental circumstances. Lithic and faunal discard patterns – as proxies for occupational intensity as one dimension of environmental response – are compared in two temporally equivalent glacial settings, one in southwest Tasmania and another in Late Pleistocene southwest France. The material proxies selected for drawing comparisons – faunal and lithic discard rates – are purposely, and probably necessarily, general in nature.

Cosgrove *et al.* also make a number of assumptions regarding the character of the archaeological units of analysis, and in particular what they represent in terms of human behaviour. One anticipates such assumptions to be unavoidable at the sweeping geographic scale of comparison in question, but this does not make them any less problematic. For example, time-averaged quantities of material remains are assumed to measure levels of site occupation intensity. Yet the authors state explicitly that stone artefacts represent markedly different components of the technological repertoire in each region, and this is clear from the tool types described. This implies that the rates at which different lithics are discarded in each region are underpinned by very different sets of behavioural drivers. The reliability and thus usefulness of raw comparison is therefore questionable.

Frankel & Bird use a wide range of data to investigate how social structures and land-use patterns in Australia were variably influenced by climatic context. They use excavated lithic assemblages and rock art interpretation to construct their explanations. Unfortunately this chapter contains a number of terminological and interpretive inconsistencies in their use of stone artifact analyses. For example:

"The Gariwerd assemblages can generally be described in terms of a single general reduction sequence...The clearest change...of specialized burin cores made on large flakes associated with the production of blades for making bondi points."

In conventional terms it is difficult to imagine how burins on flakes can be associated with laminar strategies within the same operational sequence. In addition the inference that backed pieces are uniformly extractive weapons has been disproved by a number of recent use-wear analyses (e.g. Igreja and Porraz, 2013). Consequently the argued association of backed pieces with "men's places" is misplaced.

Part Two comprises a set of chapters that investigate in broad terms how technology shapes specific sets of social responses to environmental context, and how landscapes are shaped in consequence by these processes. Denham shifts his focus from interpreting to documenting how people interacted with their environment during plant food extraction. He traces the historical trajectory of this tradition in Holocene Papua New Guinea, and shows how this practice broadened human impact and ultimately resulted in landscape degradation. Falconer & Fall mount a fascinating study that focuses on a range of agrarian economies, and investigates linkages between farming strategies and specific associated technologies. They demonstrate that three different sedentary communities had very different social and environmental consequences.

Webb's study, set in third millennium BC Cyprus, documents the contribution made towards competition for resources by the emergence of a dramatically new and superior set of technologies. This covers both the competitive advantage to the group in possession of them and the adaptive stresses faced by those groups initially without them. This broad account evokes parallels throughout a multitude of archaeological contexts, and the phenomena can be traced back far in the record, for example, even to interspecific competition hominins faced when breaking into the carnivore palaeo-guild 2.6 Ma, and the associated competitive advantages that specific lithic technologies afforded.

Lawrence & Davies bring this common focus into the present by problematizing colonial Australia, in particular how specific strategies to adapt to water-availability constraints in the context of the 19th century gold rush were used, and conversely how the landscape was transformed in this context.

Part Three shifts attention away from tangible archaeological elements to more unconventional approaches to the analyses of environment and technology. These studies look at the relevant factors through the lens of social systems, viewed in the context of relationships enabled by yam (tuber) production and deployment by Australian Aboriginals (Atchison & Head), as well as the ideological factors that affect cultural landscape designation under the World Heritage Convention (Smith).

The primary focus of the book – interactions between environments, culture and technology – is an ambitious challenge to methodological practice in our discipline. A few of the papers articulate these central themes in relation to specific case studies, and for the most part do so coherently.

However, it has to be said that the wide-ranging subject matter of the book as a whole makes for a disjointed read. The editors repeatedly refer to the contributions as "different strands within a tangled web". Indeed, this analogy rings true when one reads them, and attempts to trace a common strand throughout the volume; or attempts in this light to make sense of the groupings of different chapters applied within each section. The editors also twice state that "The diversity of chapters... demonstrates the inherent weakness in any [presumably past] attempt to prioritize environment, technology or society". Yet the linkage to which they refer is left unclear, and the diversity of subject matter between as well as within each Part makes the volume structurally, and in some cases theoretically, puzzling.

This may be a useful book for researchers interested in specific approaches or chosen aspects of the Australian archaeological record. Unfortunately it is likely to have limited utility as teaching material, particularly as a useful overview for students.

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THESIS ABSTRACTS

Environmental controls on coccolithophore blooms in the Southwest Pacific Ocean during Marine Isotope Stages 5e (125 ka) and 7a (210 ka)

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Coccolithophores play a key role in the ocean carbon cycle, regulating the uptake and release of CO_2. Satellite observations over the past few decades show ocean change in a warming world is accompanied by changes in the latitudinal distribution of coccolithophore blooms. Despite their importance in the carbon cycle, knowledge of the causes of coccolithophore blooms, and how they may respond to future climate change is limited. In this study evidence from marine sedimentary cores is used to derive longer, more complete records of past coccolithophore productivity, and the factors that potentially caused enhanced coccolithophore productivity in previous interglacials.

Carbonate-rich marine cores; subtropical P71 from north of New Zealand (33°51.3' S, 174°41.6' E) and subantarctic Ocean Drilling Project (ODP) 1120 from the Campbell Plateau (50°3.803' S, 173°22.300' E) show abrupt changes between foraminiferal-rich sediments during glacials to coccolith-rich sediments during interglacials. Both cores encompass the last two interglacial cycles, Marine Isotope Stage (MIS) 5 (71-130ka) and MIS 7 (191-243ka). While MIS 5 has been well-studied in the Southwest Pacific Ocean, research on MIS 7 is limited. From the literature, and data from this study, new insights are presented into the climatic and oceanographic conditions during MIS 7. Sea surface temperatures in the subtropical Tasman Inflow were comparable to present during MIS 7a (191-222ka), but were cooler in MIS 7c (235-243ka). During MIS 7a and 7c the temperature gradient across the Subtropical Front (STF) was greater than present on the Chatham Rise, at >2°C per 1° latitude. In the Tasman Sea, the STF was further north by ~2° latitude.

This thesis employs grain size data and scanning electron microscope images to show that significant coccolith deposition occurred during MIS 7a at subtropical core P71, but not during interglacial peak MIS 5e (117-130ka), whilst the reverse is true at subantarctic core ODP 1120. A range of paleo-environmental proxies are used to determine the potential conditions that caused these increases in coccolithophore productivity. The results suggest that no one factor was responsible, rather it was the combination, and interactions between different environmental processes, that was important. At P71, key factors for enhanced productivity in MIS 7a were high insolation, thermal stratification of the uppermost ocean, and well-mixed source waters from the Tasman Inflow. At ODP 1120, increased coccolithophore productivity in MIS 5e resulted from decreased windiness, warmer sea surface temperatures and reduced oceanic circulation over the Campbell Plateau, resulting in marked thermal stratification. At P71, modern oceanic trends suggest that conditions that caused increased coccolithophore productivity during MIS 7a will not be met in the near future, and productivity is unlikely to increase at this core site. At ODP 1120, modern trends are less clear, but future conditions are projected to be comparable to MIS 5e, suggesting that coccolithophore productivity may increase in the future in subantarctic waters.

Thesis weblink: http://researcharchive.vuw.ac.nz/handle/10063/2414

Quaternary fluvial responses of the lower Shoalhaven River, NSW, Australia

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This study examined the mid to late Quaternary landscape evolution of the Shoalhaven River. It aimed to fill the spatial and temporal gaps of existing work which focused on Tertiary evolution in the upstream reaches, and development of the modern deltaic plains. It provides an understanding of fluvial responses to Quaternary climate that may contribute to both theoretical understanding of features and regional catchment management. This thesis, therefore, examines how far upstream Quaternary sea level changes are recorded; how rivers in confined valleys adjust to long-term changes in flow regime; and the structure of in-channel benches as a modern sedimentary process.

Key results establish that the sedimentary signature of Holocene sea level rise is preserved tens of kilometres inland and into bedrock-confined reaches. At Wogamia, some 32 km from the current coastline, Holocene estuarine depositional environments extend to 2.2 m above present sea level (AHD).

Slightly upstream at Bundanon, where the channel bed lies at approximately – 3 m AHD, some ~35 km from the current coastline, a laterally migrating channel with a floodplain built dominantly by vertical overbank deposits is recorded. The absence of estuarine facies at Bundanon is interpreted to relate either to the barrier provided by flow conditions associated with the bedrock constriction downstream, or their removal due to subsequent river-channel migration. Channel migration has occurred since ~4 ka, which coincides with channel stabilisation downstream at Wogamia and the formation of the deltaic plains farther downstream.

A significant outcome is the contrast between the long-term preservation of terraces in Bulls Reach with modern inset, in-channel benches. Bulls Reach lies ~7 km upstream, where the channel bed lies at 6 m AHD at the downstream end, and at 18 m AHD at the upstream end. The river in this confined reach has adjusted to changes in flow regime during the Quaternary, and demonstrates a long history of sediment preservation in this lower gorge of the Shoalhaven River. Three of the four sites suggest considerable lateral stability of the river within its valley for up to 200 ka.

In addition to these old terraces, the polycyclic depositional history of the alluvium here is reflected by Holocene sediments capping these ancient features, and at lower elevation of longitudinal benches of sand and gravel that have been periodically reworked over much shorter periods. This study finds that deposition and erosion of benches is more complex than accounted for in previous models. Deposition may occur across multiple surfaces in a single event, and scouring occurs during small magnitude as well as extreme events. Furthermore, the vertical boundaries described previously in the literature and the suggestion that benches are formed almost exclusively by vertical accretion is not upheld in these results. The location of the bench front may laterally accrete, and/or be laterally or vertically eroded. The existing premise that events of a specific recurrence interval are responsible for the formation of individual benches of a particular elevation cannot, therefore, be supported.

The implications of these findings are that the preservation of diachronous alluvial terraces in the wider reaches reduces the variability of channel dimensions and resulting channel capacity. The youthful benches provide a dynamic form of channel adjustment in response to reduced flows in recent decades.

Natural and anthropogenic drivers of Australian temperature extremes, simulated over the last millennium

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Research has built extensive knowledge of most climate drivers and a detailed timeline of the climatic changes that have occurred over the past millennium. However, many cause and effect relationships are not yet robustly understood. Assessment of mean temperature can dangerously mask extremes that have a profound impact on human society and the natural environment. The daily temporal resolution required to assess climate extremes has confined much previous research to the observational record. This research seeks to understand the relationship between climate drivers (internal and external, natural and anthropogenic) and temperature extremes in Australia over the last 1000 years.

Natural variability is a strong driver of temperature extremes in Australia. Cloudiness relates to the variability of all extreme indices. El Ni no Southern Oscillation is a strong contributor to the variability of hottest days in Australia. Cloudiness, the Indian Ocean Dipole and the Interdecadal Pacific Oscillation drive the variability of coldest days; which exhibits almost no signal from external forcings.

Solar irradiance and volcanism act as a dynamic duo driving temperature extremes. Across Australia volcanic eruptions cause large and abrupt cooling; although this cooling is not necessarily proportional to the size of eruption. Solar forcing is found to have little influence on temperature extremes but enhances (or reduces) and temporally extends (or shortens) the impact of volcanic eruptions on temperature extremes.

The anthropogenic signal dominates during the industrial period, where Tmax indices exhibit larger trends and are generally heavily influenced by external forcings. Tmin indices on the other hand, either maintain complex relationships with external climate drivers or are primarily forced by the internal climate variability.

The findings of this study indicate that the relative influences of external forcings and natural variability differ for each index. Because of the influence of natural variability and the potential for external forcings to amplify and dampen each other, the response to a specific external forcing is not necessarily proportional to the signal.

Planktic foraminiferal proxy development and application to paleoceanographic change in the Southwest Pacific Ocean

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This thesis investigated the use of foraminiferal calcite geochemical and physical properties as paleoceanographic proxies, to improve identification of past climatic change and provide a more quantitative basis for forecasts of future climate. Both new and well established paleoceanographic proxies were used on a high resolution, well-dated marine sediment core, MD97 2121 from north of the Subtropical Front (STF) off the eastern central North Island of New Zealand to determine paleoceanographic changes in the South Pacific Gyre since the last glacial period, 25 ka to present.

Various analytical methods to measure foraminiferal calcite trace element geochemistry were first investigated using core top samples. Two main analytical techniques were deployed; "pseudo" solution – or laser ablation-based ICPMS analysis. Ratios tested include Mg/Ca, Sr/Ca, Ba/Ca, Zn/Ca, Mn/Ca and Al/Ca. Trace element/calcium ratios Mg/Ca and Sr/Ca values were consistent between these methods, provided that currently recommended 'Mg-cleaning' protocols were followed for solution-based measurements. However, discrepancies of up to an order-of-magnitude for Zn/Ca, Mn/Ca and Ba/Ca occurred between solution and laser ablation-based measurements if both oxidative and reductive cleaning techniques were not employed prior to solution-based analysis.

Using down-core trace element values Mg/Ca, Zn/Ca, Mn/Ca and Ba/Ca from MD97 2121, coupled with modern core top and plankton-tow samples, multiple geochemical proxies for the SW Pacific Ocean were developed and/or tested. Results suggest that Zn/Ca may act as (i) a surface water mass tracer, in this case differentiating between subtropical and subantarctic surface waters and (ii) a proxy for nutrients. Mg/Ca and Zn/Ca values from different test chambers in *Globigerina bulloides* were also found to reliably re-construct surface ocean temperature and nutrient stratification. Using these new proxies, coupled with oxygen isotopes, standard Mg/Ca paleothermometry and foraminiferal assemblage data, this investigation showed that surface water nutrient and thermal stratification significantly reduced during the last glacial period. In addition, the relative strength of the South Pacific Gyre, which affects the inflow of subtropical water to New Zealand, was a major influence during the last glacial termination. In particular, the period from 17-14.5 ka, otherwise known as the 'Mystery Interval', appears to be genuinely anomalous with foraminifera indicating cooling trends while alkenones continue to warm. This may reflect changes to both gyre strength and Antarctic forcing prior to the Antarctic Cold Reversal (14.2-12.5ka) and an offset in the timing of species productivity.

The high resolution Mg/Ca paleotemperature record developed here, together with published alkenone paleotemperatures were compared to core MD97 2120, south of the STF to evaluate the relationship between Mg/Ca and alkenones temperatures and how these reflect environmental change. It appears that the season of maximum alkenone and *G. bulloides* flux varied over the last 25kyr in response to insolation and water mass changes. Seasonal offsets in flux may have acted to dampen or exacerbate the glacial-Holocene temperature offsets by up to 4°C especially for the surface dwelling, alkenone producing coccolithophores.

Finally, the use of *G. bulloides* size normalised weight (SNW) as a proxy for surface water carbonate ion concentration ([CO_3-2]) was investigated by comparing modern SNW data sets from five different ocean regions to their specific environmental variables including [CO_3-2], chlorophyll-a, nutrient and temperature values. It was identified that the 'ocean' from which the foraminifera originated appeared to have the strongest control over shell SNW, potentially reflecting geographically distinct, genetic variations within the *G. bulloides* species. Calcification of *G. bulloides* tests appeared to be region specific; therefore, proxy calibrations based on shell SNW for one ocean are not applicable to other settings.

Thesis weblink: http://hdl.handle.net/10063/2834

Ocean and terrestrial response to a Pleistocene warm interglacial (MIS 11) as revealed by pollen and dinoflagellates from marine sediment cores, South Island, New Zealand

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The response of the surface ocean and terrestrial climate in the New Zealand region to interglacial Marine Isotope Stage (MIS) 11 (423-380ka) is documented, using assemblages of fossilised marine algae (dinoflagellate cysts, or dinocysts) and spores/pollen from terrestrial plants, analysed from marine sediment cores. This work is underpinned by studies on the modern distribution of dinocysts, factors that influence their accumulation in marine sediment, and the use of dinocyst assemblages to quantify past sea surface temperature (SST).

In the first of the modern-process studies, a dataset of modern sea-floor dinocyst assemblages from the Southern Hemisphere is collated, including new observations from the SW Pacific. Variations in the assemblages are related to environmental gradients. Cluster analysis reveals distinct biogeographic assemblage zones, individual taxa indicative of specific water masses are identified, while ordination of the databases indicates that the assemblages vary most with changes in SST.

A second modern process study reports on the dinocyst assemblages from two time-incremental sediment traps (3 years of data) moored north and south of the Subtropical Front in the ocean east of New Zealand. This study provides observations of seasonal and inter-annual variability of dincocyst flux to the deep sea, which are used to identify possible biases in the sea-floor dinocyst assemblages.

Observations from these first two studies are used in a systematic analysis of the strengths and weakness of using dinocyst assemblages to quantify SST in the SW Pacific. The best transfer function performance achieved was a root mean squared error of 1.47 C, for an artificial neural network model, and the benefits in considering a range of model results are also established. Fossil records that document the oceanographic and terrestrial response to MIS11 are developed from two areas around New Zealand; (i) dinocysts assemblages are collected from the east Tasman Sea, from giant piston cores MD06-2987, – 2988, and 2989, and (ii) dinocysts and pollen assemblages are analysed from Deep Sea Drilling Project (DSDP) Site 594, from the east of New Zealand.

Dinocyst assemblages confirm that SST in the east Tasman Sea was ~2-3 C warmer than the present during late MIS11 (415-400ka), while SSTs were slightly below modern levels during an early phase (428-415ka). Two assemblage–based productivity indices suggest that the elevated SSTs during MIS11 were accompanied by lower rates of primary productivity in the east Tasman Sea study area than the present.

As in the east Tasman Sea, two distinct phases of MIS11 are recognised in both the dinocyst and pollen assemblages at DSDP 594. The dinocyst assemblages of late MIS11 are similar to, but qualitatively represent warmer waters than the Holocene. The succession of pollen assemblages during MIS12-11 is very similar to that observed during the previous two interglacials at this site (MIS1 and MIS5), with two notable variations: (i) the deglacial vegetation succession during MIS11 was prolonged, and (ii) the pollen assemblage representing the warmest forest type was also present for longer (ca. 15ky) than later interglacials.

Changes in the pollen record during MIS11 at DSDP 594 correlate more closely to SST variations in the east Tasman Sea than to ocean variations at DSDP 594, suggesting that the eastern ocean had only limited influence on conditions on the adjacent landmass during MIS11.

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Diatom distribution and community composition variability on the seafloor in a naturally iron fertilised region of the Southern Ocean

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The Kerguelen Island annual phytoplankton bloom is a naturally produced biological phenomenon in the otherwise High Nutrient, Low Chlorophyll Southern Ocean.

Investigations under the KEOPS (KErguelen: compared study of the Ocean and the Plateau in Surface water) mission in 2005 found the bloom is caused by high iron concentrations in the surface waters during spring. In this study, seafloor samples from the second KEOPS mission (2011) at seven new locations around Kerguelen Island were analysed, and compared to 21 samples from existing databases in an attempt to confirm the biogeographic signature of diatom distributions and their relationship to the bloom. Of the 56 diatom species encountered across all samples in this study, the distributions of the top five species (~89% of total abundance) were compared with 'physico-chemical' and 'preservation' factors (sea surface temperature, sea floor depth, distance from the island and mixed layer biogenic silica).

The relative importance of these factors to diatom distributions was both species and site-specific. *Fragilariopsis kerguelensis*, the most abundant species in the Southern Ocean, showed a preservation-controlled distribution, and was strongly associated with deep-water, non-bloom sites. *Thalassiosira nitzschioides* var. *nitzschioides* abundance and geographical distribution was also preservation-related, but distributions were restricted close to the Kerguelen Island coastline. *Chaetoceros* resting spores were primarily bloom-related (a proxy for high iron) in their distributions, while *Eucampia antarctica* and *Thalassiosira lentiginosa* showed a combination of preservation and physico-chemical controls. Absolute diatom abundance, species diversity and evenness were found to be higher on the Kerguelen Plateau than at surrounding sites.

This investigation also focused on a second line of investigation related to the use of replicate samples and local site variability. Here the variability in species abundances between replicate multicorer tubes from the same site was analysed. The results indicate that one multicore tube is sufficient to capture site diversity, however further study with a much larger number of replicates per site is required to confirm this.

"THE HOBBIT HUNTER" A tribute to Mike Morwood

22nd OCTOBER 1950 – 23rd JULY 2013

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Professor Mike Morwood, archaeologist, rock art specialist, visionary, lecturer, colleague and friend, died in Darwin on July 23rd after a year-long battle with cancer. Mike was a forward-thinking archaeologist who had a great appreciation of Quaternary techniques and used this to aid his archaeological interpretation.

As a newly-graduated New Zealand archaeologist in the mid 1970s, Mike Morwood began his archaeological career in Australia with the Queensland State Archaeology Branch, DAIA. With a developing enthusiasm for the prehistory of the Central Queensland Highlands, Mike's travels took him to Injune where he struck up a friendship with the local service station owner who shared his zeal for uncovering the complexities of Aboriginal rock art. The service station owner's name was Grahame Walsh, and their friendship burgeoned into a dynamic and fruitful Kimberley research partnership that extended over two decades.

The pioneering PhD thesis on the Carnarvon Ranges Mike submitted at the Australian National University in 1980 changed the direction of rock art studies in Australia and was described by Emeritus Professor John Mulvaney as the best he had ever read. Rather than considering Central Queensland rock art in isolation, Mike combined excavation, environmental and ethnographic studies to establish the social and environmental contexts in which the assemblage was produced. Such an approach is now widely adopted in regional rock art studies.

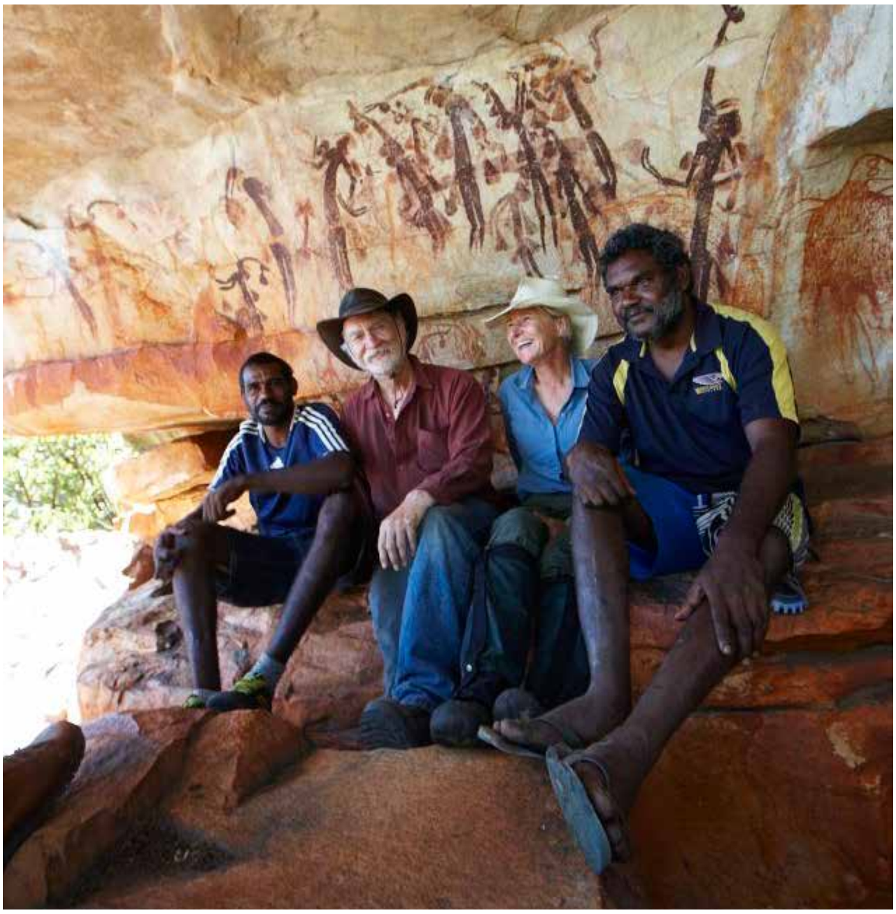
In 1981 he was appointed to the Archaeology Department at the University of New England (UNE). During his 32 years at UNE, Mike proved to be a stimulating lecturer who transmitted his enthusiasm for the potential of archaeology to answer the 'big' questions of Australian, Pacific and South East Asian prehistory. Those of us who were lucky enough to attend his lectures remember him pacing the room while gesturing wildly, words pouring out as his enthusiasm for the topic grabbed his imagination. It was impossible not to be caught up in the excitement. His lectures on rock art formed the basis of the acclaimed book, *Visions from the Past: the Archaeology of Australian Aboriginal Art*.

Students and postgraduates were encouraged to participate in fieldwork on Mike's archaeological projects, firstly in South East Cape York and later in southeast Queensland, the Kimberley and Indonesia. Mike's approach to fieldwork was eccentric and his fieldwork teams were often an eclectic mix of his own research students, other academics' students, undergraduates, former students, and non-archaeologist acquaintances he invited during his travels. This diverse and chaotic mix seemed to create synergies between people and places that would have been impossible with a more orthodox approach. Mike never acknowledged this as his explicit intent, but he was never shy to proclaim more conventional approaches as 'boring!' Mike's students necessarily learned important lessons in pragmatism and organisation through fieldwork and we are all the better for it. A field apprenticeship with Mike provided a solid training ground for a generation of students who now hold major academic or professional positions in archaeology and heritage management around Australia.

The Kimberley coastline, tantalisingly close as it is to South East Asia, appeared to Mike as a likely beachhead for the arrival of humans to Australia. From 1994, he developed research projects aimed at establishing the timing of human settlement in the northwest Kimberley, and ascertaining the ages of stylistic phases that comprise the relative rock art sequence Grahame Walsh had formulated. Excavations at Drysdale 3 revealed human occupation at 25,850±300 years before present. While more recent than dates obtained from sites in the western and southern Kimberley, this date extended the timing of occupation in the northwest by tens of thousands of years. The innovative rock art dating project drew together an expert team including Grahame Walsh, Rhys Jones and Bert Roberts, but the results proved controversial. The experimental OSL dating of a fossilized mud wasps' nest on a rock art panel featuring a Gwion figure provided a minimum age of 16,400 years before present. In an attempt to clarify the uncertainty surrounding these results, Mike adopted 'best practice' by incorporating an additional dating technique into the project. He invited Alan Watchman to undertake radiocarbon dating of calcium oxalate crusts, wax motifs and charcoal pigments occasionally found on Kimberley art panels. Preliminary results suggested that Gwion figures were considerably younger than the OSL dates had shown, but revealed that Wanjina figures emerged around three thousand years ago, and classic Wanjina forms more recently.

The uncertainty surrounding the dating of the vast and varied Kimberley rock art assemblage provided the impetus for Mike's most recent research, an ongoing Australian Research Council Linkage project with us along with Mark Moore entitled Change and Continuity: archaeology, chronology and art in the northwest Kimberley, Australia. The project is generously supported by the Kimberley Foundation of Australia, and its results will stand as testament to Mike's single-minded focus on major research questions and the multi-stranded approach to rock art research that he pioneered. Thirty-nine new rock art dating samples are being analysed and material from nine excavation sites are being tabulated alongside a range of new contextual data to formulate a clearer picture of past Aboriginal life in the northwest Kimberley. It was during this period that Mike's attention turned to Indonesia – the place from which the first Australians migrated. Homo erectus was found in Indonesia but never crossed to Australia while the ancestors of Aboriginal people did.

Much more than a lucky find, the uncovering of the bones of a new species of human, *Homo loresiensis*, in 2003 resulted from an inspired and audacious research programme. The discovery remains one of the most significant palaeoanthropological finds of our times. The skeletal material recovered from a 6 m deep excavation in Liang Bua, a limestone cave on the Indonesian island of



Flores, was soon nicknamed 'the Hobbit' due to its small stature. The joint Indonesian-Australian excavation team, led by Mike along with Randen Pandji Soejone, Thomas Sutikna, Wahyu Saptomo, Jatmiko, Rohkus Awe Due and Wasisto, pushed through layers of volcanic tuff to reveal a lower occupation layer. The original description of the bones was published in Nature in 2004 and drew vigorous debate. The conclusions of the research team have since been supported by independent studies and have resulted in a reassessment of human evolution. Latterly, Mike argued that a study of regional biogeography might provide precedents from which to model the migrations of early hominids between the islands of South East Asia and Australia. Mike's globally significant research in Indonesia includes his work on Flores and has expanded to include Sulawesi. It will continue under the guidance of Adam Brumm and Gert van den Bergh from the University of Wollongong, in collaboration with Mike's close colleagues from ARKENAS in Jakarta and the Geological Survey of Indonesia in Bandung. Despite the acclaim, Mike always remained humble and was dedicated to improving the lives of the Indonesian rice farmers who became important excavators at Liang Bua. Mike made sure that the villages received funds to build religious houses, improve the schools and ensured that the sick were taken care of. During my many trips to Liang Bua I (KW) often saw sick children brought to the cave, who were then whisked away to the local hospital for treatment. The locals affectionately named him "Pa Mike'.

Mike moved to the University of Wollongong in 2007 to take up a position at the School of Earth and Environmental Studies. As a leader in the discipline of rock art, Mike served as the President of the Australian Rock Art Association for eight years until 2000. He became a Fellow of the Academy of Humanities and was awarded the Rhys Jones Medal in 2012 in recognition of his outstanding contribution to Australian Archaeology.

UNE colleague Emeritus Professor Iain Davidson described Mike's collaborative principles, saying 'he understood that the past, particularly in Australia and South East Asia, is the past of indigenous peoples ... and his ability to work with them and with Indonesian scholars is testament to his humanity'. Mike's approach was quintessentially egalitarian. He had no patience with academic hierarchies. Over the past week, many Aboriginal families from Kalumburu and Kandiwal in the Kimberley have conveyed their sadness to me on hearing of Mike's death.

Mike's unwavering enthusiasm for research is exemplified by his determination to return to the Kimberley one last time, a trip he was still planning to make a fortnight before he died. In fact, even in his last few days archaeology was never far from his mind. He spent much of his time discussing the direction of papers that he was in the middle of writing. Mike is survived by his Indonesian wife, Francelina, his former wife Cath with whom he remained close, their daughter Catherine and two grandsons, Deaghan and Riley. Jarla, his daughter with partner Penny Jordan, died aged ten in 2011 from a brain tumour.

Mike was the initiator and the motivator of research. He was a mentor and an unstoppable driving force and he was fiercely loyal. He found the answers to the big questions and wasn't afraid to address the even bigger issues. But it was his support he gave to early-career researchers that really stands out. He was a mentor to a great many of us – myself (KW) included. I know that our careers would have floundered many times without Mike's support. Quaternary science and archaeology have lost a great mind and we have lost a great friend.

RIP Mike

Mike Morwood

22 OCTOBER 1950 – 23 JULY 2013

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