BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1984/14

RECORD

Quaternary Studies in Australia: Future Directions

Discussion papers presented at a Symposium held in

Canberra, May 1984

Sponsored by the Bureau of Mineral Resources, Geology and Geophysics

Compiled by

G.E. Wilford

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PREFACE

Over the past few years the Bureau of Mineral Resources, Geology and Geophysics has been changing its image. One aspect of the new BMR is an increasing emphasis on research. A second change is an increasing interest in surficial materials: the old maps with large areas of undifferentiated green or yellow patches to represent "alluvium" or "Quaternary" will in time be replaced by more detailed and meaningful symbols.

The renewed interest in surficial materials is very widespread in Australia, prompted to some extent by workers in the mineral industry who see the regolith partly as a resource, but more often as a barrier between them and their targets. They are anxious to learn more about the regolith, and the Regolith Program at the BMR is meant to provide some of the answers.

But to understand the regolith we need more than a knowledge of the materials and their distribution. It is important to understand the processes involved, and the history of landscape and regolith evolution.

Australia has a very long landscape history, and the regolith history in many places goes back far beyond the Quaternary. Nevertheless the Quaternary made the last imprint, and in many places the topmost materials that are available for direct observation are of Quaternary age. Furthermore, if we cannot understand what is going on in the Quaternary we have little chance of deciphering the more distant past.

We anticipate, therefore, an increasing concern with things Quaternary at the BMR, and we are pleased to host this Symposium on the Quaternary in Australia. The Discussion Papers in this Record will provide an integrated starting point, previously lacking in Australia, which we hope will stimulate future research on the Quaternary of Australia.

Cliff Ollier
BMR
and Member of the National
Committee for Quaternary Research

BACKGROUND TO THE SYMPOSIUM

In 1980, in response to a policy decision of Council of the Australian Academy of Science, the National Committee for Quaternary Research undertook what was to be a review statement of Quaternary studies in Australia. With the benefit of hindsight, we must admit that the purposes of such a review were never thoroughly spelled out.

A group of authors was identified on the basis of their acknowledged specialities and invited to contribute review statements on those specialities with the prospect of producing an Academy publication on Quaternary Studies in Australia. Some responded promptly and with enthusiasm, others delayed while some saw no point in the exercise at all. The situation degenerated into something of a stalemate, especially when the Academy's publishing section became less than enthusiastic about publishing anything that was not going to pay its way. Experience with other quadrennial reviews did not auger well for publisher's profits.

At its December 1983 meeting, the National Committee reviewed the situation in terms of the manuscripts in hand. It was resolved then to seek alternative ways of salvaging the material available at that time, to use it for the purpose for which it was originally intended, namely as a basis for informing others of the "state of the art" and to stimulate discussion on future developments, technical needs, areas of relevance to other science groups and possible political and financial implications. Towards this end, the Committee asked a group of three, Cliff Ollier, Bruce Thom and myself to investigate immediate avenues of publication. If no suitable outlet could be identified by early March, manuscripts were to be returned to authors withapologies.

We are indebted to Cliff Ollier and the Director, Bureau of Mineral Resources, for resolving that impasse by facilitating publication as a BMR Record. Additionally, Bruce Thom as incoming Chairman of the Committee has been particularly active in making arangements for this meeting.

The occasion for which the enclosed documents provide the basis for discussion will almost certainly address itself to some of the major organizational challenges with which practitioners of Quaternary sciences inevitably will have to contend in the next decade or so. Questions such as organization of adequate chronologic facilities will loom large. The ongoing needs for improved accuracy, longer time coverage and more diverse ranges of dateable materials are of central interest to the advance of our discipline. Improved methods of radiocarbon dating are emerging side by side with new developments in thermoluminescence, electron spin resonance, palaeomagnetics and uranium-series dating to name just a few already changing the pattern of the Australian scene. But how do more people obtain improved access to such facilities on an equable basis?

Additionally, the prospect of Australia's participation at the international level needs careful consideration. We must identify what we wish to see included by way of major sessions at the 1987 INQUA conference in Canada. Moreover, should we ever wish to host INQUA within the next decade or so we should begin to address that question now. Already we would be looking at 1991 at the earliest. But even to contemplate that means sounding out feeling from the wider community well in advance of the Canada meeting.

Finally, the occasion of this meeting provides the first opportunity to discuss with a wide audience the arrangements for a first field meeting of AQUA, the Australasian Quaternary Association. In that sense the opportunity afforded by discussion of the papers contributed to the Symposium could be most valuable.

In conclusion, let me reiterate my apologies to those authors who contributed on time. With this opportunity provided by the BMR, we can say with some degree of optimism that, despite the frustrations, all has not been in vain.

Jim Bowler
Retiring Chairman
National Committee
Quaternary Research
April 8, 1984

CONTENTS

DATING THE AUSTRALIAN QUATERNARY

Compiled by Mike Barbetti

Introduction

The need to place events or changes into a time frame is basic to virtually every aspect of Quaternary research. A wide range of dating methods is known, but not all are practised in Australia.

A list of facilities available in this country is included as a Table. It was compiled from answers to a questionnaire sent in 1980 to over 60 scientists; some of them specialists in one particular method, others really 'users' of dates, though the majority fall between these extremes because they have facilities for some methods and obtain others by collaboration or contract.

Views on future developments and likely areas of special need were also solicited by questionnaire. A brief and perhaps rather personal summary is given. Some key areas are presently underdeveloped, and recommendations for improvement are offered.

It is regretted that space restrictions made it impossible to discuss basic principles, problems and current research projects for every dating method.

Present Facilities and Their Availability

A summary of existing Australian facilities for dating the Quaternary is given in the Table. Methods are divided into those which can give direct estimates of ages, those which can be used to correlate new sites or stratigraphic sections with those elsewhere which have previously been dated by direct methods, and relative dating methods which can be used to sort assemblages of objects with different ages (e.g. deposits of bone, where some pieces may have been reworked from more ancient deposits). Direct methods are listed roughly in order of the time span to which they are applicable, from dendrochronology and radioactive isotopes with half-lives of tens of years, through methods such as radiocarbon and thermoluminescence which operate from about one hundred to several tens of thousands of years, to the potassium-argon method which can be used for volcanic rocks with ages in excess of a few hundred thousand years. Correlative methods range from those which can immediately pinpoint an instant in time (e.g. recognition of a distinctive layer of volcanic ash in a sedimentary sequence) to those which depend on matching records of subtle and often irregular changes over longer periods of time.

Facilities are grouped by region in the Table; most of them are located around capital cities. Policies controlling access are summarised by entries in three categories; research by staff only, collaborative research with individuals from other institutions (generally restricted by machine time and the interests of staff at the facility), and readily available as a service (usually for a fixed fee).

It can be seen that facilities for correlative methods for which demand is high (e.g. geochemistry and sedimentology) are to be found almost everywhere. Access is generally not difficult unless a very large number of analyses is required. Some of the more specialized correlative methods (e.g. palaeomagnetism) are less ubiquitous, but again access is generally not a severe problem.

Relative dating methods are at present little used in Australia and adequate service is available.

Direct dating methods are an entirely different proposition. Only Canberra has or soon will have facilities for nearly all methods. The Sydney region has a number of facilities spread around several institutions, and Adelaide is sparsely endowed. Brisbane, Melbourne, Hobart, Perth and Darwin suffer an almost total lack of facilities, which is surprising in view of the volume of Quaternary research conducted in those places.

Most facilities have policies which restrict their use to research and collaboration. Indeed, Universities in general seem to discourage extramural service work if it does not involve research and publication. This attitude may, however, be relaxed for sister departments within a particular University.

Time and resources also restrict the availability of direct dating methods, even for those methods where a contract service is available. Bottlenecks of this kind are becoming more severe, particularly for tritium and radiocarbon dating.

The overall situation in Australia at present is one where facilities for dating are dispersed among University departments and Government Institutions, and generally not very accessible to individuals from other establishments. Dating laboratories are regionally concentrated around Canberra, Sydney and Adelaide, but Quaternary research is being carried out all over Australia. Demand for most types of dating outstrips the supply available; the situation is already serious for tritium and radiocarbon.

Future Needs

Two decades ago radiocarbon dates were difficult to obtain and one had to make do with just a few for each project. A decade ago Quaternary events and changes were being studied in greater detail; more accuracy was demanded, problems in selection and environmental contamination of radiocarbon samples were being tackled, and upwards of a dozen dates were needed for many projects. Other direct dating methods were by then becoming established. Nowadays ten or even a hundred dates may be obtained for one project, radiocarbon is by no means the only method used, and both users and dating specialists are constantly on the lookout for opportunities to compare and cross-check different dating methods

Forecasting needs for the eighties is a tricky job in any situation, but it would be surprising if recent trends did not persist. One can fairly confidently envisage increasing demands for all kinds of dating. Radiocarbon will probably remain the workhorse, but other methods are likely to flourish. A dramatic increase in the use of methods applicable to short time scales seems imminent, in view of increasing concern about very recent environmental and climatic change, water resources, pollution and the increasing concentration of carbon dioxide in the atmosphere. The message is fairly clear for dendrochronology, ice dating in Antarctica by annual layer counting, and isotopic analyses (tritium, lead-210, caesium-137, carbon-14 and others).

The demand for dates in the 50,000 - 100,000 year range is also likely to increase substantially in the next decade. The earliest archaeological sites so far discovered in Australia date from about 40,000 years, close to the limit of radiocarbon dating by conventional techniques, and it is quite possible that older sites will soon be discovered. There is also a growing interest in climatic, vegetational and faunal history over this period. Two dating methods particularly appropriate to this time range are thermoluminescence (for terrestrial sites) and uranium series (for marine deposits). It may be possible to extend the range of radiocarbon dating, and amino acid racemization techniques may also have a role to play. Only fission track and potassium-argon dating are not likely to be used much more frequently than at present, because little igneous activity occurred in Australia during the Quaternary.

Correlative methods seem likely to be used more in the next decade, particularly where they may help to pinpoint marker horizons or special events. Relative dating methods probably have a limited but useful role to play.

If forecasts about trends are arguably speculative, then forecasts about revolutionary new developments must be downright hazardous. Nevertheless, it would be an omission not to mention some of the possibilities. Isotope measurements by nuclear accelerator have already been proved feasible and, given technological advances needed to make the method routinely applicable, will make a dramatic impact. Carbon-14 dating will be made much easier, with centigram instead of gram samples and dating back to perhaps 70,000 years. New methods such as ^{36}Cl, for groundwater, or ^{26}Al and ^{10}Be for sediments, and possibly others will be opened up. Only one suitable accelerator is currently installed in Australia, and it may well be dedicated entirely to mineralogical applications at the CSIRO Division of Mineral Physics near Sydney.

Another important area deserves mention because it is not covered satisfactorily by existing methods and may not be covered by new developments under way. Many projects in prehistory, particularly studies in settlement patterns, require large numbers of relatively inaccurate dates. The sorting precision needed is, say, modern, 200 - 2000 years, 2,000 - 5,000 years and beyond 5,000 years. It may be hard to interest physical scientists in this kind of problem, but there may well be some basic methods as yet untried which might be applied cheaply, quickly and easily.

In summary, needs for the next decade are going to be mainly for increasing numbers of analyses of the kinds used at present. Isotope dating by accelerator will certainly make an impact, with present methods becoming easier to apply and new methods made feasible. Some effort needs to be directed towards reducing the costs and improving the availability of analyses. Research into new methods must continue.

Areas requiring special support

Virtually every existing dating method and Australian laboratory could well do with more support. In attempting to single out areas of special needs, one should first consider sources of funding already available.

It therefore seems appropriate to draw a line between 'research' and 'service'. 'Research' includes methods under development where every new application throws up new problems to be solved (uranium-series dating is a good example), and laboratories which restrict their operations to research-oriented problems. They can obtain funds through Universities, the ARGS, AMSTAC, NERDDC and private foundations, subject to well-established research criteria, and they should be encouraged and supported in their continuing efforts to do so.

Establishment of 'service' facilities to apply well-established methods is an area of special financial need, because such activities are not rated highly by committees which distribute research grants. Committees will, however, grant funds on individual research projects to pay for analyses by contract service. But existing service laboratories are few (see Table) and their resources very limited. Australia needs a national centre for research and contract analyses (of, say, tritium, lead-210, caesium-137 and carbon-14) to cope with existing and projected demands for the 1980 s. A nuclear accelerator for isotopic measurements could eventually be part of such a facility. Operation of a national service facility is not compatible with the philosophy of individual Universities, but it may be possible to persuade a number of them to support a joint facility. Alternatively, such a facility could be set up in a Government scientific establishment. Funds for capital expenditure and equipment would have to be found, in the first instance, but operating costs after that could be recouped to some extent by charging for analyses. The facility should be located where there is a strong Quaternary research group with a need, possibly in Sydney or Melbourne.

Acknowledgements

The ideas, suggestions and cheerful encouragement of many colleagues is gratefully acknowledged.

Table. AUSTRALIAN FACILITIES FOR DATING THE QUATERNARY

Facilities are grouped by region. Methods are divided into those which give ages directly, those which can be used to correlate sites or sequences, and those which can give relative ages in special circumstances. 'Other annuals' includes varves, ice layers and growth layers in shells or coral. 'Geochemistry' may include X-ray diffraction or fluorescence, proton-induced X-ray emission, atomic absorption spectroscopy, electron microprobe or chromatography (and the list here is by no means a complete one). 'Stable isotopes' refers to deuterium, carbon, oxygen or sulphur isotope measurements by mass spectrometer. Fluorine uptake and nitrogen loss may occur in bones in sedimentary deposits. Electron spin resonance may soon become a direct method.

A more detailed list of facilities and contacts is given by Joanne Porter and Mike Barbetti, Directory of Australian Archaeometry and Conservation, in Archaeometry : An Australian Perspective (W. Ambrose and P. Duerden, eds.), Department of Prehistory, Australian National University, 1982, pp.373-391.

● = now ⦶ = near future ○ = envisaged

<u>Table.</u> AUSTRALIAN FACILITIES FOR DATING THE QUATERNARY
(see page 8 for explanation)

REGION, INSTITUTION & DEPARTMENT	DIRECT METHODS														CORRELATIVE METHODS							RELATIVE METHODS			CONTACT	USAGE		
	Dendrochronology	Other annuals	Tritium	Lead-210	Caesium-137	Obsidian hydration	Radiocarbon	Amino acids	Thermoluminescence	Uranium series	Chlorine-36	Be-10, Al-26	Fission track	Potassium-argon	Tephrachronology	Geochemistry	Palynology	Palaeomagnetism	Sedimentology	Palaeontology	Stable isotopes	Fluorine/uptake	Nitrogen loss	Electron spin resonance		Research	Collaboration	Service
BRISBANE																												
University of Queensland																												
Geology																	●			●	●				R. Orme	●	●	●
Chemistry																								●	P. Pomery	●		○
SYDNEY																												
Australian Atomic Energy Commission - Research Establishment			●	●	●	●	●			●	●	○	●								●	●	○		P. Airey	●	●	●
																●									R. Bird	●	●	
CSIRO Mineral Physics											⊖	⊖				●		●			●				S.H. Sie	●	●	
Macquarie University Earth Sciences															●	●			●	●					R.J. Blong	●	●	
Biological Sciences																	●			●					D.A. Adamson	●	●	
University of N.S.W.																												
Geography															●		●								C. F. Pain	●		
																	●								J. R. Dodson	●	●	
Chemistry							●																		V. Djohadze	●	●	
Physics									●																J. Kelly	●	●	
University of Sydney																												
Geology & Geophysics														⊖		●					●				D. Hendry	●	○	
Biological Sciences																	●								A.R.H. Martin	●	⊖	
Macintosh Centre	○						●														○				M. Barbetti	●	●	●
WOLLONGONG																												
University of Wollongong Geography																			●						G. Nanson	●	●	
CANBERRA																												
Australian National University																												
Biogeography & Geomorph.	⊖	●														●	●		●						J.M.A. Chappell	●	●	
Earth Sciences				●	●		⊖			●						●					●				T. Torgersen/ARC Fiver	●	●	
"														●											I. McDougall	●	●	
"																		●							K. Lambeck		●	
Prehistory R.S.Pac.S.						●																			W.R. Ambrose	●	●	
"							●				○										●				H. A. Polach	●	●	●
"																			●	●					J. Hope	●	●	
Botany SGS																	●			●					P. Ladd	●	●	
Geography SGS																	●		●						G. Hope	●		
Geology S.G.S.																●										●		
Physics S.G.S.									●																A.J. Hortlock	●	●	●
CSIRO Land Use Research																			●						R.J. Wasson	●	●	
Aust Inst. Aboriginal Studies																				●					D.R. Horton	●	●	●
MELBOURNE																												
Antarctic Div (Glaciology)		○																			●				V. Morgan	●	⊖	
CSIRO Atmospheric Research																					●				R. Francey	●	●	
Monash University																												
Earth Sciences																●												
Geography																	●								P. Kershaw	●		
Zoology																				●								
National Museum of Vic.																				●					T.H. Rich	●		
Prahran CAE - Toorak S.C. Museum Studies Science																	⊖		●						D.W. Orchiston	●		
State Laboratories Vic.							○																		A. Bermingham			

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MELBOURNE (Con't)																												
University of Melbourne																												
Chemistry				●												●									J. D. Smith	●	⊖	
Geology				●	⊖											●									T. C. Hughes	●	⊖	
"													●												A.J.W. Gleadow	●	⊖	—
"				●															●						J. B. Keene	●	⊖	
CSIRO Atmospheric Research																					●				R.J. Francey	●	●	
Victoria Archaeological Survey																			●						A. McConnell	●		
HOBART																												
Antarctic Div. (Biology)		⊖														⊖									H. Burton	●		
CSIRO Forest Research	●																								T. Bird	●	●	
University of Tasmania																												
Geography																	●							●	E.A. Colhoun / H. Goede	●		
Geography/Geology/																					●				D.C. Green	●	●	●
Central Science Lab.																								●	A. Goede	●		
Dept. of Mines																	●		●	●					D.C. Green	●	●	●
ADELAIDE																												
Aust. Mineral Development Laboratories													●												F. Radke	●	●	●
														●											A.W. Webb	●	●	●
CSIRO Soils			●				●														●				G. Allison	●	●	●
Flinders University																												
Biological Sciences																				●					R. Wells	●	●	
Earth Sciences		●		●	○					●			○									●			H.H. Veeh	●	●	
"																		●							F. H. Chamalaun	●	●	
University of Adelaide																												
Geology																●			●						V. Gostin	●		
Physics				●	●				●																J.R. Prescott	●	●	
PERTH																												
University of W.A.																												
Geography																			●						K.-H. Wyrwoll	●		
Geology																●									J.E. Glover	●	●	
"																	●								B. Balme	●		
Chemistry																								●	F. Hewgill	●	●	
W.A. Institute of Tech.																												
Physics																					●				K.J.R. Rosman	●	●	
Chemistry							●																		I. Twaddle	●	●	●
W.A. Museum Palaeontology																				●					G.W. Kendrick	●	●	

MAN IN THE LATE QUATERNARY HISTORY OF AUSTRALIA

John Beaton and Rhys Jones

The intimacy of man-land relationships in Australia has long been recognised, and indeed most of the fundamental discoveries in Australian prehistory (e.g. Mulvaney and Joyce 1968; Bowler et al. 1970; Dortch and Merrilees 1973) have resulted from enquiries directed precisely at the nature of the interaction of man and late-Quaternary environments and landforms. In recent years various authors have continued this trend and contributors to four substantial volumes (Mulvaney and Golson 1971; Walker 1973; Allen, Golson and Jones 1977; Kirk and Thorne 1976) have addressed the considerable multi-disciplinary problems of palaeo-geographic, environmental, and occupation-history reconstructions from both chronostratigraphic and broad areal perspectives.

The dark continent of prehistory

The last 25 years have seen a revolution in our knowledge of Australian prehistory. In a major review published in 1961, John Mulvaney could write that Australia was the 'dark continent' of world prehistory.

The method of radiocarbon dating had only been invented a few years previously, and only a handful of assays had been made from Australian archaeological sites. The oldest claimed date was one of 8700 years from a sand-dune in South Australia (Tindale 1957); the oldest in a stratified excavated rockshelter being only 4900 BP; and there was a considerable opinion that the entire prehistory of Australia did not extend back beyond mid-Recent times (Abbie 1951). Excavated sites were few in number and restricted to a few locations. Active research was confined to less than half a dozen isolated workers, many of them part-time archaeologists in the State Museums, especially of Sydney, Adelaide and Melbourne, with almost no research being done in the universities or government research agencies. The reasons for this were many and have been discussed by Jones (1979, 1982) and Mulvaney (1981) but two major factors may be isolated.

Firstly, the Aboriginal inhabitants of Australia, since the days of Dampier and other European explorers had been perceived of as exemplars of 'Stone Age' man living a life, as the American geologist Gregory put it of 'living fossils Their culture survived unchanged from ancient times, due to their isolation from the evolutionary developments such as agriculture which had transformed the economic and social lives of man in Europe, Asia and Africa some 10,000 years ago. A corollary of this argument is that the lives of ancient Aborigines were substantially the same as those of contemporary ones and that direct investigation of that past through excavation would be futile since, in the words of Pulleine, (1929) speaking as the President of the Anthropology section of the Hobart meeting of the Australasian Association of Science in 1928, 'everything points to their being an unchanging people in an unchanging environment'. A challenge to such views, which might have been expected to emerge from the universities, did not eventuate. At the University of Sydney the first department of archaeology in the country specialised exclusively in Classical and Middle Eastern studies. The first department of anthropology which was established in 1929, also at the University of Sydney, dominated the field for the next 30 years was a functionalist school of social anthropology with little tolerance for what was denigrated as 'conjectural history' (Radcliffe Brown 1930).

The second reason lies in the very personality of the Australian landscape with its generally subdued and ancient land forms. Compared with the other continents, there is a paucity of obvious deep Quaternary sequences due to erosion following tectonic uplift. Desert and tropical geomorphic processes were unfamiliar to workers with a temperate European training and pollen analysis could not be carried out until the basic pollen identification of an unfamiliar flora had been carried out, and so on. The tardy development of Australian prehistory is mirrored by a similar delay in the initiation of the specialist field of Quaternary studies. As other chapters in this book make clear, detailed demonstration of Pleistocene geomorphic and palynological sequences have only been achieved within the same 25 years as have the archaeological ones.

The late development of Australian prehistory is not a trivial episode in the history of Australian science because fundamental questions about the antiquity and subsequent history of man on this continent have been asked over the past 180 years by some of the most penetrating scientific minds of their generations, including from the early 1800s Flinders and Peron, to Topinard Leichhardt, Huxley, Lyell, Tylor, Howitt, Baldwin-Spencer, Edgeworth-David, Wood Jones and Macintosh to name but a few.

There is no doubt that new methods of absolute dating, particularly radiocarbon dating, acted as a massive stimulus to both prehistoric and Quaternary palaeo-environmental studies, from the early 1960s onwards. University posts in prehistory, established initially as junior lone pickets within departments of anthropology or history were established in the Universities of New England, Sydney and the ANU where they formed the nuclei of what 20 years later have become fully fledged departments or sections of departments.

In 1984, prehistory is taught as a full degree course leading to MA and PhD in 7 Australian universities. Most external funding for research comes from the ARGS, the Australian Institute of Aboriginal Studies, various state National Parks Services, the Australian Heritage Commission and private consultancies which usually result from environmental impact studies. State legislation in all states and territories, with the noticeable exception of the ACT, has led to the establishment of archaeological services to administrate them and in some cases to act as institutions for basic research. Increasing interaction with Aboriginal organisations has resulted in Australian archaeologists becoming deeply aware of the moral and political implications of their researches to the Aboriginal emancipation cause, and has also resulted in some situations of confrontation regarding who owns, administers or has the right to investigate the Aboriginal past as was exemplified by the 1983 Aboriginal Australian Academy of Humanities symposium - "Who owns the past?").

Today, there are some 400 members of the Australian Archaeological Association, almost all being professional archaeologists or pursuing postgraduate degrees. Broader archaeological issues are important to several of the fundamental debates of Australian society, particularly in the fields of environmentalism and Aboriginal emancipation. Three out of five Australian nominations for World Heritage Status (viz. Willandra Lakes, Kakadu, Southwest Tasmania) to the UNESCO had in their nominations major sections devoted to their archaeological resources. In particular, the Pleistocene cave occupation sites of the Franklin River, discovered as recently as 1981, played an important part in the scientific case put up to prevent inundation of this region for hydro-electricity development (Senate Select Committee 1982).

Issues, problems, and paradoxes which have arisen from the fundamental discoveries of place and time have, for the most part, become increasingly complex - not simple. In the remainder of this short communication we identify some of the persistent and emerging issues of man-land history in Australia. In some cases we can point to a much higher resolution in our understanding of particular areal or temporal facts than was possible even five years ago. Other problems remain as intriguing but vexatious as ever.

Antiquity of man

The question of the antiquity of man in greater Australia cannot be answered at a single site. Rather, it is the pattern of dated discoveries from a range of sites in different environments which allow us to be confident of the presence of man by c. 40,000 BP. New evidence continues to mount from areas of the original discoveries of nearly two decades ago, especially the lunettes and palaeo-shorelines of the Willandra and other lake systems of the lower Murray-Darling. Excavations by Bowler, Mulvaney and Shawcross (Shawcross and Kaye 1980) at the original Lake Mungo 1 cremation and occupation site revealed stone tools in situ down to soil levels apparently near the upper limits of 14C dating. At the nearby Arumpo lunette McBryde has freshwater mussel middens dating to 37,000 BP (Bowler 1976). On the anabranch system of the lower Darling, especially at Lake Tandou, a systematic survey of middens and other occupation sites (see Hope 1982; Hope, Dare-Edwards and McIntyre 1983; Balme 1983) has revealed extensive occupation evidence in the time period of c. 25,000 to 27,000. In the extreme west of the continent stone tools excavated from sedimentary facies of the upper Swan River date to c. 38,000 BP (Pearce and Barbetti 1983). In the north, excavations at Walkunder Arch cave in the Chillagoe karst date occupations there to terminal Pleistocene times (Campbell 1982). Recent excavations at the Lindner Rock shelter at Nauwilabila (Jones 1984) in Kakadu National Park revealed stone tools in a weathered and compacted rubble down to 1 m below a 14C date of c. 20,000 which was obtained in the test excavations of Kamminga (Kamminga and Allen 1973). In New Guinea, excavations at the Nombe rockshelter in the eastern highlands has produced stratified stone tools in association with a varied marsupial fauna dating in the lower levels to at least 24,000 BP (Gillieson and Mountain 1983). These dates and the dating of a hearth at the base of Kuk swamp to 30,000 BP (J. Golson pers. comm.) underline the antiquity of human occupation before the height of the last ice-age. Sites now under investigation which may date as old or older than the above sites include the raised terraces of the Huon Peninula (L. Groube, J. Chappell pers. comm.).

In Tasmania, recent discoveries of limestone caves and rockshelters such as Kutikina (Fraser) Cave in the Franklin River Valley have shown rich occupation deposits dated to between c. 14,500 to 20,000 BP (Kiernan et al. 1983; Jones 1983). These were the most southerly hunters on earth during the height of the last ice age. The numerous discoveries of human occupation dating to near the limits of the conventional radiocarbon method underscore the necessity for development of dating techniques (e.g. T.L., electron spin) which will date older and smaller samples.

Man and Landscape

Two of the continuing and pivotal issues regarding man and his evolving relationship with the new landscape and its biota are the effects of human fires and the association with megafauna. At Nombe rockshelter (PNG) Mountain has discovered bones of extinct marsupials (e.g. Protemnodon) in association with artefacts in a stratified sequence. Similarly clear associations for Australian sites still elude us, although there is no doubt that man and megafauna co-existed for some time. At Mungo 1, bone fragments of Procoptodon were found in post-25,000 BP content (McIntyre and Hope 1978) and isolated finds of Procoptodon and Sthenurus at Tandou occur above the pedoderm, i.e. post 27,000 and overlapping in time with humans (Hope et al. 1983). However, whether these are genuine functional associations of hunters and their potential prey, or whether they are due to spurious stratigraphic correlation has not been established. To illustrate the complexity of the problem, in southwestern Tasmania man was hunting exclusively modern fauna (especially Macropus rufogriseus) between 13,000 and 20,000 BP, but at Tambah Springs in northern New

South Wales, Wright and Horton (pers. comm.) report an apparent temporal overlap of man and megafauna (Diprotodon) which places this potential prey species there as late as 6000 BP. This date is anomalous compared to the pattern of extinction which in eastern Australia appears to have occurred prior to c. 25,000-27,000 BP (Hope et al. 1983). Competing theories regarding the contribution of climatic factors (viz. glacial-arid) as opposed to human hunting are still unresolved.

Fire

The effects of mans' fires on the landscape, vegetation communities and biota are registered in the depositional records of lakes and swamps in tropical northern Australia (Kershaw 1974), the New Guinea Highlands (Hughes and Golson 1976), and in southern temperate Australia at Lake George (Singh, Kershaw and Clark 1981). In their pollen curves both Kershaw and Singh have demonstrated that the late-Pleistocene was a period of rapid change in the distribution and relative abundance of forest taxa. They show that fire-adapted species (esp. eucalypts) dominate at the expense of fire sensitive species such as the podocarps, many of which became extinct on the Australian mainland. These changes are not associated with any known climatic changes, but rather with increases in charcoal in sediments and increased slope instability which lead the authors to implicate a greatly increased fire regime due to human burning practices. Archaeologists are actively engaged in documenting such fire regimes among contemporary Aborigines, especially in Arnhem Land (Haynes 1978; Jones 1980) and central Australia (Latz and Griffin 1978; Kimber 1983). The implications of fire regimes for the patterning of contemporary monsoon forests is being studied by J. Russell-Smith in western Arnhem Land and Clark (1983) has summarised the major issues involved in fire history reconstructions from geomorphic evidence including a critical review of the human impact hypothesis.

Colonisation

The colonisation of the various ecological zones Sahul/Australian land mass is a subject of continuing controversy. The geographic pattern of early 14C dates is evidence that man was present and his explorations were widespread by 25,000 BP. Caves and rockshelers in the New Guinea highlands, lake shores in western New South Wales, river sediments in Western Australia and further discoveries in cave sites in Tasmania all indicate the use of local resources and the manufacture of maintenance and extractive tools by men living in late Pleistocene environments. It is not clear however just what were the means and routes by which man came to occupy (by mid-Holocene times at least) all the various land types and ecological zones of the continent. Bowdler (1977) has argued that the original colonists were people of coastal/maritime origin who would have practised a marine or intertidal economy and thus would have followed the coasts in their colonising before exploring and eventually settling on the major river systems. Alternatively, Horton (1981) has recently argued that woodlands and freshwater systems would have been more important conduits of exploration and colonisation (see also Birdsell 1957). Certainly there are numerous well-dated Pleistocene occupation sites found along inland rivers and relict lacustrine lake systems, but it is not possible to search for equivalent sites on what are now the submerged continental shelves where early coastal colonists might have lived.

Human variation

The study of Aboriginal and palaeo-Australian physical anthropology is also important in reconstructing the history of population migration, population growth, and interactions between populations in prehistory. Unfortunately we seem to be no nearer to identifying the place of origin of Australia's first migrants. On the basis of physical and cultural similarities and geographic proximity, physical anthropologists and prehistorians have pointed vaguely to southeast Asia and particularly the Java region (Thorne and Wolpoff 1981) as the most likely source for colonists. Recently Thorne has also sought a more northerly Asian origin linked with sea-going bamboo rafts which he believes could have brought people from the north central Asian mainland and down through western Pacific islands to Australia before 40,000 BP.

In a study of human morphological variation in Australia Pardoe (ANU PhD thesis) has mapped gene-based skeletal morphology against geographic parameters including the major barriers (e.g. Bass Strait) and the likely corridors of gene flow such as the larger rivers. This new direction in Australian physical anthropology plus other illuminating studies such as Brown's (1981) interpretation of the Coobool Creek crania are redefining the questions and providing much improved perspectives on the physical history of Aborigines. Pardoe, for instance, has identified both discrete and clinal patterns which he interprets as reflecting long-term population associations and the history of broad scale gene flow. This study has clear implications for the colonising history and has provided archaeologically testable correlates.

Intensification

The increase in the numbers of practising prehistorians has meant that complementary studies can now be combined to investigate regional sequences in a more precise way. At the same time it is possible to ask questions of a more subtle nature than was possible in years past. An example is the research into the relationships between man and late-Holocene environments in western Victoria. In the southwest of the State changes in resource use are suggestive of local intensification (Lourandos 1980a, b, 1983) but not all lines of evidence are unequivocal (Head 1983). In the north of the state, in the Mallee, changes in the Holocene occupation pattern have been described (Ross 1981) but they may not be tightly associated with changes in environmental conditions. These western Victorian studies agree that an increase in population numbers in late-Holocene times was likely.

Regional demographic and population reconstructions are as difficult as they are enticing, but as the Victorian researchers have found, an appreciation of changes in population densities (even if in the absence of reasonable estimates of actual population numbers) has very profound consequences for man-land relationships. Hughes and Lampert (1982) for instance point out the relationship between site use incidence and relative population numbers and conclude that a late-Holocene increase can be detected on the NSW south coast. Although different regions may have quite different population growth histories with some regions even experiencing early occupation followed by absolute vacancy it is still desirable to consider the problem of how the total Australian population grew from nought to .3-.5 million persons by 1770 AD. Birdsell (1957) first considered this problem and argued that it was theoretically possible for a founder population to grow to such a figure in just a few thousand years. With the benefit of numerous 14C dates and a much more detailed archaeological record it has been recently suggested (Beaton 1983) that a long and slow population growth with a rapid increase in late-Holocene times is equally theoretically likely and better fits the archaeological data. Clearly, a better picture will come into focus with more detailed regional studies which are able to estimate the relative population numbers and their impact on the environment.

Agriculture

Deforestation, increased erosion, water management channels, changes in settlement pattern - all these are archaeological markers of the development of plant domestication or horticulture. None of these markers are present in pre-

European Australia but all the markers are clearly evident in New Guinea and are known to have at least 9000 years of antiquity there. Golson (1976, 1977) has described a network of swamp drainage channels, raised planting mounds and associated implements which mark several phases of cultivation and likely changes in the cultigens grown at Kuk, near Mt Hagen. Golson's work has raised a fundamental question for Australian prehistorians - why in almost 10,000 years was horticulture not taken up in northern Australia? No fully satisfactory answer can be put forward at this time and much research needs to be done on this question although some elements of the problem are becoming clearer. Certainly hunting/gathering Australians had options (Jones 1981). Food plants (e.g. Dioscorea sp., Oryza sp. Colocasia sp.) occur in northern Australia and are suitable cultigens but their use was restricted to the gathering of wild crops. Although Aboriginal use of plants may not have been agricultural it was nonetheless astute and in the vicinity of campsites certain useful plants were protected and even nurtured to a degree. Hynes and Chase (1983) have aptly termed this Aboriginal man-plant relationship domi-culture. Recent discoveries of relict raised planting mounds and water diversion channels in lowland southwestern Papua and on the low sedimentary western Torres Strait island of Saibai (Barham and Harris 1983; Harris and Laba 1983) suggests that the southern limits of horticultural experimentation may have been very near the north coast of Australia.

Ethnoarchaeology

Although the thrust of this review concentrates on more traditional archaeological methodology and discipline alliance with other Quaternary scientists, a major departure must be noted; that current archaeological research has renegotiated its longstanding contract with ethnography. Because the questions being asked are new ones it has become necessary for archaeologists to carry out their own ethnographic studies on topics which have been largely ignored by previous generations of ethnographers whose interests were narrowly social anthropological. Ethnoarchaeological issues concentrate on the ecological base of hunting/gathering societies, their technology, their choice of site location and their methods of site formation and discard behaviour. This integration of archaeology and ethnography in the construction and testing of behavioural models is a major contribution to current world archaeological theory building.

In the field of stone tool analyses and the relationship between Aboriginal behaviour and stone tool discard there have been a number of fundamentally important Australian studies, particularly among Aborigines of the arid zone (Gould, Koster and Sontz 1971; O'Connell 1977; Hayden 1977, 1979; Cane 1984). Recent trends in investigating the significance of stone tool attributes look at manufacturing techniques and use-wear on surfaces of worked stone tools. Use-wear studies (Kamminga 1979; Fullagar 1982) involve the establishment of criteria for distinguishing the particular characteristics of polish and wear resulting from experimentally controlled activities such as flesh cutting, woodworking or hide preparation.

Other analyses of stone tool assemblages focus on the manufacture of edge ground axes (Dickson 1980) and on the stepwise reduction processes in manufacture (Luebbers 1978, Hiscock 1979). These studies provide an independent baseline for the linking of stone tool form to function against which both ethnographic and prehistoric stone tool assemblages may be interpreted.

The second major focus of recent ethnoarchaeology has been studies of diet, hunting behaviour and energy capture among hunters. Among these the studies of Meehan (1977a, b, 1982) are widely quoted in the world literature. On a broader regional scale the Arnhem Land studies of Jones (1981) and the desert studies of O'Connell and Hawkes (1981) seek to account for the behaviour of hunters in relation to the geography of resource distribution and availability. Related studies of potentially great value in understanding man/plant relationship are being carried out by J. Devitt (University of Queensland) in the desert, W. Beck and N. White (Latrobe University) in Arnhem Land, J. Russell-Smith (ANU) and D. Yen (ANU) whose cytological investigations of Ipomoea and Colocasia are fundamental to our understanding of the origins of use of these plants. On the Cape York Peninsula D. Smyth, A. Chase and other contributors to the Cape York Ecological Transect Project are documenting Aboriginal plant use. Bridging the Cape York and south coast of Papua research by Barham and Harris (1983; Harris 1979) are pointing up important similarities and differences which may help to account for this apparent frontier of plant domestication at Torres Straits.

Multidisciplinary studies

Multidisciplinary projects in Australia have a long and respectable history, indeed most of the landmark discoveries (e.g. Fromm's Landing, Keilor, Kenniff Cave, Willandra Lakes) resulted from the co-operation of archaeologists and other Quaternary scientists. This trend has continued but has increased in scope and is now armed with improved techniques. At Kakadu National Park researchers primarily from the Department of Prehistory, RSPacS, ANU, but including colleagues from geography, botany and geomorphology are carrying out a series of investigations on sandstone rockshelters and open sites which border wetlands. The objectives are to describe the changing human response to recent evolution of the Alligator River Valleys and the late-Holocene development of the rich freshwater wetlands. The enquiries involve aspects of the Aboriginal burning regime, geomorphic processes and consequent vegetation patterning.

Similarly, at Princess Charlotte Bay, on the east coast of the Cape York Peninsula another multidisciplinary project, again based at ANU, is reconstructing the occupation history and peri-coastal evolution of a tropical reef and mangrove estuary environment. Archaeological, geomorphological and ethnobotanical studies on the nearby Flinders Islands and the Princess Charlotte Bay mainland are integrating different lines of research to reconstruct the history of mid- to late-Holocene changes in the human occupation pattern and changes in the bay foreshore ecology which result from rapid episodic progradation.

These projects illustrate the value and potential of research where numerous and varied lines of evidence are brought to bear on problems with overlapping data bases and intertwined evolutionary histories. In such studies, where information is rapidly and copiously collected much greater attention is being paid to the problems associated with research designs, data collection and retrieval. It has been whimsically said that the wild west of Australian archaeology of the 1960s was the day of the lone cowboy* - now, in the early 1980s we are seeing the emergence of 'posse archaeology'.

*Apologies to Carmel Schrire and other cowgirl archaeologists (cf. Mulvaney 1983:160).

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THE RELATION OF SOILS WORK UP TO 1981 TO STUDIES OF THE QUATERNARY

G.G. Beckmann

I. INTRODUCTION

This report outlines some of the work currently being done by soil scientists in which there are aspects relevant to the Quaternary. Many opportunities exist for utilising soils information in Quaternary research in Australia. While the buried soils identified in many overseas countries are of less prominence here, there are still many examples of buried soil materials and also of relict and polygenetic soils on the surface. Some of these could have been initiated in pre-Quaternary times and could have been modified during the Quaternary.

A number of soils workers within CSIRO, universities, and State Government Departments were approached to ascertain their current activities which could be relevant to Quaternary research. While the number approached was not great, the replies may be considered a fair sampling of current work, both in areal spread and in type of activity.

The various sections of the report summarise the current situation, assess as its relevance to the Quaternary, discuss some current trends and gaps in knowledge and comment on information needed on the Quaternary to improve interpretation on soils.

2. LIST OF INSTITUTIONS AND PEOPLE CONTACTED

This does not pretend to be a complete list of the institutions in which soils work with a bearing on Quaternary studies is carried out nor of the people in Australia working on soils themes which have a Quaternary flavour, but is representative of the organisations and the individuals involved. A number of individuals were contacted and replies were received from nearly all of them.

Institutions	Respondents
CSIRO Division of Soils, Adelaide	G. Blackburn
	K.H. Northcote
CSIRO Division of Soils, Canberra	P.H. Walker
CSIRO Division of Soils, Brisbane	G.G. Beckmann
	C.H. Thompson
	D.C. van Dijk
	W.T. Ward
CSIRO Division of Soils, Townsville	R.J. Coventry
	G.G. Murtha
CSIRO Division of Land Resources Management	H.M. Churchward
	W. McArthur
Macquarie University, School of Earth Resources	P. Mitchell
	G. Humphries
	P. Hunt
Queensland Department of Primary Industries	B. Powell and others
CSIRO Divison of Land Use Research	R.H. Gunn

3. SUMMARY OF ACTIVITIES

CSIRO Division of Soils, Adelaide

G. Blackburn - coastal landforms and aeolian landscapes, particularly in Murray Basin (coastal parts) and southeastern South Australia; soil cover on these landforms; dating of ashfalls and soils at Mt. Gambier, using buried charcoal; Quaternary aspects of salinity studies along Murray River.

K.H. Northcote - field relationships of soils on aeolian materials, and of these aeolian materials to underlying calcrete and lateritised rocks.

CSIRO Division of Soils, Canberra

P.H. Walker - two current studies -

(1) study of soil development on terraces in NSW and ACT; relating soil development to landscape age (with D. Chittleborough, Univ.

Adelaide).

(ii) Cainozoic stratigraphy and soils, Bunyan area near Cooma, NSW; area composed of early Tertiary lake clays and mid-Tertiary basalts; stratigraphic relationships of Quaternary alluvium, slope deposits, and aeolian sand are to be investigated, as a basis for pedological studies.

CSIRO Division of Soils, Brisbane

G.G. Beckmann - soil-landscape relationships on hills of the southern Lockyer valley, southeastern Queensland, study of layers of soil materials on hillslopes and in fans of minor valleys and study of their relationship to rock types and to later Quaternary landscape history of these valleys.

C.H. Thompson - two current studies - (1) soil-landscape relationships of river terraces and fan deposits in the valleys of the Mary River and smaller streams of the Gympie 1:100 000 sheet of southeastern Queensland.

(ii) studies of podzol soil development on a succession of siliceous sand dunes in the Cooloola area, southeastern Queensland, and of sedimentary layers in the Noosa Plain to the west of the Cooloola area.

D.C. van Dijk - principally involved in a study of soil stratigraphy and soil-geomorphic history of the clay plains of the Tara brigalow lands, southeastern Queensland. Its aim is to explain differences in seemingly uniform clay mantle; a "pedomorpholith" framework, a development of the "K-cycle" approach, has been adopted to differentiate soil-landscape units. It has been found that many materials of the soil mantle and many of the associated landforms are probably early Pleistocene to later Tertiary; this approach has been recently applied in the Albury-Wodonga area also. (The Soil Conservation Authority of Victoria is also carrying out surveys on this basis.)

W.T. Ward - engaged in soil-landscape studies in two separate areas:

(i) episodic dune and beach ridge development in southeastern Queensland (with I.P. Little); dunes were deposited during several glacial periods, while beach ridges accumulated during interglacials, over perhaps the last 1 m. years;

(ii) a study of solodic soils in inland southeastern Queensland; the stages are difficult to relate to specific Quaternary events, but features of the landforms (pediments) imply a past advance of vegetation.

CSIRO Division of Soils, Townsville

R.J. Coventry - has been studying the origin and distribution patterns of red, yellow, and grey earths of North Queensland, particularly those of the Charters Towers - Torrens Creek area. Current work is concerned with explaining soil genesis in terms of physico-chemical and biological processes active in the landscape over the past two million years.

G.G. Murtha - is carrying out a soil survey at a scale of 1:100 000 on an area of the wet tropical coast between the Tully and North Johnstone Rivers North Queensland (the Tully - Innisfail area); the soils have developed on hills of igneous and metamorphic rock and on alluvial materials derived from these. Constructional landforms of Quaternary age include riverine terraces, levees, and flood plains, freshwater and salt water marshes, and coastal beach ridge systems.

CSIRO Division of Land Resources Management, Perth

H.M. Churchward and W. McArthur - are studying soil pattersn and landscape development along the south coast of Western Australia, west and east of Albany. They are mainly interested in Quaternary events, W. McArthur concentrating on dune systems, and H.M. Churchward on shield areas and on Tertiary sedimentary formations.

CSIRO Division of Land Use Research, Canberra

R.H. Gunn - fairly detailed examination of relationship between secondary salinization of soils and deeply weathered rocks in the Braidwood area, near Canberra; the causes of this may be related to Quaternary events.

Macquarie University, School of Earth Sciences, Sydney

P. Mitchell - is working on the distribution of texture contrast soils in small landscape units within the Sydney Basin, in part with the aim of understanding the factors responsible for the presence of the mobile sandy topsoil.

G. Humphries - is also working on texture-contrast soils in the Sydney Basin, concentrating on the effect of meso-fauna and the fabrics they produce in the mobile sandy topsoil.

P. Hunt - is investigating laterites and silcretes near Sydney, using paleomagnetic techniques to work out the history of the hematite of the Hawkesbury sandstone.

Department of Primary Industries, Queensland

B. Powell and others - The soil survey program of the Agricultural Chemistry Branch covers several areas of eastern Queensland. These are being mapped at scales of 1:25 000 to 1:100 000. Some areas include a sizable component of Quaternary alluvium and detailed descriptions and laboratory analyses of representative profiles of the major soils will be presented. Areas being surveyed are:

Emerald Irrigation area;
Ayr-Burdekin-Barratta-Morton area;
Proserpine;
Kalbar;
South Burnett;
Lockyer Valley.

With mapping at larger scales, individual alluvial bodies, e.g. terraces, could be delineated separately, providing basic data for subsequent Quaternary studies.

Soil mapping at a range of scales is also carried out by the Division of Land Utilization of the Department of Primary Industries.

4. RELEVANCE OF CURRENT SOILS WORK TO QUATERNARY, TRENDS, AND SOME GAPS

(a) Relevance

Because the responsibilities of the organisations employing soil scientists are in areas other than the Quaternary, the activities of the pedologists are usually in localities selected because they -

(a) are currently used for agriculture;

(b) have some potential for use;

(c) are likely to be degraded or, at least, altered by some change in land use;

(d) are areas with some features of special scientific interest.

An awareness of the significance of Quaternary events to soil studies and how soil studies may contribute to more complete knowledge of Quaternary history would, however, assist both the soil projects and Quaternary studies generally. Some fields of work are important in this regard:

(a) Studies of terrace sequences and of sequences of coastal sand dunes and beach ridges have indicated progressive soil development with age.

(b) Studies of distribution of soil layers on hillslopes have shown that apparent soil horizons within supposedly genetic profiles may be distinct sedimentary layers.

(c) Soil-landscape mapping units may be distinct enough and of such a form that they may be related to stages in the Quaternary and their profile features may reflect the sum of the climate of these stages.

(b) Current Trends

(1) An improved picture is appearing of the pattern of terraces and their associated soils in eastern coastal valleys, and of soil and landform associations of coastal sand dunes and beach ridges, both in eastern and western Australia.

(2) Some of the work, e.g. that of P.H. Walker in the Bunyan area New South Wales and that of W.T. Ward on Fraser Island in Queensland, already recognise the need to incorporate Quaternary stratigraphy in pedological studies.

(3) Some current pedological studies deal with current surface processes. These are not directly relevant to interpretations of Quaternary events, but application of such studies could lead to a better appreciation of processes operating during the Quaternary to produce surfaces and soils.

(4) While areas are selected for study because of agricultural potentials or problems within them, judicious selection of criteria for establishing mapping units can let them be considered as representative of wider areas, and extrapolations from a local Quaternary base can be made more readily.

(c) Some Gaps

(1) Correlations between soil (and landscape) sequences across wide areas would be expedited if there were an overall stratigraphic (or historical) framework for the Quaternary into which new data could be fitted. Much soils work carried out for a variety of purposes could contribute to refinements of this. Many projects are currently restricted to coastal areas and to lower parts of valleys. If these areas at least, were understood and corresponding units adequately correlated, later work could cover the hinterlands and extend to inland areas.

(2) There are doubts, on occasion, as to whether soil horizons are the result of pedological processes or are surface sedimentary layers. Unequivocal criteria are needed so that such problems can be settled and also criteria for separating buried soil layers from sedimentary layers.

(3) Although this is already being dealt with in some studies, the relations between surface forms (e.g. terraces and alluvial plains) and the deeper layers of the sedimentary bodies on which they are situated should be established.

(4) Clarification is necessary on the meaning, in terms of age of soils at the surface, of radio-carbon datings of material within underlying sediments, and also the meanings to be given to figures for "mean residence time" from measurements of organic carbon in soils. The meanings of the general term "age of the soil" should also be clarified.

5. COMMENTS

In assessing what soils studies can contribute to Quaternary knowledge, and what other Quaternary studies - geomorphology, vegetation, climate, sedimentation - can offer to make soil interpretations more certain, several points may be noted:

(a) A comprehensive stratigraphic framework for the Quaternary should be established, into which events inferred from soils studies can be included; if a continent wide scheme is impracticable at present, some regional schemes could be put forward.

(b) Climatic successions within regions are also needed to assist pedologists in their interpretations; these successions should be based on non-soil criteria, to avoid circular arguments from the use of climatic inferences from soil profile features.

(c) All pedologists, whether undertaking applied (i.e. agronomic) soil surveys or more basic soil studies, should be encouraged to interpret their data in terms of Quaternary history. Even if the data available are incomplete, the exercise would be useful in adding to knowledge of the Quaternary, and in stimulating further enquiries.

(d) Work should be carried out in future on the details of the 5,000 years over the continent, and especially over the last 1,000 years along the coast.

(e) Unequivocal criteria should be set up for distinguishing pedological features from stratigraphic, both in materials at the surface and within sedimentary successions. These could encompass both mineralogical and fabric features.

AUSTRALIAN LAKES IN THE QUATERNARY

Contribution by J.M. Bowler

Lakes

The study of closed or terminal lakes provides a strategy of proven value in reconstructing past changes in the hydrologic and climatic regime. In the simplest system, a relatively small saucer-shaped lake in which the lake surface area is large relative to the catchment, the hydrologic parameters controlling the area can be evaluated. Provided the lake does not leak or overflow (assuming that it is closed) then the water input = runoff from catchment as supplied by streams + rainfall onto the lake surface (PxAL)).

I = RO + P.Al

RO = runoff

P = precipitation

E = evaporation

Al = area lake surface

Water loss = average evaporation (E x lake surface area)

For any steady water level (a system in balance as represented by a stable shoreline)

Input (RO + P x Al) = loss (E x Al)

When the shoreline position is known the corresponding lake surface area can be calculated. If one or other variables are known or assumed, the unknowns may be estimated. Theoretically, it appears simple but in practice it is very difficult to solve the equation especially to determine values for runoff under varying conditions involving changes in rainfall intensities and variation in catchment vegetation. Thus we are only now just beginning to estimate changes in precipitation, evaporation and runoff for past periods including those represented by the phase of maximum glaciation.

The best way to illustrate the efficacy of lake studies and their contribution to Quaternary sciences in Australia is by reference to particular case studies.

Lake George

From the early part of the 20 century Lake George had been recognised as a lake in sensitive balance with its hydrologic environments. Its record of past oscillations therefore may hold a key to help unravel the history of this part of the southern tablelands of NSW. Various attempts were made to evaluate the history in general terms. But it was not until the early 1960s that Dr. R.W. Galloway from CSIRO examined the evidence and demonstrated that Lake George could be used to study the relationship between past water level changes, glacial temperatures and precipitations pattern. From a shoreline dated around 13,000 Galloway assumed that the high lake level at that time was probably associated with cold lake glacial conditions which would have affected the southern highlands. In doing so he calculated the amount of rainfall necessary to maintain the lake at the level represented by the 13,000 shoreline. To do this he assumed that during periods of cold when temperature were depressed, evaporation loss from the lake surface would have been somewhat reduced below today's value. Galloway arrived at the conclusion that the rise in lake levels was essentially due more to reduced evaporation rather than to increased precipitation as others had believed.

This view immediately challenged existing orthodox theory: it was in fact consistent with independent evidence that was emerging elsewhere from the study of Australian deserts. R.C. Sprigg and R.W. Fairbridge had independently concluded that Australia's deserts had expanded significantly during the last period of low sea level i.e. corresponding to the last global glaciation. Thus as ice melted at the end of glaciation and sea level rose in the period between 16,000 to about 7,000 years ago, the rising seas slowly drowned dunes that had formed from deserts expanded onto the continental margins. There was developing then the unorthodox view that the deserts, instead of being related to warm interglacial environments, were formed during cold dry phases when global ice masses had expanded i.e. during glacial rather than interglacial periods.

Galloway's work proved to be an important factor in lending weight to the arguments later to emerge in support of the dry glacial hypothesis, arguments the final resolution of which have not been clarified to this day.

Lake George continued to be a productive source of new information. R.J. Coventry from examination of shoreline sequences was able to reconstruct and date a succession of water level oscillations extending back to near 25,000 years ago. Coventry found that although Lake George oscillations range only through a few metres during recorded historic times; that about 22,000 years ago it stood 36 metres above the present lake floor at which time it actually overflowed to the west. Additionally, it dried about 18,000, coincident with that period regarded as representing the maximum of global glaciation consistent with the theory of relatively dry glacial climates. Subsequently, its fluctuations record a wet period in the early Holocene about 8,000 years ago with a decline about 3,000 towards levels rather consistent with those of today.

Several disadvantages arise in attempts to reconstruct the lake environment from shoreline sequences alone. One stems from the inability to interpret environments during periods of low lake levels. Whatever shoreline features may have developed at such times will almost certainly be destroyed during the next high water level phase. Additionally shoreline sequences, by reason of constant changes in their positions, seldom provide long and unbroken records necessary to produce a continuous environmental record.

At Lake George this limitation has been largely redressed by the study of sediments within the basin itself. In recent years, the combined studies of vegetation history, palaeomagnetic chronology, sedimentology and stratigraphy undertaken by Singh, Opdyke and Bowler respectively have yielded for the first time a long and relatively continuous record of lake level variations extending from present day back to perhaps 8 million years ago. The different disciplines involved in this study have combined to provide the type of record which allows us a glimpse into the contrasting nature of the Late Miocene environments and those which have characterised the last 2 million years. Moreover this record provide the longest available for Australia and enables us to begin to correlate changes recorded in the continental sequence with those often much better known from studies of the surrounding continental shelves. One of the major requirements in the ongoing study of this nature is to be able to reproduce in other parts of the continent a record as long and as securely dated as that now available from Lake George.

Western Victorian Lakes

Western Victoria contains many diverse lakes associated with the Newer Basaltic terrain. Some were caused by lava blocking previous drainage such as Lake Corangamite, whilst others were formed in volcanic craters associated with eruption points. Of these the latter group, by reason of their relatively small size and high lake to catchment ratio are especially favourable for the study of palaeohydrology. Foremost among them are three lakes in particular which have been subjected to intensive study, Lake Bullenmerri, Lake Gnotuk and Lake Keilambete. An additional advantage of these relatively deep lakes is that because they take a long time to dry (the relative depth change each year is small compared to that recorded in broad shallow lakes) they may be used to monitor long-term as well as short-term changes. In this way they enable us to extend the record and to discriminate small changes in the precipitation evaporation ratio beyond that short time available during which accurate climatic statistics have been collected since European occupation.

At Bullenmerri and Gnotuk, examinations of palaeomagnetic stratigraphy (Barton), pollen analysis (Dodson), and limnic faunas (De Deckker) have yielded a record back to about 15,000 years.

Lake Keilambete some 20 km to the west, and hydrologically unconnected to Gnotuk - Bullenmerri craters, has provided a continuous record of comparable length. Here study of sediments has yielded a continuous water level curve covering the past 14,000 years (Bowler). This is being confirmed by an independent study of ostracods (De Deckker) and pollen (Yezdani, Dodson). It shows that the lake was dry about 14,000; it began to fill about 10,000 but remained at low levels with relatively high salinity until a relatively rapid rise about 8,000. The lake stayed high until it began to fall near 5,500 reaching low levels between 2,000 to 3,000. From 2,000 to the last century it remained well above the levels of today. A fall, initiated in the latter part of the last century, continued until about 1960 when the water level seems to have stabilized somewhat. However the lake today stands near the lowest level recorded throughout the past 10,000 years, a salutory reminder that climates of the 20th century may be amongst the driest for many millienia.

The apparent synchroneity in the major changes recorded by all three lakes provide strong evidence that such changes are due to regional climatic influence rather than local hydrologic variations. For future studies of changes in the precipitation/evaporation ratio, long term accurate monitoring of Lake Keilambete could provide an invaluable reference baseline to help identify sensitive changes in PE ratios which the historic records are too short to identify.

Lunette Lakes - The semi-arid zone

Interior Australia possesses a wide variety of lake basins scattered the length and breadth of the continent. Ranging in size from Lake Eyre (9400 km sq.) to less than 1 km sq. they are almost entirely dry or ephermeral under today's climate. Although they occur in a wide range of rock types from Archean gneiss on the Yilgarn block of southwestern W.A. through palaeozoic sediments (Lake Amadeus) to Mesozoic or Late Cenozoic sediments underlining lakes in the Great Artesian or the Murray Basins respectively, they possess surprisingly uniform water chemistry. Australia's inland salt lakes are almost entirely of the sodium chloride-calcium sulphate type yielding halite and gypsum as almost uniquitious crystallisation products.

One additional distinguishing feature of many such lakes is the common susceptibility to deflation processes. On the downwind margins they often possess large dune ridges aligned parallel to the lake shore. Across southern Australia, on basins that are circular or elliptical in plan, these dunes commonly composed of sandy clay or gypsum-rich clay are termed lunettes, a name reflecting the crescentic or lunar shape. Such dunes represent a legacy of phases in the history of the lakes during which wind action has removed large quantities of sediments either from the lake shore or dry lake floor and transported it to form the large shoreline dunes. These processes have often contributed to deepening of the basins or forming deflation basins, a term which adequately describes many of the inland lakes.

In terms of their contribution to our understanding of the history and evolution of Australia's physical and biological environments, the lunette lakes have provided some of the richest repositories for Australia's Quaternary history. Indeed they combined to yield data, the scale and diversity of which was unanticipated only 2 decades ago.

The case study of Australia's lunette lakes may be taken from western NSW where the Willandra system and Lake Mungo in particular have become hallmarks in our understanding of the evolution of semi-arid Australia in their records of Man's earliest occupation on this continent and in demonstrating the environmental changes that his occupation has witnessed. In more recent years comparable studies have been undertaken of related basins on a branch of the Darling where sediments and soils similar to those recorded in the Willandra basins are now being used to extend the environmental history of this important region.

The Glacial Stratigraphy of Australia: An Assessment, 1980

Eric A. Colhoun

Data on Quaternary glacial stratigraphy are available from five areas in Australasia (excluding New Zealand) viz, (1) Irian Jaya and Niugini, (2) Kosciusko Plateau, (3) Tasmania, (4) the Sub-Antarctic Islands, and (5) the Australian Antarctic Territory. The intensity of study has varied greatly in the different areas which collectively present important evidence of present and former glaciation throughout a longitudinal transect from the Equator to the Antarctic polar icesheet mainly between 130 to 160°E.

Irian Jaya-Niugini

Since 1960 there have been observations on the Carstensz Mountains (Hope *et al.*, 1976) which show that together with Mt. Idenburg and Mt. Mandala there is about 8 km^2 of glacial ice in Irian Jaya. This ice is but a trace of the much more widespread plateau ice caps and valley glaciers that extended to 1400-1600 km^2 in the high mountains of Irian Jaya and 600 km^2 in Niugini at the maximum of the Last Glaciation (Löffler, 1977), which is inferred from pollen data to have occurred between 15,000 and 18,000 BP, Table 1 (Bowler *et al.*, 1976; Walker and Flenley, 1979).

The stratigraphy of the general deglaciation has been best documented from the Ertsberg Mine near Mt. Jaya and from the Pindaunde Valley near Mt. Wilhelm which demonstrate that the ice retreated from its Last Glaciation limits between about 15,000 and 9,000 BP (Hope and Peterson, 1975; Hope *et al.*, 1976). Between 9,000 and 4,000 BP there is no evidence for glaciation but sometime before 2,930 ± 100 BP (SUA-20/2) the first till associated with renewed ice advance is recorded from the

Yellow Valley at Mr. Jaya. Two further neoglacial tills overlie the organic deposits dated to 2,930 BP and underlie deposits dated to 1,520 ± 105 BP (SUA-177); a fourth till post dates 1,520 BP (Hope *et al.*, 1976).

Prior to the maximum of the Last Glaciation pollen data suggest that ice may have been continuously present on Mt. Wilhelm since before 30,000 BP (Hope and Peterson, 1975). Weathered glacial deposits of unknown age occur on the Kemabu Plateau and Saruwaged Range outside the Last Glaciation limits (Dow, 1968; Löffler, 1971). These indicate the occurrence of older glacial events in both Irian Jaya and Niugini as do the lava flows and palagonitic breccias dated to 320,000 and 290,000 BP in the Gogon Valley near Mt. Giluwe, Niugini (Löffler, 1972).

Although small scale modern and larger scale fossil periglacial structure soils and deposits occur at above about 4,000 m and 3,000 m respectively, periglacial processes neither are nor were very important in the evolution of these high mountain landscapes (Löffler, 1975).

Kosciusko Plateau

The suggestions by Browne (1957) and Browne and Vallance (1957) that 1000 km^2 of terrain had been glaciated on the Kosciusko Plateau and adjacent parts of the Victorian Alps have been demonstrated to be in error and Galloway (1963) has reduced the extent of certain ice cover to 19 km^2 with a possible maximum of 32 km^2. This ice consisted of some thirteen cirque glaciers in the Mt. Kosciusko area and a short valley glacier in the upper part of the Snowy River. All the ice is believed to belong to the Last Glaciation which was the maximum glaciation of the area and no certain evidence of earlier glaciations has yet been recorded.

Radiocarbon dates bearing on the age of this Last Glaciation give circumstantial rather than precise evidence on when the maximum occurred and for how long ice was present. A ^{14}C assay of 35,200 $^{+1600}_{-2150}$ BP (ANU-76) on a *Nothofagus cunninghamii* stump beneath a block stream in the Toolong Range indicates that cooling occurred after that time in the Snowy Mountains (Costin and Polach, 1971; Ross, 1978), yet assays of 20,200 ± 165 BP and 8,650 ± 990 BP (NZ 435 and 436) have been obtained from near the base and top of organic deposits that occur on the floor of the main cirque at Mt. Twynam which lies within the Last Glaciation limit. This 20,200 BP assay implies a very early deglaciation for that cirque which holds the largest and most enduring winter snowpatch today. This contrasts with an assay of 15,000 ± 350 BP (NZ 399) for wood from the bottom of fen peat that overlies glacial or periglacial debris at 1830 m in the Upper Snowy River (Costin, 1972) and though the status of the underlying rubble is uncertain this is a more expectable date for the commencement of deglaciation.

Landforms and deposits developed by periglacial processes such as block streams, block fields, screes, solifluction terraces, and moraine-like ridges associated with perennial snowbanks occur widely in the higher parts of the Kosciusko Plateau and Victorian Alps. The contrast in sharpness of profile between the Last Glaciation cirque moraines and the more subdued outlines of the periglacial forms, and the greater chemical alteration of some of the associated slope deposits did much to suggest that there may have been widespread earlier glaciation. But the lack of understanding in Australia prior to about 1960 of alpine-periglacial frost and nival processes explains why such forms were frequently interpreted as being of glacial origin (Beavis, 1959; Galloway, 1963).

Tasmania

Early research work in Tasmania suggested that there had been three, possibly four, periods of glaciation (Lewis, 1934, 1939, 1945) but later work indicated that the stratigraphic basis did not warrant an interpretation of more than one glaciation viewed as the Last Glaciation when ice covered more than 2000 km^2 - a conservative estimate (Derbyshire *et al.*, 1965; Derbyshire, 1966). However, since 1972 there has been considerable research work on the glaciation of Tasmania and the emphasis has been on developing a stratigraphic model of Tasmanian glaciations from the West Coast Ranges.

In the West Coast Ranges unlike the Kosciusko Plateau, the Last Glaciation appears to have been a rather small event. The ice cap and cirque glaciers attained their maximum extents of 108 km^2 about 18,800 ± 550 BP (ANU-2533) (Colhoun unpubl., Kiernan, 1980). The ice retreat from this, the *Margaret Glaciation* of Lewis probably commenced before 14000 BP and ice had almost disappeared from high Tasmanian cirques by 10,000 BP (Macphail and Peterson, 1975).. The date of commencement of development of ice during the Margaret Glaciation is not yet known. The radiocarbon assay of 26,480 ± 800 BP (W-323) given by Gill (1956) for wood incorporated in morainic deposits at Linda is not to be relied on as the wood is probably contaminated by younger carbon.

Recent study of numerous sites has shown that multiple glaciation occurred in Western Tasmania and that the maximum extent of glaciated terrain is ten times that known to have been glaciated by the Margaret Glaciation. The *Henty Glaciation* is recognized by ^{14}C dated sequences at Henty Bridge (42°S, 145°30'E) and Tullabardine Damsite (41°40'S, 145°38'E), where *in situ* till occurs beneath organic deposits assayed at more than 34,600 BP (GaK-5595) and over 43,800 BP (SUA-1047) respectively (Colhoun *et al.*, 1979). Although this dating could imply an early Last Glacial age for the Henty Glaciation, the degree of chemical alteration of igneous clasts in the Henty Till suggests that it predates the Last Interglacial. Initial examination of the weathering of igneous clasts suggests that the pre-Margaret Glaciation deposits may belong to more than one glaciation (Kiernan, 1980).

Little research work has been done on the Central Plateau ice cap and its adjacent valley glaciers in recent years although Paterson (1965; Paterson *et al.*, 1967) recognised the first evidence of multiple glaciation at Lemonthyme in the Forth Valley, where weathered till and associated glacial deposits overlie a highly indurated deposit that has been interpreted as a tillite (Spry, 1958). The relationship between outwash gravels associated with the weathered glacial deposits and marine deposits of the Last Interglacial in the lower Forth Valley shows that the upper till deposit is probably of Henty age (Colhoun, 1976). The status and stratigraphic position of the underlying deposit interpreted as tillite needs to be reinvestigated.

Periglacial landforms and deposits such as block streams, glacis, block fields, screes and solifluction deposits are extensively developed in Tasmania above 450 m elevation (Davies, 1974), with the last two extending locally to lower elevations (Colhoun, 1978). The periglacial deposits probably are mainly of Margaret Glacial age as they are virtually absent from areas within certain Margaret ice limits. Some deposits may be older. Only small scale stone polygons, stone stripes and solifluction terraces occur today where needle ice forms regularly in unvegetated areas above 900-1000 m.

Sub-Antarctic Islands

Research on Macquarie Island (54°40'S, 158°50'E) has been of a reconnaissance nature only. The island is not presently glaciated and the snowline occurs at about 780 m. Views differ on the extent of former ice cover of the 200-300 m plateau from complete submergence by an ice sheet developed on and to the west of the plateau (Blake in Mawson, 1943), about 40% cover by local ice generated on the plateau (Colhoun and Goede, 1974), relatively little ice cover on the southern part (Peterson, 1975), to about 80% ice cover of the northern part of the island (Löffler and Sullivan, 1980). Whatever the extent of ice cover all workers are in agreement that the data recorded so far relate to the Last Glaciation but no ^{14}C assays have yet been obtained on organic materials that have direct reference to the glacial deposits.

Periglacial landforms and deposits which include small tors, stone polygons, stone stripes and spectacular staircases of solifluction terraces are well developed at various localities on the island. These features appear to be currently forming under the present oceanic tundra climate.

In contrast to Macquarie Island lying north of the Antarctic Convergence, Heard Island (53°S, 73 30'E) lying south of this zone consists mainly of the complex volcano of the Big Ben Range which culminates in Mawson Peak 2,745 m and is 90% glaciated by an ice cap with radiating glaciers (Lambeth, 1950). The snowline lies at 300 m, the ice is more than 50m thick, and moraine and outwash deposits associated with relatively recent retreat occur at the ice margins and in the deglaciated periphery (Budd *et al.*, 1968). Although the ice must have been substantially thicker during the maximum of the Last Glaciation there is no dated stratigraphy. However, numerous tillites of unknown age occur interbedded with agglomerates, lavas and pillow lavas, and some may have been deposited below sea level (Stephenson, 1964).

Australian Antarctic Territory

There has been very little stratigraphic research on the numerous presently deglaciated enclaves that extend from Enderby Land to Oates Land between 50°-160°E at 70°S on the fringe of Antarctica. Some observations have been made that indicate recent greater thicknesses of ice in the Prince Charles Mountains (65°E, 72°S) (Trail, 1964). At Gaussberg (89°E, 67°S) lavas dated by K-Ar to between 50,000 and 60,000 BP (McDougall in Tingey, in press) have striated surfaces which also bear glacial erratics that indicate ice expansion and recession after 50,000 BP. Stratigraphic work has also commenced in the Vestfold Hills (78°E, 68°S (Adamson and Pickard, pers. comm.) which were covered by several hundred metres of ice after about 30,000 BP and were largely deglaciated by 6000 BP. This, *Vestfold* event seems to represent the maximum phase of the Last Glaciation in other Australasian areas. A regional variation in striation pattern in the south suggests a later readvance which has not yet been dated.

ASSESSMENT

The foregoing synopsis indicates that knowledge of the glacial stratigraphy of Australasian regions has advanced over the past 15-20 years largely through the studies of individuals or small groups tackling particular areas and problems from time to time. These studies have been sufficient to point the way ahead for future research which will necessarily have to be better funded than in the past if a substantial body of research work on Australasia's glacial history is to be forthcoming.

In Irian Jaya-Niugini further work should include the dynamics of the present ice masses of the Mt. Jaya area, better definition of the limits of ice during the Last Glaciation, mapping and differentiation of older glaciations, and the acquisition of further organic deposits for ^{14}C dating and analysis of conditions during the Last Glaciation through pollen studies.

There seems to be little to be gained from searching for older glacial deposits in the Kosciusko Plateau-Victorian Alps region, because, if such deposits were extensive they would have already been found. Greater profit may be obtained from studies of the periglacial landforms, the operation of frost and snow processes, and pollen analytical studies of vegetation history and palaeoclimates.

Tasmania promises to add substantially to the knowledge of Australian glacial stratigraphy through the combined application of glacial geomorphological, palynological and radiometric dating methods being applied to the West Coast Ranges. As such studies are extended to other formerly glaciated areas in Tasmania they should produce the stratigraphic framework of glacial and interglacial stages for Australian temperate mountain regions.

There is a need to study and ^{14}C date glacial and associated organic deposits on Macquarie Island as present assessments are based on the observations of landforms only. Heard Island presents some of the most exciting possibilities because there is not only the opportunity to study recent ice retreat in conjunction with recently formed glacial landforms but also to study the stratigraphy of interbedded tillites (? tills) with lava flows and pyroclastics that were probably deposited both on the island and in adjacent water. It is possible that quite a long record of Quaternary glaciation may be obtainable.

Although it appears that most of the now deglaciated enclaves of the Australian Antarctic Territory were glaciated by expansion of the ice sheet contemporary with the Last Glaciation of the temperate and tropical regions, there is a need for systematic investigation of the glacial landforms and deposits, and associated marine and lacustrine deposits of these areas.

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TABLE 1 Glacial Stratigraphy of Australasia (excl. New Zealand)

Approx. Age ^{14}C BP	Irian Jaya-Niugini	Kosciusko Plateau	Tasmania	Sub-Antarctic Islands	Antarctic Territory
	Glaciation current Irian Jaya			Glaciation current Heard Island	Glaciation current
					Minor readvance (?)
0(?) - 3000+	Four Neoglacial advances in Yellow Valley, Irian Jaya				
6,000				Partial deglaciation Heard Island (?)	Deglaciation of Vestfold Hills by 6000 BP
9,000					
10,000					
	General deglaciation in Irian Jaya & Niugini	Deglaciation more likely	General deglaciation complete by 10,000 BP	General deglaciation Macquarie Is. probable by 10,000 BP	
15,000	Period of inferred maximum Last Glaciation				
18,800			Maximum Margaret Glaciation - dated	Probable maximum Last Glaciation Macquarie Is. and Heard Is. but undated	Vestfold Event)
20,200					Gaussberg Event)
		Deglaciation suggested but doubtful			
30,000	Ice probably present on Mt. Wilhelm, Niugini	Maximum Last Glaciation (?)			
35,200		Last Glaciation commences after 35,200 BP	Commencement of Margaret Glaciation(?) not dated		
>35,000 >44,000			The Henty Glaciation		
290,000	Palagonite breccia Mt. Giluwe, Niugini			Tillites interbedded with agglomerates and lavas on Heard Is. - age unknown	
Pre Quaternary			Lemonthyme Tillite(?)		

THE KARST POTENTIAL FOR QUATERNARY HISTORY

J.N. Jennings

Solution is the distinctive process of karst so it is a condition of carbonate and evaporite rocks. In Australia it is confined to the former, bar a few small caves in gypsum flooring Wolf Creek Crater. Other controls on its development are water and, depending on it, biomass. The more extensive karsts - Nullarbor Plain, Limestone Ranges of W. Kimberley and Barkly Tableland - lie in dry climate and consequently remote from big cities, with the exception of the long belt of Quaternary dune limestone through Perth. These restrictive factors help explain why karst geomorphology has yet contributed little to Quaternary research, few being attracted to it professionally. Partially concealing this situation is the importance of limestone caves in prehistory and vertebrate palaeontology, typified by names such as Koonalda Cave and Devils Lair.

Nevertheless much groundwork has been accomplished in recent decades when speleological societies have multiplied since the Tasmanian Caverneering Club formed in 1946. Exploring and mapping caves, and tracing underground water are fundamental for understanding karst and much descriptive information is now lodged in the archives and publications of these amateur groups. In 1962 Helictite began its role as the national journal of cave science; its pages have been dominantly devoted to geomorphology. Proceedings of some of the Australian Speleological Federation biennial conferences have been published, less given over to physical speleology and more variable in quality.

Morphogenetic accounts of a number of karsts and of larger or more distinctive caves have appeared in these publications, and in the customary serials of geology, geography and geomorphology. In part this literature spelled out the grammar of a branch of natural science which in Australia, prior to the late fifties, had received cursory attention at best. It must suffice to point to themes directly relevant to Quaternary history.

In the Eastern Uplands, where limestones often have steep attitudes, successive quasi-horizontal cave levels commonly represent epiphreatic development in relation to springs which succeeded to one another as the nearby river halted in cutting down its valley. At Jenolan, Yarrangobilly and Wee Jasper in N.S.W. such sequences find little or no expression in surface relief, thus amplifying the record for regional denudation chronology.

In karst literature the strength of structural control is a major theme. The risk in thinking that steep dip minimises this control was demonstrated at Bungonia (N.S.W.); the major karst spring, originally thought to reflect an externally caused halt in gorge cutting, was revealed by some detailed geological mapping to be localised by close-set strike and dip faulting. Similarly at Chillagoe (northeast Qld.) later work has downgraded the importance given earlier to pedimentation in the fashioning of this tower karst. Many towers are simply due to differential erosion, some of it fault-guided.

Despite this, pedimentation accentuates and perpetuates here a distinctive karst style, found also in the differently structured Limestone Ranges of W. Kimberley. This karst style, with its pediments and superficial calcite deposition as important elements, was attributed to tropical semi-arid and savanna climates. This interpretation can still be defended against protagonists, both of rock control, who link it to massiveness and horizontal bedding - despite a variety of structure in the regions concerned, and of climatic control, who attribute it to former humid tropical climate - despite the apparent 'actuality' of crucial landforms. But mention of such controversies must be made to point up the difficulty of employing karst style as a climatic indicator.

Karst development, surface and underground, has been regarded as minimised in the Nullarbor Plain by dryness, which there is some reason to think began practically at its middle Miocene emergence. Yet relict water courses reaching out into its presently streamless surface relate to a comparatively young phase of effectively wetter conditions as does former prolific calcite deposition in south-central caves. Now there is distinctive halite deposition and significant salt and gypsum wedging of both bedrock and speleothems. A swing from wetter to drier conditions is inferred. The calcite speleothems of the Nullarbor caves show variation in colour from the whiteness of high purity to blackness attributable to organic impurities. As the latter may imply greater vegetative cover of the surface, it is possible that this variation may provide another tool for reconstructing environmental change.

The presence of red quartz dune sand in a group of caves and dolines in a dune-free part of the eastern Nullarbor points on the other hand to a phase, short-lived though it may be, when aeolian activity was greater than at present, implying a change in wind regime certainly and probably also greater aridity.

Deep caves here reach to a regional water table of brackish water, giving rise to long lakes and water-filled passages; slow movement coastwards has been measured recently in the face of previous notions of stagnancy. Diving has recently confirmed that cave development has taken place below present sea level and well inland. This is attributed to glacioeustatic low sea level rather than to deep phreatic looping, disfavoured by small hydraulic head and horizontal bedding.

The Nullarbor is matched in some ways by the South-East of South Australia, also in horizontal Tertiary limestone. Diving in cenotes here and the presence of submarine springs offshore have likewise proven cave development well below sea level. Here lower altitude and greater effective precipitation keep the watertable nearer the surface; water movement is probably faster but this has yet to be established. The distinction between conduit and diffuse flow has not been pursued here by hydrogeologists.

Some surface features and caves reach up into overlying Quaternary dune limestone ridges and there is difficulty in distinguishing between primary dune hollows and closed depressions of karst origin in the South-East. This is important since it has been divided into sub-regions on the basis of c aracter and pattern of closed depressions, in turn explained primarily by depth to watertable and the latter's gradient.

There is more dune limestone in Australia than elsewhere and in the South-West (W.A.), karst is especially well developed in it. Here some features have been attributed to syngenetic development, i.e. simultaneous with the lithification of the calcareous dune sane.

Australia's longest and deepest caves are in western Tasmania with its high rainfall, prolific forest and high relief. Here glaciofluvial and periglacial-fluvial fans and valley trains have affected karst development, by decanting water sideways into limestone divides and pumping gravel into caves, practically to choke some of them. Blind valleys were sedimented to threshold level and surface flow temporarily restored. At Cooleman Plain in southern N.S.W., a mudflow performed a similar feat, inferred to be due to periglacial slope instability. Likewise at Wombeyan Caves in the Central Tablelands, (N.S.W.), stratified slope deposits are correlated with angular gravels in the forward parts of certain caves, regarded as cryoclastic; ^{14}C dating of both facies has confirmed they belong to the last glacial maximum.

Thus the keynotes of Quaternary studies - climatic and vegetational change, sea level and other components of base level change, coastal dunes - recur in recent karst research. It is worth examining more closely why more history has not come forth from it.

Problems of chronology are amongst the reasons. These arise even in relative chronology. Thus overlying rocks and sediments apparently in place may have been lowered by solution of the karst surface below. With cave sediments, interpretation of arrangement and stratigraphy must beware of characteristics unknown or rare on the surface which introduce ambiguity. Even though three-dimensions may ensure more survival of abandoned erosional forms, these also may not be readily ordered timewise. Vadose and phreatic conditions can function side by side in the one level and cave breakdown can cause a resumption of phreatic action upstream. Some of the classical props of relative chronology which have helped elsewhere have not yet been realised in Australia, e.g. vertebrate palaeontology.

Only latterly have absolute chronological methods been seriously applied in Australia karst. Basalts for K/Ar are rarely suitably positioned for this as they are at Yarrangobilly and even there widespread solutionally lowered basalts point to a long, indeterminate interval between lava flow and the age of most of the present surface.

So far radiocarbon has been most seriously applied in some small karsts in the central western N.S.W. slopes - Abercrombie, Borenore, Douglas Cave and Wellington - employing charcoal from cave fluvial and entrance facies deposits, bone of similar origin, organic matter, probably bat guano, within flowstone and the inorganic carbonate of flowstone. In some cases the different materials corroborated one another. Speleothem dating requires special methods to correct for incorporation of 'dead' carbon. In all the caves where radiocarbon was used, much of their history lay beyond its range.

A more powerful weapon in cave chronology is $^{234}Th/^{230}U$ with its much greater time range. Studies at Flinders University on material from the South-East (S.A.) have shown that speleothems are neither the best nor the worst type of specimen for this method. It is in Tasmania that this method has so far been successfully applied, though caves such as Exit Cave in south-west Tasmania have shown that the older parts lie beyond the 400,000 years range of the dating technique. Nevertheless in multiple level cave systems it has been possible to rate the lowering of the active level. Also the frequency distribution of speleothem dates from the state begins to parallel that established in N. America and Britain where high frequency corresponds with warmer intervals in the Pleistocene and low frequency with colder ones. Dating flowstones capping other sediments sets a minimal age on the latter whereas dating speleothem fragments included in them provides an upper limit for them. These means have shown that unweathered, angular clastic sediments regarded as cryoclastic in origin belonged to both the Last Glacial maximum and an earlier glacial stage. Differences in weathering rind thicknesses of dolerite pebbles in cave alluvia are being used to extrapolate from speleothem-dated sediments to undated ones. The promise for dating karst events elsewhere in Australia by uranium-thorium is therefore considerable. Samples collected from the Nullarbor Plain may date a swing from wetter to drier conditions and search for speleothems below sea level in the cenotes of the South-East (S.A.) is an obvious prospect in relation to sea level change.

The potential for palaeomagnetism, which can reach throughout the Pleistocene, in the cave context has already been successfully exploited abroad with fluvial sediments in respect of detrital remanent magnetisation and the first results from the chemical remanent magnetisation of speleothems have also appeared. Now results from fluvial silts and clays in a many storeyed cave system at Wee Jasper, N.S.W., are in course of publication; they fine down the age of the caves by an order of magnitude and imply low rates of valley deepening to agree basically with surface denudation studies in nearby non-karst terrain.

Lack of discriminatory evidence in much cave deposition also limits the Quaternary contribution from karst. The most intensive sedimentological studies of Australian cave deposits (admittedly lacking the electron microscope tool) were made in cave areas of the western central slopes of N.S.W.; the results chiefly contributed to the understanding of the cave development and little to reconstruction of regional environmental history, though they did indicate a dry period between 30,000 and 22,000 B.P. It is true that much input of material from surrounding non-karstic rocks, on which persist a mosaic of paleosols of varied nature and age, is confusing. However, even with Koonalda Cave well inside the Nullarbor Plain, a thick layer of Late Glacial Maximum fluvial sediment, sandwiched between cave breakdown, found ready explanation in local geomorphic terms, not in climatic ones. Later palynological results from a not too distant Nullarbor cave supported this interpretation.

More fruitful may be stable isotopic ratios, in particular $^{18}O/^{16}O$ but possibly also $^{13}C/^{12}C$, from speleothem layers. If seepage water at time of deposition was in isotopic equilibrium and if liquid inclusions are determined for deuterium/hydrogen ratio, cave temperature at that time can be determined and this lies close to mean annual surface air temperature.

In this way temperature curves for quite long periods of time have been established from N. American and New Zealand caves. In Tasmania, a cylindrical, rapidly growing stalagmite from Little Trimmer Cave, well dated by $^{234}Th/^{230}U$ has also yielded a valuable palaeotemperature record of this kind from the end of the Last Interglacial to well into the Last Glacial. Such thermal history cannot be overvalued in Australia where so often Quaternary evidence tells only of effective precipitation changes, which a temperature record can help to convert into absolute precipitation terms. However, this conversion has greatest significance in arid and semi-arid areas and there dryness in cave atmosphere may upset isotopic equilibrium of seepage water through evaporation and so complicate fractionation. Stalagmites from the Nullarbor Plain and Lawford Range in the Kimberleys should soon put this to the proof.

Dating by electron spin resonance, calibrated by radiocarbon dates, has yielded a detailed chronology from a stalagmite from Lynd's Cave, Tasmania, for which a uranium-thorium palaeotemperature record has also been derived.

The Little Trimmer stalagmite provided a $^{13}C/^{12}C$ record, which may also yield indications of palaeoenvironmental change when the factors controlling changes in this stable isotope ratio are better understood.

The functioning of karst today can only be understood in terms of its history, which in some areas at least runs right through the Quaternary, though morphometric and modern process studies, not discussed here, are needed also. Reciprocally, of course, the past must largely be interpreted in terms of present processes. Both present functioning and past history are requisites to proper resource management, whether this concerns availability and pollution of underground water, minerals, grazing capacity, engineering foundations and recreational values. Admittedly the distribution of Australian karst dominantly in low rainfall areas with thin populations diminishes the applied value of its study (the South-East of South Australia is a notable exception). Nevertheless there is a significant level of both academic and applied interest which warrants more support for further karst geomorphological study. In this what seems most needed now is to combine more radiometric dating and stable isotope analysis with the older morphological and sedimentological approaches to karst and cave evolution.

Acknowledgement

Because of the role conceived originally for this report, references were not provided; in any case they would have included a number of papers in course of publication and several personal communications because it was especially meant to convey the state of the art at the moment. I propose therefore to acknowledge my debt in general terms to the following friends and colleagues - Bao Haosheng, Jim Caldwell, Adrian Davey, Dave Gillieson, Albert Goede, Jerzy Grodicki, Russell Harmon, Ian Lewis, Vic Schmidt, Andy Spate and Bob Wasson.

REVIEW OF QUATERNARY STUDIES IN AUSTRALIA - PLANT AND INVERTEBRATE PALAEOECOLOGY

by

A.P. Kershaw

Scope of the review

This section deals with those groups of plants and invertebrates which have proven or potential value in the reconstruction of Quaternary environments. It incorporates the knowledge and ideas of a number of research workers active in the field though I must be responsible for the structure of and emphases within the report. A summary of the state of knowledge to 1980 is followed by an assessment of some major limitations to the development of the subject. From these, some recommendations for future research are put forward.

Areas of development within palaeoecology

Quaternary ecology has developed in Australia only over the last 15-20 years but within this time has become the major area of investigation for the reconstruction of terrestrial environments. The largest contribution has been made by pollen analysis and this has been included within a number of recent reviews (Bowler et al. 1976, Colhoun 1978, Kershaw 1981, Walker 1978, Walker and Singh 1981). Despite the importance of the results derived from this method, they provide only a small and biased picture of the Australian Quaternary. The situation up until mid-1978 is summarised in Figure 1 which shows the distribution and age ranges of pollen sites for which information was available, either in published or thesis form (from Kershaw 1981). Subsequent publications have not changed the pattern substantially. It is apparent that no evidence exists for a large part of the continent with most sites restricted to those areas receiving high effective precipitation where sediments suitable for the preservation of pollen are most likely to have accumulated. Within these high rainfall areas, the majority of sites are further restricted to volcanic provinces, high altitude environments which

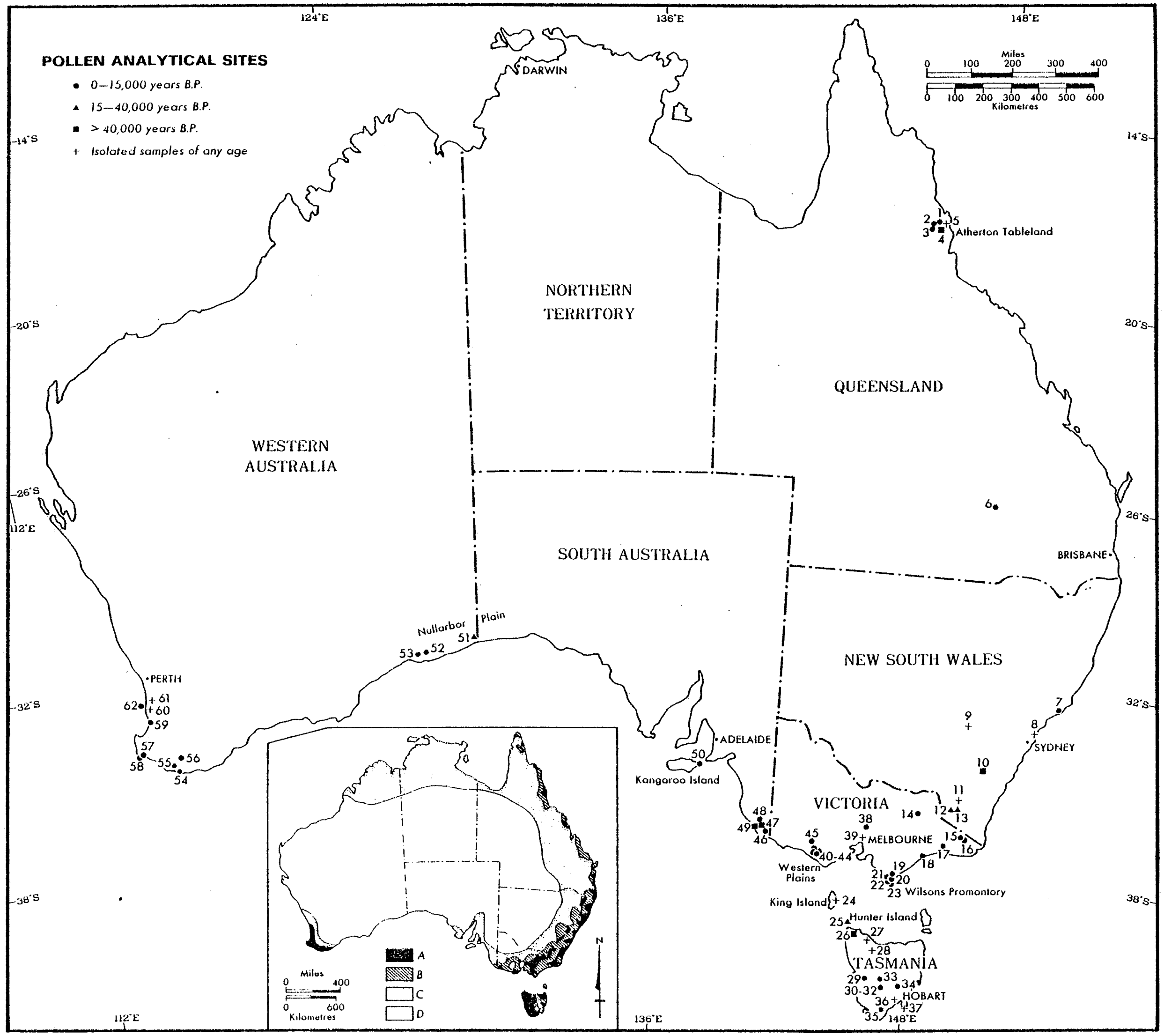

Fig. 1 The distribution of Quaternary pollen analytical sites in Australia (from Kershaw 1981).

(Inset.) The pattern of runoff regimes in Australia reflecting the effective precipitation pattern. Zone A - mainly perennial runoff; Zone B - seasonal precipitation excess, seasonal moisture deficit and mainly perennial runoff; Zone C - seasonal precipitation and non-perennial runoff; Zone D - precipitation entirely accounted for by evaporation.

have experienced glacial or periglacial activity and recent coastal landforms. The nature of origin of these sites has determined that few are of great antiquity.

Most sites analysed have been selected to elucidate past vegetation and climatic changes, with a more recent additional concern for the impact of fire (Singh et al. 1981). Regional patterns of change during the Holocene have been determined for several areas (the Atherton Tableland, southwestern Western Australia, southeastern South Australia, the Western Plains of Victoria and southern Tasmania) and sufficient information is available to produce similar syntheses for coastal Victoria, the southeastern highlands of mainland Australia, the southern tablelands of New South Wales and the Barrington Tops. In very general terms there is good correspondence between climatic inferences from Holocene records with optimal conditions having been achieved by mid-Holocene times and a subsequent deterioration within the last few thousand years. Recent evidence from Lake Frome indicates that this pattern may be extended to semi-arid southeastern Australia (Singh 1981). More detailed correlations have been made between the records from sub-coastal sites in southwestern Western Australia, South Australia and western Victoria. Inter-regional correlation between lowland and highland sites has been complicated by differences in the relative influence of various climatic parameters on vegetation changes. Regional differences have also resulted from the effects of fire on the vegetation resulting in community changes independent of climate change.

Few records provide evidence of vegetation and environmental conditions beyond about 10 to 15,000 years ago, which appears to mark the end of a dry, cool, late glacial period. Fairly continuous sequences, extending from present back to between about 50,000 and 350,000 years are available from Lake Leake and Wyrie Swamp in South Australia (Dodson 1974, 1975, 1977), Pulbeena Swamp in northwestern Tasmania (Colhoun et al. 1982), Lynch's Crater on the Atherton Tableland (Kershaw 1978) and Lake George near Canberra (Singh et al. 1981). All demonstrate the fluctuating nature of temperature and/or rainfall within the Late Quaternary but problems of dating inhibit correlation of changes beyond 30 to 50,000 years B.P. Lake George and Lynch's Crater provide evidence of major evolutionary changes in the vegetation which appear to relate to changes in fire regimes possibly due to the activities of aboriginal man. Although restricting climatic interpretations, these changes provide a basis for realistic evaluation of the nature and distribution of present day vegetation communities. Several isolated pre-Holocene samples and sequences exist, but apart from those examined in Tasmania by Eric Colhoun which are being tied into a more general stratigraphic framework, their significance is restricted by a lack of dating controls.

A number of sites have been selected to investigate relationships between man and his environment. These include pollen analyses of archaeological sequences from caves and rock shelters, which can be severely restricted in the information that they can contribute to regional changes, and swamps or lake sites adjacent to archaeological records which in association with charcoal counts, can be extremely valuable in helping to separate the influences of man and climate on vegetation. An additional application of pollen analysis has been the assessment of short term vegetation dynamics. The major study to date within this field is from northeastern Queensland where Professor Walker and associates are detailing patterns of change in selected rainforest taxa to help understand regenerative patterns and processes within rainforest. Results will not only contribute to ecological theory and forest management but assist in the interpretation of longer pollen records from similar areas. More general long term studies can similarly have direct application to problems of vegetation conservation and management (e.g. Macphail 1980).

So far, discussion has concentrated on the value of the regional pollen component of depositional sites to the elucidation of palaeoenvironments but a great deal of information may be derived also from more local organic materials preserved within accumulated sediments. These may reflect responses within depositional basins to macroclimatic variations and provide an independent measure of climatic change to evidence from regional vegetation. Alternatively, or additionally they may provide information on site or catchment changes independent of climate change such as hydroseral succession, soil disturbance and cultural eutrophication.

Pollen derived from local aquatics is almost always included within palynological studies but, considering the wealth of information on the taxonomy and ecology of these plants in comparison to most dry land plants, their value, except in very rare cases (e.g. Kershaw 1979), is never fully examined. Macrofossils derived from aquatics and plants growing immediately around accumulation sites can increase substantially information on local vegetation communities. Again, it is a technique which has been neglected or not lived up to expectations in Australian Quaternary studies though it has been adopted widely in the analysis of pre-Quaternary deposits. One application of the technique receiving some favour is in the investigation of aboriginal food plants preserved in archaeological sites. In contrast to the analysis of individual plant remains attention has been paid to gross stratigraphic variations in accumulated organic sediments which generally complement local pollen changes. In certain instances, for example raised bog deposits in the southeastern highlands, peat stratigraphy has revealed variations in effective rainfall which have not been very apparent from pollen evidence. More detailed information may be revealed by biochemical analysis of organic sediments as being undertaken by Maureen Longmore, originally at Griffith University and now at the A.N.U.

Other plants which have been employed in palaeoecological studies are the algae and diatoms. A small but select group of algae including Pediastrum and Botryococcus, with known water tolerance ranges, are used commonly in association with pollen analytical studies of lakes and provide valuable data on water salinity, related to water levels and hence effective precipitation. There are no published diatom records but their use, as lake level indicators, has been demonstrated for closed lakes in the western district of Victoria in two unpublished theses (Yesdani 1970, Tudor 1973). Their significance in this area has been heightened by the presence of lakes too deep for macrophytic plant indicators and a regional vegetation largely insensitive to changes in climate. Future developments with diatoms were anticipated with the visit of Joe Richardson to the A.N.U. but unfortunately it was found that the potential of diatom studies for a large part of the continent is very restricted.

A whole range of invertebrates can provide information on lake levels and trophic status, particularly in association with pollen analytical studies. Smaller organisms are most useful in that they occur often in sufficient numbers in small samples to allow statistical analysis. To date, little research has been published in this area though Patrick De Dekker of the A.N.U. has analysed a number of invertebrate groups, particularly ostracods, from a variety of important pollen cores. Amongst larger invertebrates, several studies have been undertaken on the molluscs, though often not in association with any other groups of biota, nor for the purpose of regional environmental reconstruction. The main interest in this group appears to be in the Western Australian Museum where the emphasis is placed on Quaternary stratigraphy and evolution.

There are limitations to the application of any group of fossils to the elucidation of very recent climatic changes important to the prediction of future weather patterns. These include the insensitivity of techniques to detection of small and short term fluctuations and to the effects of human disturbance on regional environments and accumulation sites. The study of dendrochronology has the potential to fill this gap, at least in some areas (Ogden 1978). In the main, Australian trees are unsatisfactory in that they are relatively short lived and any ring variations cannot be related to any climatic pattern. Exceptions include most of the conifers which are restricted largely to rainforests of Tasmania and the east coast of Queensland though one genus, Callitris, occurs extensively in semi arid areas. Preliminary investigations, undertaken by workers from Tucson (Arizona), C.S.I.R.O. Division of Forest Research in Hobart and John Ogden at the A.N.U., suggest that sensitive regional records through the last 300 to 2000 years may be revealed by most of the conifers growing close to their climatic limits. A greater range of species can provide tree ring information which will contribute to a better understanding of population dynamics and in turn assist interpretation of taxon changes in sediment-based Quaternary vegetation studies.

Environmental information from tree rings and dateable rings in other organisms such as corals and molluscs (presently under investigation by John Chappell at the A.N.U.) may be derived from the application of stable isotope analyses. Preliminary results from ^{13}Carbon analysis of King Billy pine individuals from Tasmania (Pearman _et al_. 1976) suggest a close correlation with summer temperature over the last 75 years and the method may develop as the most reliable climatic indicator available in the future.

Some major limitations to palaeoecological research

The degree of resolution that can be obtained on past environments from palaeoecological evidence depends on a number of factors including site selection, the range and nature of palaeoecological techniques, specificity of identification of fossils, the state of knowledge on the taxonomy and ecology of extant taxa, the possibility of relating fossil assemblages to extant communities, available dating and correlation techniques, time and money.

Sites likely to yield the greatest amount of information on Quaternary environments are those with long and continuous sedimentary sequences located within environmentally sensitive areas. Such sites are few in Australia because of the nature of the landscapes and general aridity. This necessitates the examination of a great number of sub-optimal sites in order to construct detailed regional pictures. In addition, few sites allow a great range of studies because different types of fossil preserve under different conditions. For example pollen is best preserved under constantly waterlogged conditions or within salt lakes. Much of the continent, which experiences highly seasonal rainfall, may not be well served by this method. Calcareous shells on the other hand require base rich open water. Insufficient research has been undertaken on some groups to understand differential representation.

Many available techniques are of limited value because of a lack of knowledge on the ecology and taxonomy of component taxa. Within those invertebrates which have proved useful overseas (i.e. molluscs, ostracods, cladocerans, beetles, chironomids, foraminifera, sponges and rotifers), there is really only sufficient information on two groups, the molluscs and ostracods, to assist in Australian studies.

The problem of identification is very apparent in pollen analysis. Pollen deposition over much of the continent is dominated by a few large wide ranging taxon groups such as Eucalyptus, Casuarina, Asteraceae, Chenopodiaceae and Poaceae, none of which can effectively be identified to species level. An initial breakthrough made by Churchill (1968) in his interpretation of Holocene vegetation and climatic changes in Western Australia, on the ratios of pollen of selected species of Eucalyptus, has not been achieved subsequently in any investigations in eastern Australia. Even when identifications have been made, there has been little attempt to disseminate the information in print. The computer assisted pollen storage and retrieval system at the A.N.U. is a valuable aid to identification, but of limited value to workers outside the institution, as it needs to be supported by extensive pollen reference collections within the workers' laboratories. Some specific pollen morphological studies have been undertaken but these tend to have by-passed examination of critical taxa. Electron scan microscopy could be employed more frequently to test for real differences between related species but the technique cannot be applied to routine pollen counting.

The adoption of surface sample studies to the interpretation of fossil assemblages, if used cautiously, short cuts much laborious taxonomic and ecological work, but again insufficient information on modern distributions is available. Apart from very restricted surface sample studies associated with particular pollen projects, the only significant information is from Gurdip Singh's western N.S.W. project. This pollen trapping exercise also provides information on absolute pollen deposition, in contrast to most studies which give relative proportions only for component taxa.

Progress in most of the areas mentioned would be accelerated by an injection of experienced researchers. The opportunities for qualified people to pursue Quaternary ecology are extremely limited and much of the work is undertaken by students who have little opportunity to build on originally acquired knowledge or to undertake long term programmes.

Finally, once sequences have been produced, they need to be slotted into a regional stratigraphic framework. This demands the availability of suitable absolute dating and correlation techniques. At present the only routinely available technique is radiocarbon dating which is too expensive to provide full and reliable age control on the majority of sites and waiting time in Australia is at present too long to be useful for short term student projects. Palaeomagnetism has the potential to provide quick and detailed correlation of cores from the same site and between sites but its application appears to depend on the occasional visit to Australia of interested operators.

Future Directions

Each Quaternary worker has rather different priorities, and it is inevitable that progress will continue in a rather *ad hoc* manner with interests and directions constantly changing. Nevertheless sufficient is now known about the potential and limitations of a number of palaeoecological techniques, as applied to the Australian Quaternary, to isolate some major directions for future study.

In pollen analysis there is an urgent need for a modern pollen flora. Ideally, all identifications should be checked against reference material collected from determined herbarium specimens but most workers do not have the time, finances or availability of herbarium material to do this. Best matches, isolated from the flora, could be checked by occasional visits to those laboratories possessing extensive reference collections. It is proposed by Helene Martin, that the flora should be produced as a co-operative venture with each participant working on a different family or group, to be published in an existing journal. As a complement to this, it could become an established practice, as in pre-Quaternary palynology, to publish photographs, descriptions and full possible affinities of grains identified in fossil and modern pollen rain studies.

Encouragement should be given to the inclusion of more extensive modern pollen information within fossil pollen studies. This should cover not only pollen trapping, to provide absolute estimates of pollen deposition, and surface samples, but sub-surface samples, where possible, to provide information on the nature of pollen deposition just prior to the arrival of European man. In many areas changes brought about by European man's activities may have been so great that surface samples may be misleading. The detection of the time of arrival of European man can be determined from the presence of pollen from introduced plants or chemical and palaeomagnetic erosion indicators.

The major role of fossils other than pollen is seen as subsidiary to pollen analysis in the reconstruction of palaeoenvironments except in marine, estuarine and perhaps semi-arid situations and in specific studies such as cultural eutrophication and biostratigraphy. The importance of fire in Australian environments necessitates that charcoal counts form a significant part of the vegetation history component of studies particularly those orientated towards examination of human impact. The experimental project of Robin Clark should provide a basis for standardisation of charcoal counts and their interpretation.

One major research direction should be towards the determination and interpretation of major plant geographical and climatic shifts through long Quaternary sequences. Selected sites should be subject to intensive analysis, by both palaeoecological and sedimentological methods and have a range of dating methods associated with them. The most fruitful sites are likely to be subsiding tectonic depressions, such as Lake George, and continental shelf basins in Torres and Bass Strait. Sites from the northern part of the continent and around the summer-winter rainfall boundary including semi-arid regions will be critical for understanding the Quaternary development of Australian vegetation and the influence of changes in position of atmospheric pressure systems. The collection of suitable cores will be an expensive undertaking and it has been suggested that the A.N.U. organises one major drilling program for selected terrestrial sites, to minimise costs. It may be possible to organise the collection of offshore cores through AIMS and VIMS. If these proposals are taken up, finance should be provided also for likely participants in the analysis of any of these cores to be present and involved in the drilling. Collected cores and associated information should be stored in an accessible 'library' for subsequent sampling for a variety of purposes.

A second major emphasis should be placed on detailed studies of the dynamics of major vegetation types unique to Australia or not very accessible in other parts of the world. These types would include tropical rainforest, tall open and open forests, heath and a variety of desert communities. Several suitable closed lake basins with constant sediment accumulation occur in high rainfall regions which could provide the focus of studies on 'wetter' communities. These include the volcanic crater lakes of the Atherton Tableland, glacial lakes in Tasmania, coastal lagoons along the east coast and Lake Tali Karng in the Victorian highlands, all of which are known to contain suitable sediments. A number of new methods are being devised, particularly in association with Professor Walker's study of tropical rainforest and Maureen Longmore's study of coastal vegetation on Fraser Island, to handle the degree of detail required in this kind of programme. These methods include sampling, dating, correlation, and numerical analytical techniques and in all these areas Australia has a great deal of expertise. The longer term perspective provided by sediment based studies should be complemented by dendrochronological, isotope and present day process studies. Results should be interpreted to maximise information to land use managers and conservationists who are becoming increasingly aware of their potential. Detailed records of past climatic variations should also be derived from these analyses.

The execution of these multi-disciplinary programmes would be facilitated by the presence of several very strong centres of Quaternary Research. A.N.U. is one obvious centre and encouragement should be given to the development of others with rather different emphases and expertise. Monash, for example, has the potential for integrating palynological and limnological studies and for close communication with Melbourne meteorologists, Latrobe archaeologists, the Victorian Archaeological Survey and Victorian Institute of Marine Science. The strong Macquarie Quaternary group could be strengthened by inputs from palaeoecologists at other Sydney institutions. Tasmania is developing strength in many aspects of Quaternary research.

Sustained progress in Quaternary studies depends upon greater involvement in the field of education. It is a discipline which emphasises the continuity between the past, present and future on a time-scale critical to the proper management of the world's resources and the survival of human society. This temporal perspective should be introduced at the primary level within the school system and developed at secondary and tertiary levels. In a society more aware of the benefits of Quaternary Studies, there would be greater employment opportunities for graduates. There is, at present, increasing demand in a variety of Government Departments, e.g. Archaeological Surveys, Fisheries and Wildlife, National Parks and Conservation, at the State and Federal levels, for studies to be undertaken but no provision for full employment. This must change if good students are to be attracted into the field and their interest and morale sustained.

Acknowledgements

The following kindly responded to a rather unwieldy questionnaire: John Beard, John Chappell, David Churchill, Robin Clark, Patrick DeDekker, Beth Gott, David Green, George Kendrick, Phil Ladd, Mike Macphail, Helene Martin, Maureen Longmore, Merna McKenzie, John Ogden, Alan Partridge, Donald Walker and Martin Williams. Some attempt has been made to incorporate their ideas in this review.

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QUATERNARY VOLCANICITY

C.D. Ollier

Volcanic eruptions occurred throughout the Tertiary Period in eastern Australia, in a number of provinces distributed roughly along the Great Divide. Volcanicity continued into the Quaternary, mainly in Western Victoria and Queensland, when there was an apparent shift to volcanic centres toward the west. In both places the volcanicity was dominantly basaltic, with widespread lava flows and scattered volcanoes.

The Queensland volcanicity is located in several Provinces (Fig. 1). A summary of the Queensland provinces is shown in Table 1.

Table 1. Summary details of Cainozoic volcanic provinces in northern Queensland

Province	Area km^2	No. of vents	Vent types	Approximate age m.y.
Atherton	1,800	56	Shield volcanoes Cinder cones Maars	3.0 - 0.1
McBride	5,500	164	Shield volcanoes Cinder cones Plugs	8.0 - 7.0 3.0 - 0.1
Chudleigh	2,000	30	Shield volcanoes	2 - 0.2
Nulla	7,500	25	Shield volcanoes	4.0 - 0.01
Sturgeon	5,200	45	Shield volcanoes	5 - 0.5
Coalstoun Lakes	50	4	Cinder cones	0.01

The furthest north, not numbered on Fig. 1, are the Piebald and McLean Provinces, which contain poorly exposed volcanics ranging in age from 4 to 0.5 m.y. old. Shields scoria cones, flows and a possible maar are present.

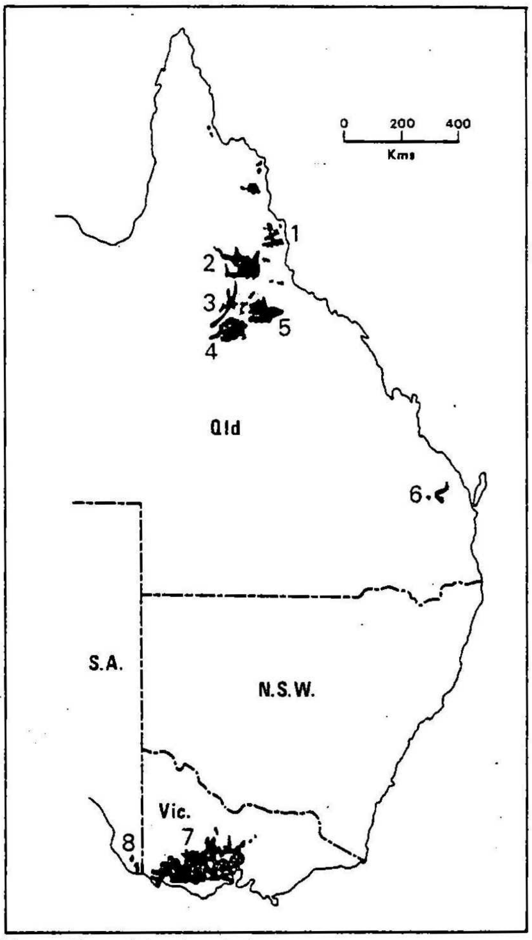
The Atherton Province (Quincan Province) includes old lava shields, like the one Southwest of Malanda, which is about 20 km in diameter with well-developed radial drainage. In the Quaternary this province seems to have been more explosive than other Queensland provinces, having eight maars and a diatreme (Hypipamee Crater). Sediment fill in the maars provides good material for Quaternary studies. The most interesting valley flows are those which filled gorges cut in the Great Escarpment west of Innisfaill. The lava flows appear to be Pliocene, but much of the subsequent erosional history is Quaternary.

The McBride Province forms a broad volcanic dome built of many lava flows, and in places almost 500m thick. Very fluid lavas built this large sheet, obliterating earlier topography and creating a new surface of low relief although very rough. There are some very long lava flows along valleys, including the Undara flow (190 000 years old) which is 160km long and is possibly the longest single lava flow in the world. It contains a discontinuous lava cave system that extends for over 90km. Most of the Province has little surface water, drainage being subsurface in the very permeable volcanics. Around the periphery of the flows streams have been dammed to form lakes, some of which have diatomite deposits (e.g. Lake Walters). The most prominent points of eruption are scoria cones, incluidng Mt Lang, 140m high The youngest is the 10 000 years old Kinrara Crater, which has well preserved features including pahoepoe lava surfaces. Further east, about 45km southwest of Ingham, is the isolated pyroclastic cone of Mt Fox, perhaps 100 000 years old (Sutherland, 1977).

The large area of basalt west of Charters Towers is divided into the Chudleigh, Sturgeon and Nulla Provinces, fairly arbitary divisions of a volcanic region that was probably once continuous.

The Chudleigh Province stradles the Great Divide, and has flows following valleys to the north, east and southwest. One flow down the Einasleigh River is over 100km long. Pyroclastic cones and a few lava shields mark the 46 known points of eruption. The youngest activity is perhaps half a million years old.

The Sturgeon Province is mainly 3 to 5 million years old but has a number of younger volcanoes. There is extensive peripheral erosion, especially where the underlying rock is soft Cretaceous shale, and the Province tends to be bounded by escarpments. The youngest flow ends near Hughenden and was erupted from Twins Crater, 120km to the south. It is perhaps half a million years old. Volcanoes include several pyroclastic cones, as well as older lava shields.



1. Atherton
2. McBride
3. Chudleigh
4. Sturgeon
5. Nulla
6. Coalstoun Lakes
7. Western Victoria
8. Mt. Gambier

Fig. 1. Volcanic Provinces with Quaternary activity.

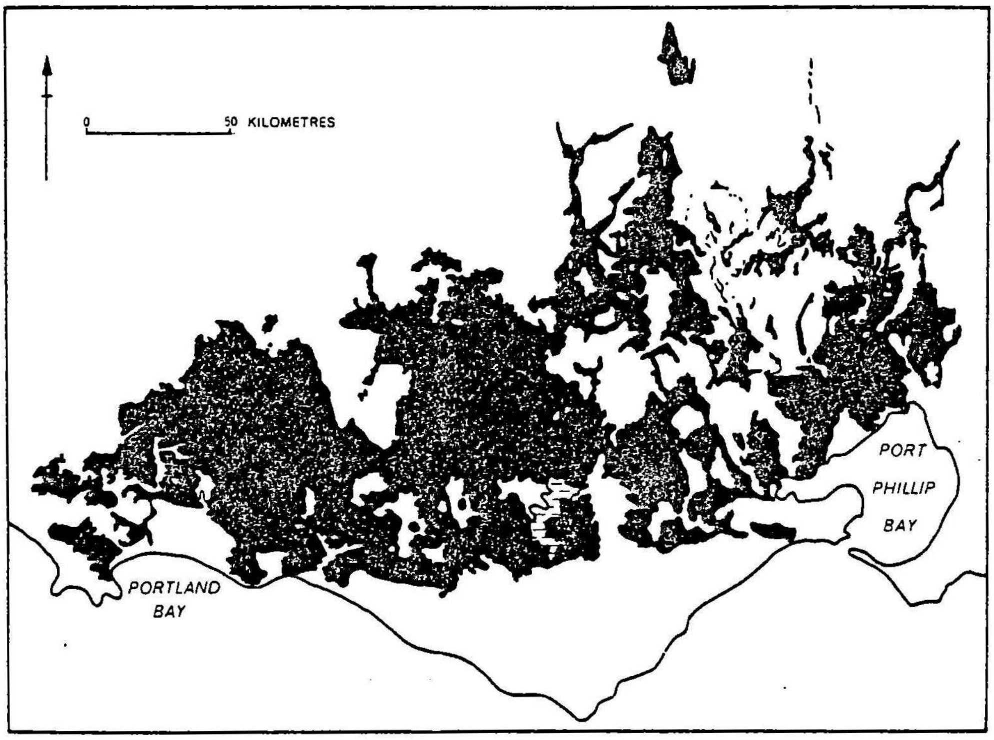


Fig. 2. Lava plains and flows of Western Victoria.

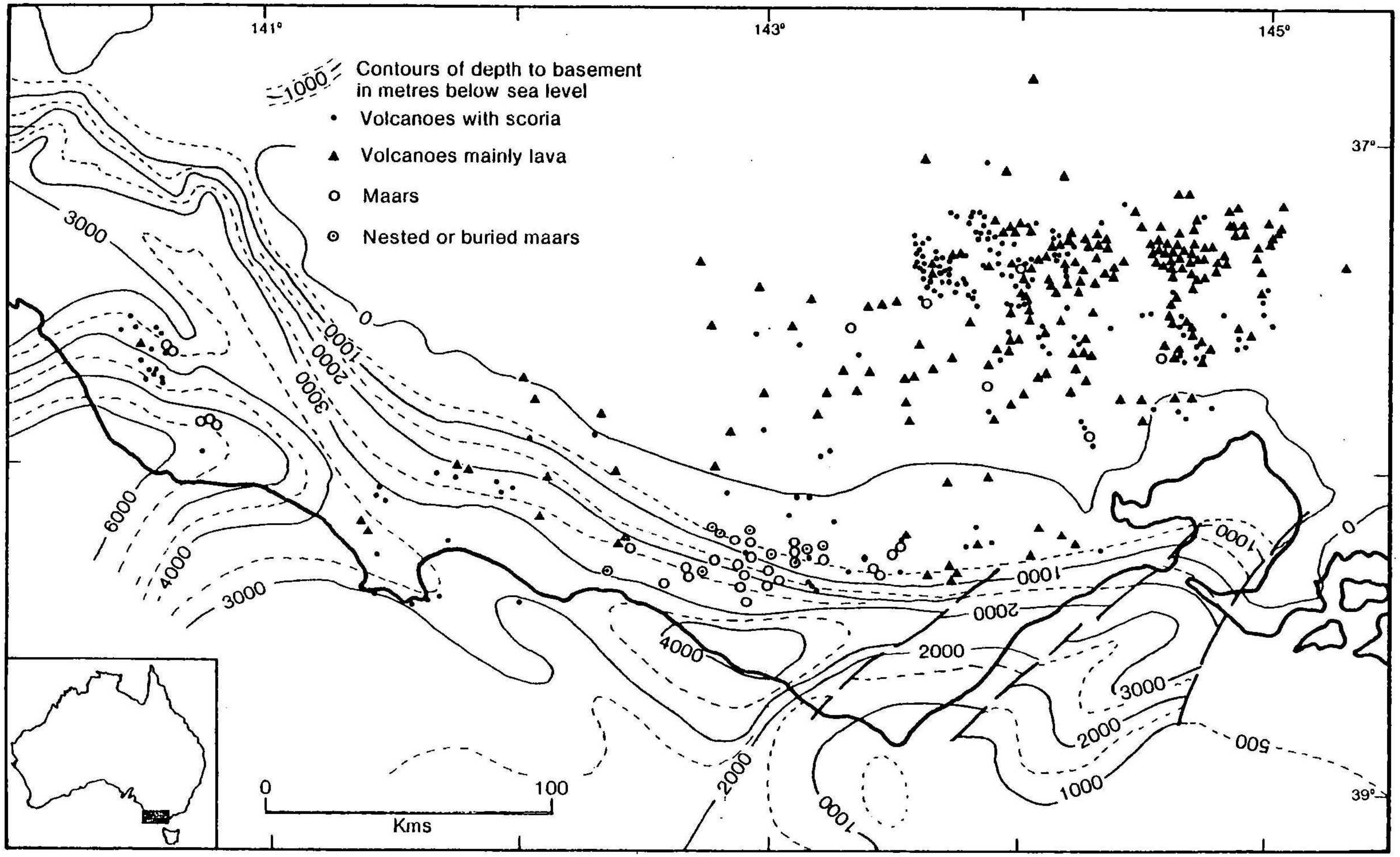


Fig. 3. Volcanoes and structure of Western Victoria.

The Nula Province consists of a large number of basalt flows which form a low dome, peripherally dissected. The Toomba flow is the youngest part, and is 90km long, possibly 1300 years old, and retains unweathered pahoehoe surfaces.

Remote from all the other Queensland activity, the Coalstoun Lakes volcanicity produced one very mobile flow that followed the Burnett valley for 130km (Stevens, 1969).

The Newer Volcanics of Victoria (Upper Tertiary to Recent) cover about 15 000 km^2 (Fig. 2.) and make up a distinctive province characterised by extensive lava flows and hundreds of small volcanoes. Known points of eruption exceed 400.

A few Newer volcanic eruptions took place in Eastern Victoria, but none are Quaternary, so we are concerned here only with Western Victoria.

On the Western plains the volcanics veneer a pre-existing plain, wheras in the highlands lava was often poured on to fairly rugged topography and frequently flowed down valleys hundreds of metres deep.

Volcanoes include scoria cones (far the commonest type), maars, basalt cones and complex eruption centres. Most of the volcanoes are less than 100m high; the highest, Mt Elephant, is 250m.

Fig. 3 reveals the spatial distribution of volcanic styles in relation to structure. Basalt volcanoes are dominant on the plateau of the Western Highlands, scoria cones are dominant on the Western Plains, and maars are commonest close to the axis of Tertiary subsidence.

There is also a temporal relationship amongst volcano types: a common sequence of eruption is maar volcano first, then lava flows, and finally construction of a scoria cone. The youngest volcano in Victoria is Tower Hill, 7,300 years old. Mt. Eccles is 19 000 years old (Ollier, 1981) but there could be a younger eruption on the same site. Several other volcanoes are probably a few tens of thousand years old.

Many primary volcanic features are preserved particularly the volcanic cones, but the flows are often somewhat dissected, with Inversion of relief by some tens of metres, and dissection into outliers.

As in Queensland the lava flows were very fluid, and flowed down valleys and over plains for many kilometres. Flows from Mts Rouse, Napier and Eccles can be traced for tens of kilometres, in place through narrow gaps only a hundred metres wide. The younger flows tend to give "stony rises" topography. Many flows have lateral streams, and numerous instances of successive flows occupying the lateral stream of its predecessor can be worked out.

Volcanicity continued into South Australia, mainly represented by a few maars. The best known is Mount Gambier, which is the youngest volcano in Australia with carbon date of 4710≠70 years, and the only one with volcanic ash overlying aboriginal hearths and artefacts. A younger date of about 1400 years is probably erronious.

The nearby scoria cone of Mt Schank is a few centuries older than Mt Gambier (Sheard, 1978; Barbetti and Sheard, 1981).

The juxtaposition of flows of different ages allows relative chronologies and drainage pattern evolution to be studied, and also provides a basis for palaeopedological studies (e.g. Gibbons and Gill, 1964).

Erosion rates can be worked out in areas of dated flows, though this has usually been done on a time scale exceeding the Quaternary Period. Wyatt and Webb (1970) found an average rate in the Burdekin River area of 10 B (=10 mm in 1000 years), with a higher rate during the last 2.4 m.y. and a rate of 35 B bordering a flow of 1.3 m.y. In the McBride Province Griffin and McDougal (1975) found a rate of 22B for the past 2.3 m.y.

In Victoria some lava flows reached the sea at times of low sea level, which enables them to be tied into a sequence of glacio-eustatic sea level changes (Boutakoff, 1963; McDougall and Gill, 1975).

Volcanic and tectonic studies have been carried out by Joyce (1975) and others, and the volcanics provide opportunity for studies of volcanic geomorphology.

A few detailed studies of Quaternary events have been carried out in volcanic craters, such as Keilambete (Bowler, 1971; De Decker, 1982) Lake Leake (Dodson, 1975), Lynch's Crater (Kershaw, 1978) Mt Gambier (Barbetti and Sheard, 1981). Studies are in progress on deposits in Lakes Eacham and Barrine in the Atherton province.

For a summary of Victorian Quaternary volcanoes see Ollier and Joyce, 1976. For Queensland see Stephenson, Griffin and Sutherland, 1980.

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QUATERNARY COASTAL AND CONTINENTAL SHELF STUDIES OVER THE LAST DECADE

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The objective of this review is to highlight major developments in Quaternary studies of the Australian shelf and coast during the last decade. To some extent we have been hindered by our environment, as well as by the lack of physical and human resources in the pursuit of Quaternary coastal science. Distance, isolation and remoteness are factors which have limited the extent and detail of studies in many parts of the continent. Nevertheless, there has been a concerted effort in recent years to conduct research over a wide area. More detailed systematic and regional studies have also been possible facilitated by an interest in drilling and dating Quaternary sequences.

Post-war studies of sea-level change, morphological patterns and sedimentation opened the way in the 1970's for more systematic work as Quaternary stratigraphy, sedimentology and chronology of coastal deposits and for continental shelf studies. It also provided a background for coastal process research which has been vigorously pursued during the last 8 years - this work will not be discussed here (see Wright et al., 1979).

In the two decades before 1970 very little work had been undertaken on the continental shelf. Notable exceptions included the study by Jennings (1959b) in Bass Strait, the sedimentation study on the Sahul Shelf (Van Andel and Veevers, 1967), geologic reconnaisance on the shelf in southeast South Australia by Sprigg (1979), and the monograph ("Atlas") of the Great Barrier Reef by Maxwell (1968). In south-eastern Australia preliminary investigations by Shirley (1964) and Phipps (1966) provided some information on shelf sediment types and sea-level change. However, little published information was available off the Gippsland coast inspite of extensive oil exploration. There has been a greater effort on the description of morphology and sediment types on the continental shelf in the last decade.

Continental shelf research has been fostered by a concerted effort by the Division of National Mapping to determine the bathymetry of the shelf. Geological surveys by the B.M.R. and various state authorities have enhanced this understanding. In this regard the work of Jones et al. (1975), Davies (1979), Jones and Davies (1979) and Marshall (1980) should be mentioned. These studies have elaborated on early work in eastern Australia and have defined sediment types and possible relict shorelines. The use of a submersible in Queensland and in the Arafura Sea led to the recovery of dateable shoreline material critical to defining lowest sea levels of the last Pleistocene (Veeh and Veevers, 1970; Jongsma, 1970; Chappell, 1974). At the present time shelf research is expanding to include more shallow penetration seismic and vibro coring (e.g. Hails et al., in press). In N.S.W. and southern Queensland such studies have been assisted by a visit from the West German research vessel the "sonne" in 1980. This work has produced more data on paleo-shorelines, heavy mineral deposits and environments of deposition at present and lower sea levels (von Stackelburg, 1982). Similar work is underway in Western Australia.

Except for the work of Maxwell (1968), very little research had been undertaken on the Great Barrier Reef between 1950 and 1970. Earlier surveys by Steers (1929) and Fairbridge (1950) required elaboration. This was undertaken in the 1970's with great enthusiasm by members of the Royal Society - Universities of Queensland expedition in 1973 (Stoddart et al., 1978), by Hopley in numerous papers (see Hopley, 1982, for details), and by Davies and Marshall of the B.M.R. (e.g. Davies et al., 1977, Davies and Marshall, 1980). A quick look at these papers shows that during this decade our understanding of Holocene sea-level change, reef stratigraphy and reef flat and island morphology/sedimentology has greatly improved.

Quaternary stratigraphic research became a major research activity in coastal environments in the 1970's. Shallow core drilling on the Great Barrier Reef has been the basis for reef stratigraphic papers mentioned above. On the Queensland mainland chenier plains have been studied in some detail in Broad Sound (Cook and Mayo, 1977), and the southern Gulf of Carpentaria (Rhodes, 1982; Rhodes et al., 1980). These studies documented the Holocene depositional history of the areas, and highlighted the possible episodic nature of processes responsible for sedimentation in these semi-arid areas. More recent work on the chenier plain of Princess Charlotte Bay by Chappell and others is showing a close relationship between modes of deposition and periods of Aboriginal occupation (Chappell et al., 1983). In southern Queensland, shallow drilling is being used to unravel the complex aeolian and soils history of the dune "islands" (Ward, 1977; Thompson, 1981). Pye (1983) has recently completed a similar study on the complex Holocene/late Pleistocene dune fields of Cape Flattery and other sites in north Queensland.

Deep drilling to rock "basement" has been carried out extensively in N.S.W. by Thom and associates over the past decade. The prime objective of this research has been to understand Quaternary depositional sequences of bay barriers along this embayed coast (Thom, 1978; Thom et al., 1978; Thom et al., 1981a and b). Two areas have received most attention: Myall Lakes and near Moruya. This work has recently been integrated with shelf research (Roy and Thom, 1981).

Drilling of Holocene barriers has been extended into South Australia, Victoria (especially Gippsland see Thom et al., 1983), and Tasmania. In Tasmania, Bowden (1981, 1983) has provided a detailed regional account of the northeast portion of the state where Lake Glacial aeolian reworking of interglacial marine deposits has taken place.

One of the most exciting Quaternary sequences in coastal areas of Australia is in the southeast of South Australia (Sprigg, 1979). Geologists from the B.M.R. and Flinders University have made several detailed studies in this area documenting the stratigraphy and chronology of aeolian, shoreline and lagoonal facies (Cook et al., 1977; Schwebel, 1978). Hails et al. (in press) have used seismic and vibrocoring to delineate Pleistocene and Holocene sediment units in Spencers Gulf; they have also examined shoreline deposits in this area (Hails et al., 1983, see also Burne, 1982).

In Western Australia, Logan and associates have continued sedimentological studies of carbonate areas and examined Quaternary sequences on the inner continental shelf. Jennings (1975) published his findings from King Sound showing the relationship between continental aeolian and Holocene marine deposits. This area has also been the focus of detailed stratigraphic and ecologic work by Semenuik (1981).

One important aspect of Quaternary coastal research in the 1970's has been the extensive use of radiocarbon dating. Many problems have been tackled including the dilemma of an interstadial high sea level above present (Thom, 1973). Documentation of in situ organic materials by dating is refining early attempts at producing a sea-level "envelope"

(Rhodes, 1979; Chappell, 1983; Donner and Junger, 1981; Thom and Roy, 1983). Difficulties of interpretation of reworked nearshore shell materials have also been discussed (Thom et al., 1981a; Donner and Junger, 1981).

Uranium-series dating has been used to a limited extent in coastal work in Australia. Corals beneath so-called Inner Barrier at two sites in N.S.W. were shown to be Last Interglacial in age (Marshall and Thom, 1976). Drury (1982) has investigated the age of estuarine fill in the Richmond Valley in considerable detail. Schwebel (1978) has been able to date younger Pleistocene deposits in South Australia. Paleomagnetic reversal stratigraphy was also used in this area to define the approximate position of the 700,000 year shoreline (Cook et al., 1977).

Future prospects involving publication of current research as well as planned projects are quite exciting. Continued work on the Great Barrier Reef by a number of groups is clearly demonstrating the value of that region to Quaternary science. Elsewhere in Northern Australia the relationship between various environments of deposition and sea level is being closely investigated, along with studies on the evolution and contemporary changes to estuaries. John Chappell is leading a team involved in such studies in the South Alligator, Daly and Macarthur Rivers of Northern Territory. Undoubtedly, the shelf and coastal work of Logan and associates in Western Australia will continue to be rewarding. K.H. Wyrwoll has embarked on exciting stratigraphic work involving E.S.R. dating in this state. The ANZAAS Congress in

Perth in 1983 provided many with the opportunity to examine estuarine sediment and paleoecologic research of Hodgkin, Hesp, Kendrick and others. In South Australia, we await with anticipation the issue of Marine Geology devoted to the sediments, morphology and stratigraphy of Spencers Gulf. Tasmania is just now revealing its extraordinarily different neo-tectonic history which deserves more geophysical attention (van der Geer, et al., 1979; Bowden and Colhoun, in press). The Gippsland region continues to provide a wealth of information on Holocene barrier, backbarrier and fluvial sedimentation (Thom et al., 1983). In N.S.W., further attempts are being made to interpret depositional sequences on a compartmented coast but less compartmented shelf. Such studies are also active in southern Queensland where the majestic dune islands continue to attract Quaternarists.

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QUATERNARY FLUVIAL PROCESSES AND STRATIGRAPHY

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For the purposes of this report, the Quaternary is considered to span a time, beginning about two million years ago, extending to the present. This follows from the proposition that most fluvial landforms in Australia had their origins in the geological past and that modern river activity reflects both past and present environments. The connection between past and present is important particularly for fluvial systems, because it allows us to interpret past events and environments from the observation of modern processes.

The factors contributing most powerfully to the development of fluvial landscapes are tectonics and climate. The former operates through changes in erosional, transportational and depositional gradients while the latter affects the volume of river flows. Climate also controls vegetative cover and the mobilisation of sediment from erosional sources. These factors are discussed here in the Quaternary context. Attention is also given to Australian fluvial landscapes insofar as they offer particular Quaternary research opportunities. Some of the more significant advances in our understanding of these landscapes are discussed and remaining problems are indicated. Notes are also made on the importance of Quaternary fluvial landforms as a national resource requiring monitoring and the continuity of research.

THE AUSTRALIAN SETTING

Factors in fluvial landscape development

The prolonged tectonic stability of much of Australia during the Tertiary resulted in large areas of land having low erosional gradients and being de :ply weathered. This phase of weathering pre-conditioned erosional landscapes to yield sediment as climates changed through the late Tertiary into the Quaternary and erosional instability was induced by wide, short-term climatic fluctuations. Only a very limited area of the Australian mainland was directly affected by Pleistocene glaciation although a relatively high proportion of Tasmania was glaciated. For much of Australia, therefore, the Quaternary stratigraphic record reflects episodic fluvial erosion and deposition rather than glaciation. The association of episodic landscape development with Quaternary climatic changes in eastern Australia appears to be substantiated (Bowler et al., 1976; Coventry et al., 1980). The record, however, is much better documented for the late Quaternary than the early Quaternary. The interpretation of some fluvial stratigraphies and landscapes such as river terraces, reflecting climatic effects of relatively wet versus dry, remains equivocal (see Bowler et al., 1976). There is considerable scope for increasing our understanding of the climatic implications of certain fluvial landforms and stratigraphies.

The influence of Quaternary tectonics on fluvial landscapes through changes in erosional and depositional gradients appears to have been minor, judging from the small documentation that exists. The observations of Bowler & Harford (1966) in the Riverine Plain of southeastern Australia and Pillans (1974) in the erosional uplands of the Murrumbidgee River indicate, however, that Quaternary tectonics were at least locally significant. They have probably been underestimated as a geomorphic factor in Australia.

The effect of Quaternary sea level variations on coastal fluvial landforms has been observed in parts of eastern Australia

(Warner 1972; Coventry et al., 1980). Quaternary stands of sea level must have been synchronous around Australia and could provide a unifying principle for the study of coastal fluvial landforms and processes. There appears to be too few data available at present, however, for a comprehensive statement to be made about Australian Quaternary coastal flood plains.

River systems

Entrainment and differential transport and deposition of Tertiary weathering products during the Quaternary was generally accomplished by river systems of low gradient traversing dry climatic regions. The low sediment delivery of these streams has meant that much of inland Australia is characterised by alluvial fans and extensive depositional plains of Quaternary age.

The significance of these conditions in Australia is highlighted in Figure 1. Here the map of Walker & Butler (in press) is used to characterise modern rivers based on the presence or absence of certain landscape components: upper catchments of essentially hillslope terrain with overland flows dominant (W); riverine landscapes where flood plains are extensive and catchments relate to river channel and overbank processes (R); landscapes in dry environments where rivers either lose their flows in aquifers, or by evaporation, or in lakes (L). Rivers that discharge into the ocean (O) are separated from those that do not. Some rivers such as the Murray-Darling system have all the above components and are thus designated WRLO. Others such as the

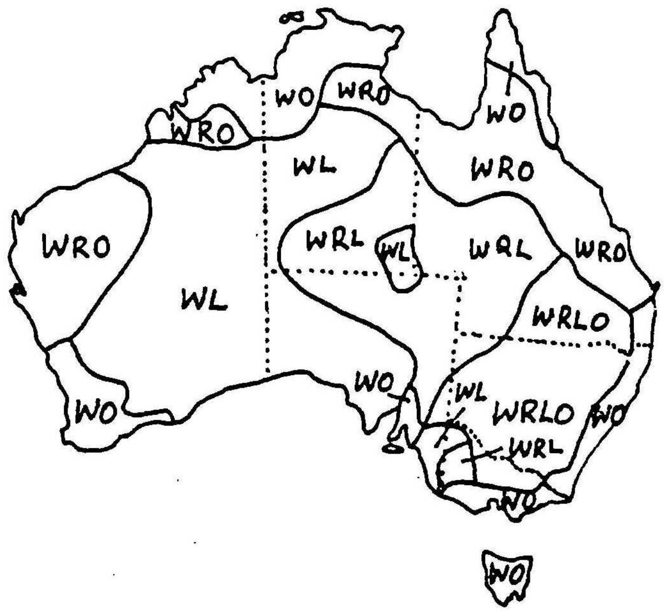

Figure 1. Areas of Australia in which the river systems are classified after Walker & Butler (in press) according to the presence of certain fluvial landscape components. W = watershed (hillslopes) where overland flows dominate; R = riverine landscapes where channel and overbank fluvial processes dominate; L = lacustrine influence on stream flow and fluvial transport; O = river systems terminating in the ocean.

Diamantina and Finke drain into Lake Eyre (WRL). Many of the most arid areas have no integrated drainage systems (WL).

The extent of fluvial aggraded landscape in Australia is indicated in Figure 1. Only 15 percent of the continent is drained by rivers which flow to the ocean without the development of extensive flood plains. 50 percent is designated WRL or WL and is land in which the products of fluvial erosion remain within the system. Although a significant proportion of this area is covered by sand dunes, fluvial processes modify dune slopes and fluvial sediments are differentiated and deposited in dune corridors.

Taken as a whole Australian landscapes offer considerable scope for a comprehensive account of Quaternary environmental changes and the response of fluvial processes to them in a wide range of geographic settings.

FLUVIAL PROCESSES

Hillslopes

The essentially fluvial nature of hillslope erosion by overland flows was suggested by Meyer & Monke (1965) and has been confirmed in recent studies in Australia by Moss & Walker (1978). Although the separation of bed load and suspended load is spatially constrained in such water flows, behaviourally distinct grain populations are differentiated, even where flows are only several millimetres deep. It is physically appropriate therefore to extend the concept of fluvial processes through drainage systems to include upper watersheds as well as valleys and those environments where streams enter a lake or the ocean. The processes involve detachment, transport, differentiation and deposition of particles and the transport of solutes.

Hillslopes and associated soils are the ultimate surficial source of sediment for fluvial systems and the supply is generally limited by detachment rather than flow capacity. The vegetative cover of soils therefore has a key role and environmental factors that control vegetation such as rainfall, temperature and fire essentially control sediment supply. These principles of hillslope stability are fundamental to understanding the history of Quaternary fluvial landscapes but have received relatively little systematic study.

One of the key areas of research is the identification of the environmental limits of stability of watershed ecosystems. Studies of the orographic distribution of the ecosystems in the Snowy Mountains by Costin (1954) have elucidated some aspects of stability at high elevations. For much of Australia, however, inferences can be made only from palynological studies of fluvial or lake sediments (Pels 1960; Singh et al., 1981). An associated area of study concerns the protection afforded by various kinds of natural vegetative cover to soil surfaces against soil detachment by fluvial erosion. Some of the physical principles of cover effects in humid and arid regions have been outlined by Moss (1979). Apart from the size and geometry of vegetative cover, the separation of ground cover and canopy effects is required. In this respect, much needs to be done in the study of a wide range of eucalypt forest and woodland types.

Fluvial hillslope processes such as splash, sheet erosion, rilling and gullying tend to have been studied in the modern agricultural context. They are, however, equally important as Quaternary processes. Recent Australian studies by Walker et al., (1978) and Moss et al.,(1980) indicate that the main transporting power of sheet erosion lies in rain-impacted overland flow or rain-flow transportation rather than splash. Rain-flow transportation operates effectively on gradients up to 0.05 and must have been an important Quaternary fluvial agency in dry inland areas of low vegetative cover such as the sand plains of Western Australia or many erosional slopes of northern Australia. On the other hand, recent studies of fluvial erosion of aeolian dunes in southeastern Queensland (Bridge et al., in press) have established the significance of splash erosion of sand under a forest canopy. The relative importance of the above mechanisms in the initiation of fluvial erosion and tranpsort in a range of geographic settings has yet to be ascertained.

The occurrence of hillslope mantles of colluvium and fanglomerate of Quaternary age has been noted in various parts of Austrlia (e.g. Churchward 1970; Costin & Polach 1973; Wasson 1977). The likelihood that some of these deposits in the eastern highlands may relate to Pleistocene periglacial processes has been suggested by Galloway (1965). In this case the requirement is for sedimentological criteria to distinguish fluvial from periglacial deposits so that useful palaeoenvironmental interpretations can be made.

Riverine environments

Materials derived from fluvial detachment and differentiation on hillslopes are fed downslope and thence downstream into river systems. There they are further differentiated into bed load and suspended load, these grain populations being much less spatially constrained than those differentiated in shallow water flows on hillslopes. In riverine landscapes, bed load is associated with specific features such as point bars and gravel features in the stream channel whereas suspended load tends to be associated with flood plains developed adjacent to channels. The mechanisms of river sediment transport and differentiation are relatively well understood. However, the river system parameters favouring the development of specific fluvial landforms representing bed load as against suspended load deposition are not well understood. Lack of basic knowledge of these factors permeated the debate about Quaternary fluvial landscapes in the Riverine Plain of southeastern Australia (Butler 1960; Langford-Smith 1960).

Schumm (1968) proposed that these fluvial systems responded to changing Quaternary environments in catchments causing changes in water discharge and the kind and amount of sediment load. In the flood plain of the Murrumbidgee River, the most direct interpretation was that the older Quaternary palaeochannels (prior streams) were bed-load and mixed load streams developed at a time of ineffective vegetative cover on catchment slopes and relatively high sediment yield. The younger Quaternary palaeochannels (ancestral rivers) were associated with suspended load transport when more humid climates favoured stronger vegetative covers and much reduced sediment yield. Schumm (1977) later observed, however, that relatively little is known about the response of drainage systems to tectonic events and climatic change, bearing in mind that such systems include hillslopes, channels, terraces and flood plains which may be separated by large distances. The possibilities of delayed responses to change or non-synchronous responses through the system need to be considered. These aspects of fluvial landscape development represent one of the more important areas for research in the Australian Quaternary.

FLUVIAL LANDSCAPES AND STRATIGRAPHY

Erosional landscapes

Recognition of the importance of Quaternary episodes of hillslope erosion in Australia came largely from pedological studies of the 1950's and 1960's. In Western Australia, significant areas of relict Tertiary surface remain little modified by Quaternary fluvial erosion (Mulcahy & Bettenay 1972). In south-eastern Australia, however, Quaternary fluvial erosion and deposition were much more widespread (Butler 1967). Some of the principles involved in these studies are shown diagramatically in Figure 2 for hillslopes and adjacent (proximal) riverine landscapes. Downslope of the relict erosional surface (X_R), a new erosional surface (Y_E) is cut and erosion products (Y_D) are distributed downslope over the older erosional-depositional surface (X_B).

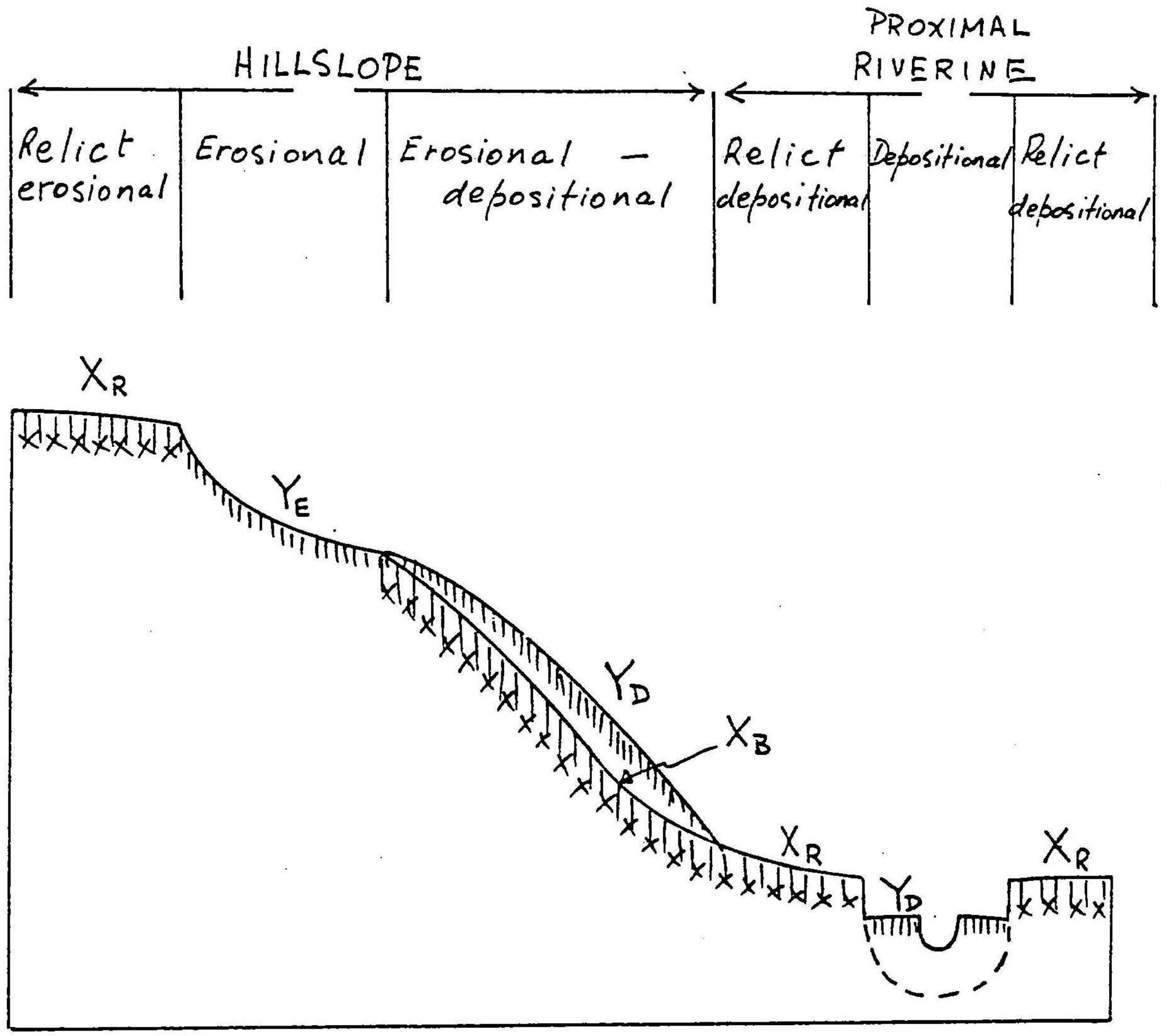

Figure 2. Diagrammatic representation of fluvial erosional and depositional landscapes and stratigraphy. X_R = relict erosional/depositional surfaces; X_B = buried erosional surfaces; Y_E = new erosional surface; Y_D = new depositional surface.

Deposits of lower slopes are typically colluvial mantles and alluvial fans. Surfaces and sediments corresponding to those of the hillslopes are represented in the proximal riverine landscape in Figure 2 but there they are separated as river terraces.

Buried soils in the erosional-depositional zone and the riverine landscapes (Fig.2) provide a basis for resolving colluvial and alluvial stratigraphies. Moreover, the presence of a buried soil indicates an hiatus in local erosion and deposition which may have environmental implications. It is characteristic of Australian erosional landscapes that soil profiles are complex and frequently contain parts of several soils in vertical sequence. Accordingly, pedologists have developed a variety of criteria for separating soil stratigraphic units ranging from field relationships, such as spatial independence of layers (Walker 1962), to microscopic properties (Brewer 1972; Sleeman 1975). Some of the subtleties of soil stratigraphy on hillslopes are illustrated in the studies of Finkl & Gilkes (1976) in Western Australia. Here erosional re-distribution of Tertiary weathering products has provided a complex of pedorelicts (pieces of paleosol) and granular sediment as parent material for soils developed on lower slopes.

Many problems remain in the research of Quaternary stratigraphy on hillslopes. Field resolution is made difficult by the thinness of bodies of fluvial sediment, local redistribution of weathering products and the superposition of soil profiles. The use of depth functions of both field and microscopic properties (for example Finkl & Gilkes 1976) needs to be explored further in a wide range of geographic settings.

Greater insights into the Quaternary may also be obtained through sedimentological studies aimed at deciphering the intensity of fluvial erosional-depositional events. Size-shape analysis was used by Green (1974) in a study of the profile of a small flood plain to determine the bed load or suspended load origin of soil parent materials. Moss & Walker (1978), using size-shape data from profiles in Quaternary colluvium, found sedimentological characteristics similar to sediments deposited experimentally in overland flows of moderate to high energy. Considerable scope exists for testing and developing such techniques to elucidate the conditions of Quaternary hillslope instability.

River terraces and flood plains

During the last thirty years, river terraces and flood plains have been studied in a wide range of geographic settings in Australia. In Table 1 references are listed which either review the knowledge about fluvial landforms and stratigraphy in certain regions or contain specific information that has bearing on regional understanding. For example, the paper by Butler et al.(1973) reviewed a large body of knowledge about the geomorphology of the Riverine Plain of southeastern Australia. A recent Symposium dealt with the associated fluvial stratigraphy of parts of the Murray-Darling Basin (Proceedings of the Royal Society of Victoria, Volume 90). The reader is also referred to the review by Mulcahy & Churchward (1973) in which the Quaternary history of Australian fluvi-l landscapes was discussed.

Table 1. Summary of characteristics and processes proposed for Quaternary fluvial landscapes at a range of locations in Australia.

Location	River system*	Dominant fluvial landforms	Formative factors	Reference
Northeastern Australia	WO,WRO	Eroded Tertiary surfaces, alluvial fans; coastal and inland alluvial plains	Eustatic movements; climatic change; tectonics	Coventry et al. 1980
North coast, N.S.W.	WO	River terraces; coastal flood plains	Eustatic movements; climatic change (?)	Warner 1972
Upper Darling River	WRLO	Extensive clayey flood plains	Climatic change; tectonics	Taylor 1978
Southern highlands, coast of N.S.W.	WO,WRLO	Alluvial fans; river terraces, localised flood plains	Climatic change	Walker & Coventry 1976
Southeastern Tasmania	WO	Late glacial alluvial fans	Climatic change	Wasson 1977
Eastern Tasmania	WO	River terraces and flood plains	Climatic change	Nicolls 1960
Lower Murray-Darling Basin	WRLO	Extensive clayey flood plains	Climatic change; tectonics	Butler et al. 1973
Arid South Australia	WRL	Alluvial fans	Climatic change; tectonics	Williams 1973
Arid Central Australia	WRL	Alluvial fans; river terraces, flood plains	Climatic change	Litchfield 1969
Semi-arid Western Australia	WRO	River terraces and flood plains	Climatic change (?)	Bettenay et al. 1971
Coastal Western Australia	WO	River terraces and coastal flood plain	Climatic change	Wyrwoll 1977

* The code for the river system designations is given in the text.

It is apparent from the references in Table 1 that, in Australian environments ranging from arid to humid tropics, episodic fluvial landscape development occurred during the Quaternary. Climatic change is sought as an explanation for these episodes more frequently than tectonics and, in some coastal river systems, phases of fluvial landscape development are related to variations in sea level. In the Riverine Plain of southeastern Australia and in valleys along the eastern highlands, fluvial landforms and sediments are dominantly Quaternary in age. By contrast, some fluvial depositional landscapes in Western Australia are essentially Tertiary in age (Mulcahy & Bettenay 1972).

In the upper parts of drainage systems, evidences of episodic alluviation are seen in flights of river terraces (see Fig.2). While the topographic separation of river terraces facilitates their stratigraphic separation, difficulties remain in the interpretation of terraces. Bowler (1970) has discussed these problems for river terraces of probable climatic origin in the Maribyrnong Valley, Victoria. Palaeoenvironmental and palaeohydrological interpretations of terraces require assumptions about channel section and morphology, kind and rate of supply of sediment load and climatic parameters of rainfall and temperature. Until more is known about these variables in relation to modern rivers, the interpretation of Quaternary terraces and associated river channels will remain uncertain.

In those parts of river systems where extensive alluvial plains have developed, more or less continuous aggradation has occurred during the Quaternary. The stratigraphic record is thus seen in alternating coarse and fine fluvial sediments (see Pels 1969 for the Riverine Plain) and in the occurrence of buried soils (Butler 1958). The palaeoenvironmental interpretation of such sequences remains unclear, partly because of the lack of specific environmental signatures among fluvial sediments. Furthermore, Schumm (1977) has noted that the response of large fluvial systems to Quaternary perturbations may be complex, involving first the development of a braided system in the alluvial plain which evolves to an incised channel system. This concept has particular relevance to the Riverine Plain of south-eastern Australia where there remains a controversy over the interpretation of the earlier prior streams as against the later ancestral rivers and the incised modern channels. As in the case of river terraces, explanations of varying river regimes and related sedimentation in alluvial plains will continue to be unsatisfactory until critical studies are made of modern river processes.

A particular feature of many extensive alluvial plains in Australia is their preponderance of clay-rich sediment (see Butler 1958; Taylor 1976; Rust 1981). The processes by which clayey suspended load dominates the depositional environments of large river systems such as the Murray-Darling are little understood. Similarly, the conditions of overbank deposition of very fine sediment have not been critically studied. This is a field where the understanding of contemporary fluvial processes would aid the interpretation of Quaternary fluvial clay sequences.

Some advances in Australia have been made in deciphering the stratigraphy of such sequences, particularly where they contain buried soils. These approaches have been based on geochemistry. However, criteria for separating pedological from purely sedimentological sections of a stratigraphy remain equivocal (see for example Oertel & Giles 1964; Paton & Little 1974). Further development of geochemical and micromorphological criteria in fluvial sequences is particularly appropriate for the Australian situation because of the extent and depth of Quaternary alluvial clay.

The prospects of interpreting the stratigraphy of alluvial plains graded to various Quaternary stands of sea level may be more straightforward than that of fluvial sequences in inland areas of Australia. For correlative purposes, such stratigraphies have the advantage of relating to world-wide sea level variations. The eastern coast of Australia features flood plains near the mouths of most rivers and these have developed in response to the Holocene rise of the ocean (see Walker 1970). Only a few data are available for coastal flood-plain development during the late Quaternary (Warner 1972) and the early Quaternary record is more meagre.

Problems of continuity of record exist in coastal fluvial stratigraphies because of the erosion, transgression and burial associated with sea-level fluctuations (Warner 1972; Wyrwoll 1977). No synthesis of stratigraphic data has been made for Quaternary coastal flood plains in Australia and this appears to be a worthwhile task.

QUATERNARY FLUVIAL CHRONOLOGY

Only a very general outline of a Quaternary fluvial chronology is possible for Australia. The situation is complicated by the apparent lack of synchronised climatic change in the north and the south of the continent during the late Quaternary (Bowler et al., 1976). The same was probably true for the early Quaternary. No significant regional tectonics are indicated as a basis for a broad chronology. Rather, tectonics appear to have caused only minor local changes in erosional and depositional regimes. Although eustatic sea level changes are likely to provide the only basis for broadly synchronous episodes of fluvial landscape development there are at present insufficient data on near coastal fluvial sequences to develop an appropriate chronology.

In Table 2, only the coarsest aspects of a Quaternary fluvial stratigraphy are attempted. It seems clear that, in southeastern Australia at least, a major change in river regimes occurred in the interval 30,000-20,000 BP associated with the last major cold phase of the Snowy Mountains (Bowler et al., 1976; Walker & Coventry 1976). Sediments transported during this period must have been derived by widespread erosion of highland slopes making up the major river watersheds in southeastern Australia. Following this sub-continental response to the last cold phase of the Pleistocene, however, the recovery of individual river systems and their fluvial landscapes, up to the present, was probably controlled by local rather than regional factors. The possibility of wider occurrence through southern Australia of fluvial

Table 2. Outline of a Quaternary chronology of fluvial processes and landscapes in Australia.

QUATERNARY			TERTIARY
Holocene	10^4 BP Pleistocene	1.8m BP	
Climate warming to equable	Wide climatic fluctuations with cold and dry phases prominant 20,000 30,000 Cold phase S.E. Highlands	Climatic zonation	Generally moist, equable to warm climate
Catchments erosionally stable. Low river terraces and flood plains in uplands. Extensive inland flood plains of clay-rich sediment. Development of coastal flood plains.	Episodic erosional instability of catchments giving rise to colluvial mantles on hillslopes and alluvial fan development. Widespread river terrace development in uplands. More or less continuous deposition in extensive inland alluvial plains. Alternating high and low coastal flood-plain development.		Extensive erosional stability and deep weathering of upper catchments.
Global sea level rise.	Alternating high and low sea levels.		Generally high sea levels.

stratigraphy relating to the 30,000-20,000 BP climatic episode needs to be explored further. Williams (1978) has proposed a climatically induced late Holocene episode of erosion and fluvial sedimentation in the southern highlands of eastern Australia. The spread of dates in alluvial deposits of late Holocene age (see Coventry & Walker 1977) is large, however, and the proposal of a regional fluvial episode requires further examination.

Although it can be inferred that extensive and thick fluvial deposits of early Quaternary age must occur, especially in large inland alluvial plains such as those of the Murray-Darling Basin, very little is reliably documented stratigraphically. One of the major problems is a lack of sedimentological and palaecbiological markers in fluvial sediments, especially in relation to the Pliocene-Pleistocene boundary, approximately 1.8m BP. Routine dating by radiocarbon (<40,000 BP) is applicable only to the late Quaternary. The lack of regional volcanic activity and associated pyroclastics preclude the application of volcanic methodologies to early Quaternary fluvial sequences. Palaeomagnetic reversal stratigraphies may provide time markers in early to mid-Quaternary fluvial sequences, but only where sedimentation has been continuous and of fine-grained material. These conditions are likely to be met in lacustrine rather than fluvial environments (Singh et al., 1981).

QUATERNARY FLUVIAL LANDSCAPES - A RESOURCE PERSPECTIVE

Research into Quaternary fluvial landscapes and processes is not a purely academic exercise. It concerns some of Australia's most important water and soil resources. Quaternary geological erosion and deposition within the Murray-Darling Basin led to the development of a vast system of highly fertile clay plains in hydraulic adjustment with river flows and sedimentation. These clay plains and their soils are a unique resource, virtually setting Australia apart from other continents. However, land degradation since European settlement has resulted in major changes in erosion, deposition and river water quality. Few data are available to evaluate the degradation rates and no systematic monitoring of river loads is being undertaken to assess the long-term directions and consequences to the clay plains of this degradation. Similarly, coastal flood plains are a major Quaternary fluvial resource around the Australian coastline and are being subjected to increasing land-use pressure. Virtually no data are available for these systems to indicate the long-term effects that changes due to coastal land use are having on river flows and flood plains.

The above are just two examples of Australian fluvial landscapes in which Quaternary research can provide a basis for understanding landscape stability, water quality and groundwater resources. The list could be extended to include application in exploration geology (uranium, diamonds, etc.). In general there is a dearth of data about present conditions in Quaternary fluvial landscapes in Australia. There is also insufficient monitoring of processes to assess the long-term trends.

CONCLUSIONS

1. In the majority of geographic regions in Australia, landscape development through the Quaternary has been in response to

fluvial processes. Australia offers great scope for integrating knowledge about Quaternary fluvial landscapes and for applying this knowledge in a practical way in the area of water and soil resources and exploration geology.

2. There is, however, no integrated body of knowledge of this kind. Large areas of Australia have not been studied. Where detailed fluvial studies have been made, considerable information has been obtained about the late Quaternary. There is only a meagre account of the early Quaternary.

3. Methods available for reliably dating fluvial sequences are applicable only to the late Quaternary. Virtually no useful materials are available in Australian fluvial sequences for early Quaternary dating. This applies particularly to identification of the Pliocene-Pleistocene boundary.

4. Generally, episodes of Quaternary fluvial erosion and deposition have been interpreted in relation to climatic rather than tectonic events. It is probable that the importance of Quaternary tectonics has been underestimated.

5. The response of river systems to climatic and tectonic perturbations is not well understood. Hypotheses based on a single response of whole river systems (e.g. channel incision in response to a wetter climate) ignore the complexities of hydraulic adjustment in large rivers.

6. Careful monitoring of modern rivers and experimentation could elucidate these problems of river response.

7. There is considerable scope for studies of contemporary fluvial processes and landscapes in Australia insofar as they elucidate earlier Quaternary sequences. In particular

more study is required at the hillslope erosional end of fluvial systems and the thresholds of stability there which influence sediment yield.

8. The processes involved in the development of extensive alluvial clay plains, an almost uniquely Australian landform, are not well understood. The monitoring of these plains and associated rivers is worthy of a nationally co-ordinated research effort.

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LATE QUATERNARY STRATIGRAPHY OF AUSTRALIAN DESERT DUNEFIELDS

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The desert dunefields of Australia cover about 35% of the continent's area. The dunes are presently vegetated to varying degrees, with a gradient established from the immobile and often low dunes of the semi-arid margin to the higher and sporadically mobile dunes of the driest parts of the dunefield in the Simpson and Strzelecki Deserts (Ash and Wasson 1983). The dunes contain palaeosols that point to alternations between periods of dune accumulation and stability. The timing of these events has now been investigated at various places in the dunefields and this summary will stress those sequences that have been dated by the radiocarbon technique.

SOUTHEASTERN AUSTRALIA

1. The Mallee

Hills (1939) recognized calcareous palaeosols in the east-west longitudinal dunes of the Victorian Mallee, and his observations were supplemented by Churchward's (1961) detailed pedological studies. Bowler and Polach (1971) determined an age of 15 550 ± 230 B.P. (ANU-183) for carbonate segregation in the solum of the topmost aeolian unit at Nyah West. It is clear that the last phase of accumulation occurred before this date.

The well-dated sequence of lunette construction and lake-level fluctuations in the Willandra Lakes provided Bowler (1976) with an opportunity to date the last phase of dune extension in that part of the Mallee Dunefield. Large lobes of sub-parabolic siliceous dunes extend across the western shores of Lake Chibnalwood and Lake Garnpung. This extension occurred possibly during and certainly after the high water phase that came to an end about 25 000 B.P. (Bowler 1978). The downwind margin of Lake Garnpung has been trimmed by water, indicating that the Lake was not entirely dry during dune extension. Bowler (1976) notes that dunes have not crossed the Willandra Creek overflow channel where it passes through the dune-field. This channel has not functioned for 15 000 years. From this evidence, it seems that both the sub-parabolic and linear dunes near the Willandra Lakes were actively growing from at least 25 000 to about 15 000 B.P. The sub-parabolics both grew and extended downwind while the linear dunes grew vertically more than they extended down-wind (Bowler and Magee 1978).

The linear dunes of the Mallee are clay-rich, short, rounded in cross-profile and lack y-junctions of the kind found in the central and western dunefields. The clay occurs as sand-size clay aggregates and strongly resembles clay pellets that are formed by salinization of lake surfaces and then blown into lunettes (Macumber 1970; Bowler 1973). This evidence suggests that these dunes were never very mobile and derived their sediments in a manner similar to that of clay lunettes. The groundwater conditions necessary for this have prompted

Bowler and Magee (1978) to suggest that these dunes formed at much the same time as the clay lunettes in the Willandra lakes and elsewhere - that is, between c. 20 000 and 16 000 B.P.

Sub-parabolic dunes in the Big Desert extended onto the western shore of Lake Albacutya during the last period of lunette construction c. 16 000 B.P. (Bowler and Magee 1978). In the northern Big Desert, sub-parabolics on the western edge of former Lake Wirrengren (Pine Plains) were trimmed during a high water stage lasting from c. 11 000 to 7500 B.P. (P.G. Macumber pers. comm.). These dunes have not advanced since this high water stage and obviously formed prior to 11 000 B.P.

The large areas of linear and sub-parabolic dunes of the Mallee Dunefield were actively accumulating and advancing between c. 25 000 and 15 000 B.P., along with the deposition of large quantities of wüstenquarz (Bowler 1976). Stabilization of these dunes occurred between 6000 and 12 000 B.P., as indicated by radiocarbon analyses both of soil carbonates and middens overlying dunes (Bowler 1976). In many places there is a layer of (?Holocene) sand lying over the uppermost palaeosol within the linear dunes.

Source-bordering dunes associated with channels of the Riverine Plains fluviatile network were dependent for their formation upon sources of sediment in the channels. Therefore, the history of the dunes is, to some extent, controlled by the history of the channels. Bowler (1978) has shown that these dunes were actively accumulating while the river channels were carrying large quantities of sand from before 30 000 to c. 15 000 B.P. The transition from bedload channels to suspended load channels coincided with the cessation of source-bordering dune construction. But the transition in the fluviatile regime also coincided with climatically-induced changes in the catchments of the Eastern Uplands, and is manifested in the Willandra Lakes area by the stabilization of dunes. This climatic change also enabled more vegetation to colonize both the river banks and source-bordering dunes c. 15 000 B.P.

The evidence available from the Mallee Dunefield indicates that dune accumulation was at its peak about 18 000 - 16 000 B.P.

2. Belarabon

North of the Mallee, on the western side of the Cobar Plain, lies an extensive area of generally small longitudinal dunes. The geomorphology and age of this dunefield have been investigated in the area of Belarabon station (Wasson 1976) where the longitudinal dunes have been derived from alluvial sediments. A phase of alluvial deposition between c. 6500 and 2500 B.P. was partly synchronous with, and was then succeeded by, the construction of transverse dunes and longitudinal dunes forming a pattern similar to that described by Twidale (1972). The downwind ends of the dunes had all but ceased extention by c. 600 B.P.

While the mid-Holocene alluviation allowed late-Holocene dune construction by providing an unconsolidated source of sediment, there must have been some climatic change involved to allow the dunes to form. At present, the dunes are well vegetated by a semi-arid woodland, shrubs and grass. Even the most severe droughts do not re-activate these dunes. The precise palaeo-environmental implications of this evidence are not clear but a severe drought during a time of progressive dessication may have triggered movement. Slight change of seasonality might also have had the effect of mobilizing the dunes (Wasson in press).

Dune construction occurred prior to the Holocene in this area, as indicated by palaeosols beneath the Holocene unit and by degraded dunes between the Holocene dunes. Radiocarbon analyses of pedogenic carbonate segregated within aeolian sand demonstrate a phase of dune construction prior to c. 15 000 B.P. and another prior to c. 30 000 B.P. (M.A.J. Williams pers. comm.).

3. Tilpa - Menindee, Darling River (N.S.W.)

Bowler et al. (1978) have determined the stratigraphy of alluvial and aeolian sediments in the vicinity of the Darling River near Tilpa, N.S.W. An old buried aeolian unit contains charcoal dated at 35 450 ± 1600 B.P. (SUA-435). This charcoal was found in the top part of the aeolian reddish brown sandy clay, and so the sediment accumulated prior to this date. The surface dunes have been bracketed by radiocarbon dates calculated for pedogenic carbonates. These dunes appear to have formed between 20 000 and 16 000 B.P.

J. Hope (pers. comm.) has obtained two radiocarbon dates of c. 15 000 B.P. on mussel shells from middens found within source-bordering dunes near Menindee. These dunes had their sediment source in the Talyawalka Creek, an anabranch of the Darling River.

4. Western Flinders Ranges

Longitudinal dunes, trending east-west, lie on the piedmont west of the Flinders Ranges, and appear to pass into a relict gypseous lunette on the eastern side of Lake Torrens. The lunette was stable by 16 000 to 12 000 B.P., as determined from radiocarbon dates on pedogenic carbonate in the uppermost part of the lunette. The red longitudinal dunes downwind appear to have formed between 24 000 and 16 000 B.P. (Williams 1973).

The tops of these dunes consist of about one metre of moderately consolidated red sand which contains late-Holocene stone tools. This Holocene phase of dune accumulation has also involved northwards movement of dune crests, so that some Holocene layers have moved off the Pleistocene dunes on which they began as caps.

5. Dempsey's Lagoon

At the northern end of Spencer Gulf, just north of Port Augusta, D.L.G. Williams (1981) has obtained radiocarbon dates of 35 900 ± 2980 and 25 900 ± 2170 B.P. (SUA-885) and >40 680 B.P. (SUA-1337) on egg shell from the upper part of a linear dune. The uppermost part of these dunes, which can be considered to be >36 000 B.P., overlies another four aeolian units exposed in a lunette sequence. By correlation with a sea-level sequence, D.L.G. Williams (pers. comm.) argues that the older four units are >125 000 B.P.

These dunes are close to those studied by G.E. Williams (1973) on the western Flinders piedmont. It seems that G.E. Williams has not recorded this old aeolian sequence, while D.L.G. Williams has not recorded the latest dune building phases between 24 000 and 16 000 and again in the late Holocene.

6. Eyre and Yorke Peninsulas

Dune construction on Yorke Peninsula and adjacent Spencer Gulf has been matched with a sequence of sea-level change (Jessup 1968a, b). He concluded that the longitudinal dunes formed during the 'arid' Last Interglacial. Van Deur (pers. comm.) has investigated similar dunes on the Eyre Peninsula. The downwind ends of the dunes are buried by estuarine muds which have a maximum radiocarbon age of c. 5000 B.P. On the basis of a date on pedogenic carbonate segregated in the top of a dune, Van Deur argues that the dunes had stopped forming by c. 13 000 B.P.

7. Parakylia Dunefield (South Australia)

An area of longitudinal dunes of some 9000 km^2 lies west of Andamooka and north of Woomera. It will be known here as the Parakylia Dunefield since it previously has been unnamed. No radiocarbon dates are available from this area but a recent survey by the author and P.J. Hughes has shown that the upper 2 m of red non-calcareous sand is of late-Holocene age. Microliths occur in blowouts on dunes, and there is evidence to conclude that they come from this cap of sand. These stone tools have been dated at a large number of sites in Australia, and they are all less than 5000 B.P.

The late-Holocene sand rests on a calcareous palaeosol developed in dune sand. The age of this older aeolian unit has not been determined.

CENTRAL AUSTRALIA

1. Southern Strzelecki Dunefield

In the vicinity of Lake Frome, stratigraphy by the author, P.J. Hughes and R. Lampert has shown that lee source-bordering dunes on Balcoracana Creek have accumulated in two phases. A radiocarbon date, on pedogenic carbonate segregated within the top of the older unit, is 13 660 ± 610 B.P. (ANU-2526) showing that the older phase of accumulation had ceased by that time. A layer of slope wash sediment separates this palaeosol from the youngest aeolian unit. This slopewash contains land snails dated at 12 610 ± 120 B.P. (ANU-2527). The typology and distribution of artefacts at this site suggest that the dune accumulated throughout the Holocene (R. Lampert pers. comm.) in response to availability of sediment in the creek.

On the western shore of Lake Frome, at a place called Campion Point, charcoal from an Aboriginal fire place _in situ_ within a small lake-shore dune was dated at 2490 ± 90 B.P. (ANU-2522). This dune sand overlies a near-shore lacustrine facies that contains algal remains dated at 5080 ± 100 B.P. (ANU-2524) and 4960 ± 100 B.P. (ANU-2525). This dune, therefore, has accumulated in the late-Holocene.

A number of excellent exposures in longitudinal dunes on the eastern side of Lake Frome display alternating aeolian sand and calcareous palaeosols. Radiocarbon dates from these palaeosols (Callen _et al_. 1983) show clear evidence of contamination by young carbon. The youngest palaeosol has been dated between c. 7000 and c. 10 000 B.P. (multiple dates) and this is overlain by up to 2 m of non-calcareous sand. The oldest apparent age of the palaeosol carbonates is c. 26 000 B.P., but this is likely to be a gross underestimate of their true age.

2. Northern Strzelecki Dunefield

Longitudinal and transverse dunes in Cooper's Creek flood-basin, downstream of Innamincka, display alternations of dune sand and palaeosols. Radiocarbon dates indicate that there were two phases of dune construction within the range of the dating method. Near the Strzelecki Creek due east of Moomba, low and rounded longitudinal dunes are rather different from the well-developed longitudinal dunes further west. Two dates on charcoal bedded within one of these rounded dunes are 2340 ± 110 B.P. (ANU-2835) and 2340 ± 80 (ANU-234). Some of the downwind ends of the well developed dunes consist of dune sands similar to these dated, suggesting that the northern Strzelecki dunes extended during the late-Holocene.

The well-formed longitudinal dunes have a cap of 1-2 m of well-bedded and partially mobile sand. Near Moomba, organic remains at the base of the cap have 116% modern ^{14}C activity. Beneath this cap is a calcareous palaeosol and, at one location, the carbonate has a radiocarbon age of 7630 ± 110 B.P. (ANU-2201). At another locality charcoal from an Aboriginal Fireplace <u>in situ</u> within the upper part of a dune sand unit, and below this palaeosol, gave dates of 13 850 ± 190 B.P. (ANU-2278) and 13 150 ± 830 B.P. (ANU-2279). The carbonate date records pedogenesis after deposition had ceased.

The unit which ceased accumulation c. 13 000 B.P. consists of quartz sand and up to 60% sand-size clay pellets of the kind found in clay lunettes and described by Bowler and Magee (1978) from the longitudinal dunes of the Mallee. The hydrologic conditions necessary for the production of these pellets in the northern Strzelecki were met by Cooper's Creek continually flooding sandy mud into the flats that separate the dunes. Saline flood water probably aided the flocculation of clays and mechanical pelletization by evaporative crystallization.

The modern flood regime dominantly affects the lowest parts of the floodflats. Slightly higher parts consist of muddy fine sand overlying clean river sand. The muddy fine sand has yielded a radiocarbon date at the base of 22 300 ± 1780 B.P. (ANU-2659) while the top dates at 12 460 ± 160 B.P. (ANU-2747). These higher parts of the floodflats were abandoned by floods at c. 12 500 B.P. and the area of deposition contracted. This is confirmed by a date of 12 020 ± 150 B.P. (ANU-2862) from the muddy fine sand that overlies channel sands in the centre of a floodflat. This muddy sand continues to accumulate, intermittently.

The change from sand deposition to muddy sand deposition c. 22 000 B.P. produced the conditions necessary for clay pellet formation. The area of deposition of muddy sand contracted dramatically c. 12 500 B.P., at about the time when the dunes stopped accumulating and pedogenesis began. This transition seems to have occurred between 12 500 and 13 500 B.P. The late-Holocene dunes also contain clay pellets and for their source we must look to the much diminished deposits of muddy sands.

These dunes are all pale and lie in the flood basin of Coopers Creek; their history being intimately linked with that of the creek. Earlier phases of dune construction have been recognized and, on the basis of radiocarbon analyses of soil carbonates, all that can be said is that these older dune sands are much older than c. 16 000 B.P.

Dates from the red dunes to the east of Strzelecki Creek are rare, but once again there is archaeological evidence of late-Holocene dune extension in southwest Queensland. P.J. Hughes and R. Lampert (pers. comm.) found geometric microliths in non-calcareous red dune sands at a number of localities. Palaeosols occur beneath the late-Holocene cap, and a single radiocarbon date of c. 20 000 B.P. provides a minimum age for this phase of dune construction.

For further details of this area see Wasson (1983a, b).

3. Tirari Desert

Twidale (1972) reported a date of 24 100 ± 1600 B.P. (GX 1972) on a diprotodon bone from a complex sequence of alluvium exposed in the banks of the lower Warburton River just east of Lake Eyre. Dunes overlie this alluvium but the validity of the date as a maximum age for dune construction is difficult to evaluate because of the problems attached to radiocarbon analyses of bone.

Preliminary dating has been done by R.H. Tedford, D.L.G. Williams and R.T. Wells (pers. comm.) just north of the Clayton River and 3-5 km east of the eastern shore of Lake Eyre. Two mixed samples of emu and *Geniornis* eggshell were dated at 19 900 ± 240 B.P. (SUA-1611) and >32 000 B.P. (SUA-1612) at different localities. Both samples were in dune sand and indicate accumulation both c. 20 000 B.P. and before 32 000 B.P.

4. Western Simpson Desert

Dunes adjacent to Oolgawa Waterhole (26°47'S 135°05'E) contain Aboriginal fire places that have been dated by the author at between 2840 ± 80 (ANU-2837) and 2220 ± 100 (ANU-2836). These dates refer to a non-calcareous red sand overlying a calcareous palaeosol in dune sand. The non-calcareous sand is present on almost all red dunes in the southwestern Simpson and appears to be a late-Holocene addition. At Allapalilla Waterhole, about 20 km south of Oolgawa Waterhole, a cutting through a dune exposed Aboriginal fire places in red-brown sand. One fireplace dated to 750 ± 70 (ANU-2832) shows that this dune has extended in the very late Holocene.

WESTERN AUSTRALIA

1. Lake Gregory

Well-organized longitudinal dunes of the Great Sandy Desert lie outside the former extensions of Mega-Lake Gregory. Lower and more closely spaced dunes, within the area of this once extensive lake, were formed by the redistribution of the A horizon of pedologically altered lake sediments. The dunes were formed after the deposition of lacustrine molluscs which date between 25 000 and 20 000 B.P. (J.M. Bowler pers. comm.).

2. Fitzroy Estuary (Western Australia)

In an effort to investigate the age of longitudinal dunes that extend below estuarine muds, Jennings (1975) determined the minimum age of the dunes at 8000 B.P. on the basis of both radiocarbon dates and depth below present sea-level of dune sand in relation to dated sea-level curves. By relation to other sequences in the area, Jennings concluded that the dunes accumulated during the peak of the Last Glacial. Jennings (pers. comm.) notes that an earlier phase of dune construction occurs as remnants of yellowish-red sands beneath the last phase of dune construction.

3. Puntutjarpa

Much of the sandy fill in a rock shelter near Warburton, on the southern edge of the Gibson Desert, is of aeolian origin (Gould 1977; I. Eliot, pers. comm.). The sand has been blown from the dunefield to the southwest, over a low bedrock ridge, into the shelter within the last 10 000 yrs. This indicates at least intermittent sand mobility, and presumably some dune mobility, during the Holocene.

SUMMARY

The results summarized in the preceding pages (much of which has not been documented before) are important for our understanding of landscape evolution in Australia because so much of the continent is covered by desert dunes. The environmental changes implied by these results assist our evaluation of changes in the arid-zone biota and our knowledge of occupation by man.

Radiocarbon results clearly show that, within the time range of the technique, major dune accumulation occurred between 25 000 and 12 000 B.P., with the peak of activity between 20 000 and 16 000 B.P. This chronology stands in sharp contrast with the Holocene age for the Simpson Desert dunes proposed by Twidale (1980, 1981a, b). The major phase of dune accumulation coincides with that documented in other deserts of the world, and it seems that a global climatically-induced phase of aeolian activity has been well established (see Wasson, in press). This assists us to integrate results from Australia with palaeo-environmental data from marine sediments in an attempt to understand the nature of the atmospheric changes that occurred during the peak of the Last Glacial.

It has now become clear that another phase of dune construction and extension occurred during the late-Holocene. The volumes of dune sand involved were not as great as during the phase 25 000 to 12 000 B.P., but they were nonetheless significant. This phase is not well recorded in the Mallee, and appears to be best expressed in the driest parts of the dunefield. While the sensitivity of the semi-arid margin of the dunefields allows resolution of dune-building and stabilization events, it is now known that these events are also recorded in the core of the dunefields. The less dramatic late-Holocene events can be best seen in the arid interior, although they also have manifestations on the margins.

There is now abundant evidence of episodes of dune construction prior to 25 000 B.P., with five such events reported by R.C. Sprigg (pers. comm.) at the Colson oil well site in the central Simpson Desert. All five units from Colson are within the Brunhes epoch as are the linear dunes of the Mallee (J.M. Bowler, pers. comm.). It is important for our understanding of the evolution of aridity in Australia to apply this technique to the alluvial and lacustrine deposits beneath the Simpson Desert dunes, and elsewhere within the dunefields.

The interaction between dunes and vegetation is of considerable significance to our interpretation of the history of dune construction (Ash and Wasson 1983). Pollen sequences in the arid zone are of vital importance and many lakes in central Australia are prime targets.

Finally, we do not know if the tropical part of the dunefield was in phase with that further south. A chronology of dune construction in the north could help in an interpretation of the history of the trade winds and monsoon, as noted by Jennings (1975). The modern resultant sand-moving winds diverge from the orientation of dunes (Brookfield 1970) in the southern parts of the dunefield (Wasson, in press) but it is not clear if this implied a shift in the anticyclone belt (Sprigg, pers. comm.) or a change in the shape of anticyclones.

Acknowledgments

Many colleagues gave permission for the use of their unpublished results and advice was given by J.N. Jennings and J.M. Bowler.

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CLIMATOLOGY : REPORT ON QUATERNARY STUDIES IN AUSTRALIA

P.J. Webster

(1) Introduction

During the last decade or so, a number of hypotheses have been posed which have emphasised the possibility of the Earth's climate being somewhat less robust than had previously been considered and have studied the consequences of that fragility on society. A number of scenarios had been created which had the Earth entering a rapid demise towards a new glacial maximum (supposedly due either to an increase in volcanic dust loading or anthropogenic pollution) or towards a hypsithermal or climatic optimum (due to the effects of the observed and real increases in atmospheric CO_2). Of the various hypotheses only the effects of increases in CO_2 have been seriously considered. Most scientists will agree with at least the trend it will produce on the earth's climate if not at all about the magnitude of its effect.

Depending upon one's belief, the effect on society to (say) a doubling of CO_2, which we may anticipate will occur by the early part of next century, ranges from a minimal effect to a complete rearrangement of the climatic structure as we know it today. In the latter estimate, which calls for such drastic effects such as a melting of the northern polar ice, the cereal crop regions of the globe would be seriously altered with distinct variations in the precipitation patterns around the globe. In this most drastic hypothesis, the climates and economies of all the grain exporting nations of the globe, including Australia[1], would be restructured.

Given the seriousness of the consequences of these hypotheses, it is encumbent upon climatologists to examine carefully the basis of their support. It is insufficient to state merely that climate has changed in the past and so there is no reason to suppose it won't change

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[1] A.B. Pittock, 1981; Long term climatic trends in Eastern Australia.

in the future. The proponents of the two hypotheses cited above were insisting on contractions of time scales of climate change by orders of magnitude. With this in mind the responsibility of the climatologist may be summarised as follows:

(i) establishing the controls which determine the structure of climate,

(ii) establishing the timescales of the forcing functions which may create imbalances or a need for readjustments in the climate system,

(iii) determining the physical mechanism(s) through which the readjustment will take place,

and (iv) determining or estimating the effect of the readjustment.

In the paragraphs which follow we will emphasise (iv) as the most relevent of the four responsibilities to climate reconstruction of the Quaternary. However as some of the forms of reconstruction require a detailed knowledge of the physics embodied in (i) - (iii) above, it is worth describing the complexity of the climate system and, as a consequence, the climate problem itself.

The study of climate may be seen to present a singular challenge to science because of the unique aspects possessed by the problem. We can summarise these as follows:

(i) The immense scope of the problem: The expansive nature of climate may be understood by considering the spatial and temporal scales over which it must be defined. At any fixed time the climatic state of the system may be thought of as being comprised of an ensemblage of climate types each of which are mutually dependent and equally strong functions of latitude and longitude. Each type presents its own problems in definition and explanation. If the understanding of the fixed state is difficult it must be remembered that climate is an evolving system with temporal variation ranging from seasonal to the millenia. The concept of a climate system which is evolving in time and varying in space is important and must be remembered in climate reconstructions.

(ii) The large span of the physical ingredients which rectify to make up a climate: Processes range from those existing on the turbulence scale (e.g. the transfer of heat between the land surface and the ocean depends upon turbulent effects with scales of the molecular to a few metres) to scales of motion which must be measured in factors of earth radii. Through the scales, the importance of various physical processes wax and wane so that the physical description of one component phenomena may appear initially independent of the accompanying scales. However, as with many problems with interlocking scales, the description of one phenomena depends upon an understanding of adjacent scales and, thus, the development of some closure hypothesis.

(iii) The difficulty in the establishment of the control experiment: On the shorter term climate scale (e.g. the interannual) it has proven possible to delineate the "natural variability" of the climate system (i.e. the noise inherent in a non-linear turbulent system) from the interannual variability produced by the variation of boundary forcing. In the example given, nature has provided its own control experiment by the imposition of strong variations in boundary forcing which are sufficiently abrupt and of large enough magnitude to produce statistically significant perturbations to an established mean climate whose "natural variability" was known, at least in a statistical sense. Such progress, which probably allows us to account for something like 40-60% of the interannual variability of climate in the higher latitudes, has emerged from combined effort between observation studies, which established that variations in certain forcing functions did occur, and by the development of mathematical analogues of the atmosphere-ocean system which provided a priori expectations for the subsequent statistical analyses of the atmospheric data. However it is probable that such success will be limited to the examination of the interannual variability of the mean climate existing at this time. As nature has provided even larger variations in boundary forcing over the longer time periods than the sea surface temperature variations alluded to above, we have some hope of sorting out the appropriate climatic responses. The basic problem will be the establishment of a sufficiently detailed data set through the Quaternary which will allow the isolation of clear trends.

It is against this backdrop that we must approach the climatological structure of the Australian region through the Quaternary. For many reasons, the study of the evolving climate of Australasia is a worthy problem although principally because of its unique geographical location and as a sensitive gauge to climatological variations over an almost global scale.

Australia stands to the south of the much larger continent of Asia and the "maritime continent" of the Indonesian Archipelago. Locked in that location Australasia acts as an equal partner in the vast Asian-Australian monsoon circulation being the "cold sink" during the northern hemisphere summer and the "heat source" during the southern summer. Thus, just as contemporary studies of the Australian region indicate aspects of climate of much of the interhemispheric monsoon system, it can be expected that data collected in northern Australia may indicate climatological patterns on an even grander scale.

The macro-scale monsoons are effectively subtropical and tropical circulations of immense vigour of the eastern hemisphere but Australian location is such that it lies in a region which is critical for controlling the climate of the western hemisphere as well! Generally, the Western Pacific Ocean (from the Solomon Islands to Indonesia) marks the ascending (and precipitating) part of a circulation cell which is generally orientated east-west across the Pacific Ocean. The ascent corresponds, in a general sense, with the warm waters of the Western Pacific Ocean whereas the descent, which completes the circulation, occurs over the colder water of the Eastern Pacific Ocean. Aperiodically, the temperature structure of the Pacific Ocean tends to vary with generally warmer water replacing the cold in the east. Associated with the temperature variations is a movement eastward of the circulation cell. Ascent, previously located over Australia and Indonesia moves to the mid-Pacific Ocean.

Data analyses collected over Australia during the last fifty years indicates a rather keen relationship between the precipitation in Eastern and Northern Australia and the Pacific temperature variation. Although the data record is not long we have some theoretical expectation which relates the large scale atmospheric response to imposed sea-surface temperature variations.[2,3] As a consequence data collected in Eastern and Northern Australia may provide clues for the climate of the Pacific region. That is, the establishment of whether Australia was in a pluvial or arid stage through the various periods of the Quaternary may be

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[2] Webster, P.J., 1981: Mechanisms determining the atmospheric response to sea surface temperature anomalies, J.Atmos.Sci., March,

[3] Webster, P.J., 1981: Seasonality in the atmospheric response to sea surface temperature anomalies, to appear in J.Atmos.Sci.

related to, via the modern analogy, the climatic structure of the tropical Pacific Ocean. Such determinations are extremely important as the climate state in the tropical Pacific Ocean is closely tied to the climatic state of higher latitudes.[2,3]

Finally, it should be remembered that in the present climate state, Australia is greatly affected by the propagating weather patterns of the middle and higher latitudes which are mainly responsible for precipitation in Southern and Eastern Australia during the winter. That these disturbances influence the Australian region may be viewed as an indication of the control of the large scale, slowly varying long waves of the Southern Hemisphere. Thus data collected in the southern parts of Australia may be used to infer structures over large parts of the Southern Hemisphere higher latitudes.

(2) Tools and Techniques for the Reconstruction of Climate

A number of techniques have been used to reconstruct climate states. Ultimately all techniques depend upon the consideration and interpretation of proxy climatic data either as initial input or as a check upon the reconstruction. Proxy data refers to any data from which a climatic state may be inferred. Details of the various forms of proxy data are found elsewhere in this report. For our purposes we will assume that such data exists although later we will have occasion to make some specific comparison of the various forms of the data record.

We may summarise the various techniques of climate reconstruction as follows:

(i) Comparative Techniques (Implicit Modelling): For any proxy data it is necessary to make some climatic inference. With geomorphological data the climatic inferences are made via comparison of the revealed geomorphology with that of the present. In a similar manner climatic states may be inferred from palynological data via a knowledge of the present environments of the revealed taxa. In all cases the initial step from proxy data to climatic inference utilizes the current climate as the comparative model.

Such comparative techniques have been extended to increase the sophistication of the synthesis. With the assumption that the present climate is one physically consistent subset of the climate state of the planet, entire sets of proxy data relating to a particular period are tested for consistency. The aim is to produce a climate state which is consistent on all scales of motion which will either accept the varied sets of proxy data or question their individual merit. A number of such studies[4,5] have attempted such syntheses with varying degrees of success. This implicit modelling approach may be referred to as the "synoptic" technique.

(ii) Explicit Modelling: One of the major problems of the synoptic (implicit) modelling techniques is the inability to test physical consistency of the resultant climate beyond visual comparisons with the present climate. This may be overcome to some degree by utilizing the laws of physics as the adjudicator of consistency.

Such techniques require the development of mathematical analogues of the climate system which are governed by the laws of physics, at least to the degree they may be represented.

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[4] Pittock, A.B. and M.J. Salinger, 1981: Towards regional scenarios for a CO_2- warmer earth. Climatic Change, 4, in press.

[5] Webster, P.J. and N.A. Streten, 1978: Late Quaternary ice-age climates of tropical Australasia; Interpretations and Reconstructions. Quaternary Research, 10, 279-309.

Proxy data enters the system by providing a set of boundary conditions which are used to drive or constrain the climate model. For example, the CLIMAP sea surface temperature data and continental albedo determinations[6] have been used in studies of the last glacial maximum[7,8] with large scale general circulation models. In these studies a climate was construed which was consistent with the prescribed lower boundary condition. That the models say anything at all about a consistent climatology of the last glacial maximum depends on two factors. These are the reliability of the proxy data from which the boundary conditions were inferred and the ability of the model to produce a reliable picture of the present climate using modern boundary conditions; a case which may be readily checked.

There exists a second class of physical model which is used to test a particular hypothesis (e.g. variation of insolation such as with the Malinkovich theory) with the aim of producing a consistent climate structure by merely altering some external parameter. In this manner, a situation would be simulated which would be conducive to the formation of the ensemble of proxy data. This form of modelling, at the present in its infancy, uses the proxy data as a check on the simulation rather than as the basic input to the model.

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[6] CLIMAP project members, 1976: The surface of the ice-age earth. Science, 191, 1131-1137.

[7] Gates, L., 1976: Modelling the Ice Age climate. Science, 191, 1138-1144.

[8] Manabe, S., and D.G. Hahn, 1977: Simulation of the tropical climate of an ice age. Journal of Geophysical Research, 82, 3889-3911.

(3) Status of Climate Reconstructions in the Australasian Region

During the last decade or so, considerable progress has been made in the collection of both marine and continental proxy data and in its use as a base for climate reconstruction. A concerted effort to synthesise the Australian proxy data set was undertaken at Howman's Gap in Victoria which was attended by many quaternary workers from Australia and New Zealand.[9]

Before summarizing the CLIMANZ synthesis it is important to reiterate that any climatic reconstruction must be viewed simultaneously with certain caveats. In the first case, the interpretation of data depends upon the quality of the data and its dating. Second, the reconstruction procedure, as discussed in the last section depends upon our knowledge of the present climate. Problems often exist with the data and one must question the spatial representativeness of a particular set at a particular time. On the other hand, our knowledge of the existing climate, for which we have many years of comprehensive data compared to the rather limited proxy data for various stages in the Quaternary, is still rather rudimentary.

The CLIMANZ synthesis centred on a number of climatic "spikes" and climatic "intervals". These were the 32±5 ka spike, the 25-20 ka time interval, the 18±2 ka spike, the 15-10 ka interval and the 7±2 ka spike.

At the 32±5 ka spike there appears to be significant indication of a generally cooler and drier environment. Such an environment probably extended over much of the Australian sector and appears consistent with the CLIMAP ocean core interpretations which indicate a temperature lowering of about 5°C from the present.

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[9] The so-called "CLIMANZ" conference of February 1981. The proceedings are in press.

However, there appears some problem in reconciling the general evidence of a cooler-drier climate with the observations of significantly higher lake levels in many locations. The problem of reconciling such level with vegetation and other geomorphological data probably stems from our lack of understanding of the water budget or lack of radiational data (particularly cloud data) which would be needed to construct it.

The 25-20 ka time interval synthesis indicates a general cooling and increasing aridity over much of Australasia. Temperatures in the tropical north decreased by 3 to 5°C and precipitation decreases are indicated by substantially lower water levels in Lynch's Crater. In the south the aquatic and faural remnants are in agreement with the increased formation of lunette lakes. Overall the climate had become drier and cooler and was accompanied by a 60 to 100 m drop in sea level below that existing today.

The 18±2 ka spike was chosen in that it is supposed to coincide with the last glacial maxima, although there is some dispute about a precise timing of the event. Sea levels were at least 150 m below present and overall land temperatures were at least 5°C below current values. The CLIMAP ocean data indicates only a 2°C drop in the Western Pacific Ocean but substantially greater reductions to the east and off the West Australian coast. The disparity between the 5-7°C continental drop and only an adjacent 2°C sea surface temperature drop is the cause of some concern.[5,10] Overall, Australasia appeared to be in a distinctly drier and colder phase which may have allowed cold polar incursions to affect low latitudes.[5]

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[10] P.J. Webster and N.A. Streten, 1981: Comments on Prell, W.L., Hotson, W.H., Williams, D.F., Bé, A.W., Geitzenaver, K., and Molfino, B., (1980) Surface circulation of the Indian Ocean during the last glacial maximum, approximately 18000 yr. B.P. Quaternary Research, 14, 309-336. to appear in Quaternary Research, November 1981.

The 18±2 ka spike is of particular interest to proponents of the ice-age theory of future climate. This spike probably is the best documented of all the cold epochs and can provide the most reliable estimate of the climate structure of an "ice-age".

The CLIMANZ synthesis described the dramatic change in climate during the 15-10 ka interval. The gradual change as the climate moved into the warmer early-Holocene, was accompanied by a gradual melting of the continental ice and a steady retreat of the glaciers, which continued except for a few brief advances until circa 7 ka. In the New Guinea highlands the deglaciation was extremely rapid with a temperature increase of some 6°C. Precipitation appears to have increased, as evidenced from data gathered at Lynch's Crater but still was perhaps only one third of today's rainfall. Southern Australia appeared to follow the northern latitudes and was generally less dry and less cold than during the last glacial maximum. In the polar regions, climap data has indicated that the sea-ice retreated to somewhere near its present location. This was accompanied by a very rapid warming of the ocean. Probably due to a movement south of the polar convergence zone, there are indications that the ocean temperature may have risen by as much as 8°C in the southern oceans.

The final spike isolated during the Quaternary was at 7±1 ka corresponding to the hypsithermal. Examination of this warm epoch is especially interesting to the proponents of a CO_2 warmed earth scenario. Many scientists feel that the global climate may approach conditions similar to the 7±1 ka spike with the doubling or quadrupling of CO_2 in the present atmosphere.

Data gathered in Papua and New Guinea indicates temperature rises of order 1-3°C above present with an attendent 150 m rise in the tree line in the highlands. In northern Australia, precipitation was probably 150% of that occurring in today's climate. Similar increases in precipitation appeared to have occurred in southern Australia. Lake levels were such that if evaporation was roughly the same as at present, then precipitation would need to be at least 20% above present levels for maintenance. Evidence of warming appears as far south as Macquarie Island where peat formation was occurring.

The paragraphs above are meant to provide a brief summary of the CLIMANZ synthesis and, through it, the status of the Australasian climate reconstruction throughout the quaternary. More details regarding the climatic inferences and of the proxy data, its evaluation and source, may be obtained from the conference proceedings.

(4) Future Directions for Quaternary Climate Research

It is obvious from section (3) that some important strides have been made in creating a fairly consistent description of the evolving climate of Australasia during the Quaternary. Yet, there appears some problems which we have yet to tackle and which have only surfaced through the initial attempts at climate reconstruction and the emergence of new proxy data sets. Some of these are outlined below with suggestions as to how they may be approached, if not solved.

(i) Consistency of various sets of proxy data: When two proxy data sets emerge for the same period but with conflicting messages regarding the climate at that time, the climatologist is faced with two possibilities. He may neglect one data set, indicating that it conflicts with the physical constraints which he believes control climate. On the other hand, he may somehow attempt to reconcile them. Such a situation occurs when the CLIMAP estimates for the 18 ka spike are compared with the continental botanical record. In three locations where glaciation existed on near equatorial mountain ranges (Africa, Hawaii and New Guinea) the snowline estimates, backed up by palaeobotanical evidence, indicates an inconsistency with the CLIMAP sea surface temperature record. Specifically, the continental record suggests a substantially greater cooling than the sea surface temperature estimates. In the western Pacific Ocean CLIMAP shows only 1-2°C decreases below present at 18 ka. However the continental record obtained from various levels in the New Guinea Highlands indicates temperatures which are 5-7°C lower. Such differences, especially in the tropical atmosphere, are difficult to understand physically.[5] Clearly, as the CLIMAP data set stands out as the most widely used global scale data survey it is imperative that the continental and marine proxy data sets be reconciled.

<u>(ii) Climatologist input on proxy data</u>: The climatologist is often faced with the task of being presented with an array of proxy data and having to provide a consistent physical picture but having no input as to where the location of the data points are. The climatologist dealing with the present climate is no longer faced with that problem as he can obtain a fairly reasonable description of the atmospheric and oceanic variables over much of the globe. Obviously, the choice of data points for proxy data is severely limited by the existence of suitable locations, although the climatologist may aid in the identification of particular sensitive locations which would help narrow the choice. Probably CLIMANZ will act as a vehicle in this regard.

<u>(iii) Utilization of models of the climate system</u>: Models have proven to be useful tools in the testing of hypotheses and in the provision of consistent physical descriptions of the climate relative to boundary forcing provided by proxy data distributions.[7,8] So far, we have relied upon studies from overseas. However, a more useful approach would be to utilize the skills that exist on the local scene so that a cooperative atmosphere may be generated with an emphasis on the Australasian region. It is not always necessary to have to rely upon the extremely expensive,

albeit extremely sophisticated, general circulation models. It is possible to utilize much simpler physical analogues in phenomonological studies of the climate system. It is hoped that we can attract the attention of meteorologists and oceanographers alike as, ultimately, a full synthesis of the climate state at any one time will have to rely on the use of model systems, just as we have been required to do for the present climate.

PROBLEMS IN QUATERNARY VERTEBRATE PALAEONTOLOGY

by

D.L.G. Williams

INTRODUCTION

Fossils of extinct marsupials and birds were first collected from stream and cave deposits of south-eastern Australia about 150 years ago, revealing the existence of a diverse vertebrate fauna which survived until the very recent geological past. Nineteenth century palaeontologists set about the task of describing and classifying these remains, and they also speculated as to the former habitats of extinct species, the reason for their disappearance, and the possible role of prehistoric humans in causing extinctions.

These early attempts to reconstruct the faunal history of Australia were severely hampered by the inability to date fossil sites precisely, and the difficulties of correlating them with known stratigraphic sequences. Chronological resolution was too broad to answer questions relating to faunal change and climatic history.

During the last few decades vertebrate palaeontology has benefited enormously from technical advances in dating methods, and from growing interest in Quaternary research by geologists and geomorphologists. But despite these advances, and despite the emergence of a global Quaternary history derived from analysis of deepsea sediments, vertebrate palaeontologists are still hampered in their attempts to integrate their work into the global picture. Current research has been summarised in a number of papers, ranging from catalogues of fossil localities (Williams, 1980; see also in Rich & Thompson, 1982) to summaries of the palaeontology of vertebrate groups (e.g., P.V. Rich, 1982; T.H. Rich, 1982). A comprehensive study by Hope (1982) integrates the vertebrate record with the known palaeo-environmental history of arid Australia during the Late Cainozoic. However, the common thread running through these summaries is the repeated comment that sites remain "undated".

DATING AND CORRELATION

Quaternary rocks in Australia characteristically form a veneer of unconsolidated sediments, rarely more than a few tens of metres in thickness, commonly less than ten metres. Large areas of inland Australia are covered by thin lacustrine, fluviatile, and aeolian sediments, and vertical sequences containing more than one vertebrate fossil assemblage are rare. Over such large areas sedimentary facies changes are bound to occur, so that lateral continuity is not often found. Consequently, in these environments correlation of fossil assemblages is difficult.

Localised Quaternary deposits, such as alluvial valley fills and cave deposits, also cause problems stratigraphically because the sedimentary environments are generally complex, and lateral continuity of bedding is the exception. These difficulties are compounded due to the lack of widespread marker horizons in Quaternary rocks, as might be provided by volcanic ash falls or marine incursions.

These problems have been partially solved by application of radiometric dating and magneto-stratigraphy. Radiocarbon dating has been widely used; it relies on the presence of organic material in association with the deposit to be dated. In the Australian arid zone this is uncommon, and although attempts have been made to use inorganic carbon such as pedogenic carbonates (Williams & Polach, 1971) carbon dating in these regions is not always possible. Radiocarbon dating is also limited by its time-range, which is less than 40,000 years. An insidious effect of trying to date sites that are in fact beyond the range of radiocarbon is that "finite" dates are commonly obtained due to contamination of the dated sample by younger carbon. It is tempting for researchers to accept these as absolute ages, and consequently there is a tendency for many published dates to cluster in the range 30-40,000 years.

Other radiometric techniques have not found general application in the Quaternary of Australia. K/Ar dating requires samples of Quaternary volcanic minerals which are available at only a few sites in Australia, none of them associated with major vertebrate localities. Similarly, other radiometric methods are not applicable in the Australian Quaternary.

Palaeomagnetic dating has found application in Australia, although it is only just being used specifically for dating vertebrate sites. This method requires samples of fine-grained, undisturbed sediment which contain some magnetic minerals; a vertical sequence of rocks may then reveal zones of normal and reversed magnetic polarity corresponding to known periods in the earth's geomagnetic history. The main disadvantage of the technique is the lack of continuous vertical sequences associated with vertebrate fossils. Depositional breaks in such sequences may exclude significant geomagnetic events, so that ambiguity may be introduced to the magneto-stratigraphy.

Thermoluminescent (TL) dating is still an experimental technique as applied to terrestrial sediments, however it may become an invaluable tool for vertebrate palaeontologists. The sample material is quartz, whose degree of thermoluminescence is"reset" by relatively short exposure to solar radiation. The elapsed time since deposition in, say, a sand dune, can be estimated from the accumulated thermoluminescence. TL dating could extend the chronology of the Quaternary in Australia to several hundred thousand years, instead of the 30,000 year limit provided by radiocarbon.

CONCLUSION

There have been enormous advances in our understanding of Australia's Quaternary history, made possible by the growing amount of research and by the application of new techniques. Most of these advances have arisen from fields such as deepsea coring and the analysis of the sediments obtained, and from geological research into terrestrial processes during the climatic changes of the last few million years. In a land where vertebrate fossils occur in stratigraphically isolated situations, vertebrate palaeontologists need to find ways of dating and correlating fossil deposits with known stratigraphic sequences. As vertebrate palaeontologists, we wish to know the diversity of the Australian Quaternary faunas, and their changing distribution with time. We would like to know the relationship between the extinct faunas and the vegetation, and how climate has affected their distributions. We would like to know the course of extinction, why it affected mainly the large species of vertebrate, and we would like to know the phylogenetic history of the vertebrate fauna. In order to tackle these questions, we must not only study more fossil deposits, we must collaborate more with specialists in other fields of Quaternary research, and develop the biostratigraphic potential of vertebrate palaeontology.

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PROGRESS & POTENTIAL

J.M. Bowler

From our standpoint in 1984 it is appropriate to ask the question just how far Quaternary research has progressed in the past two decades? Before 1960, study of Australia's Quaternary environments was the research interests of a few individuals scattered through the continent. E.D. Gill was the most dedicated and prolific practitioner operating from the National Museum of Victoria. E.S. Hills, with his physiographic approach and general interest in geomorphology was a strong advocate of geological studies of the recent past. R.C. Sprigg and Paul Hossfeld had, independently of each other, carried out detailed studies of coastal stratigraphy of southeastern South Australia.

Although the interests of E.D. Gill and others ranged broadly through biological and physical topics, little systematic investigation was undertaken of stratigraphic and chronologic investigation of interior Australia. In the late 1950's, CSIRO through its Division of Soils, began what was to become a major thrust into a developing area of soil stratigraphy with its special relevance to the Riverine Plain and Mallee regions of the Murray Basin. The work of Butler in particular stimulated a group of younger stratigraphers whose names rapidly became established by their contributions to Quaternary studies such as Churchward, Walker, Bettenay and Mulcahy.

Despite the rapid development of interest and activity in Quaternary research, the field-oriented studies remained contrained by the lack of quantitative developments especially in terms of laboratory analytical methods.

Chronologies often remained imprecise, stratigraphic reconstructions supported by detailed sedimentologic analyses remained few.

By the 1960's, the effects of three new developments were becoming apparent. Firstly, resulting from the relatively recent arrival in Australia of professional geomorphologists trained in the British tradition, a whole new disciplined approach to landscape processes and history began to take effect. Stemming both from universities and CSIRO institutions, the work of Jennings, Davis, Ollier, Mabbutt, Galloway and others provided a direct stimulus to Quaternary studies in general.

Secondly, in the early 60's, systematic studies of Australian prehistory made major advances. Mulvaney's work in Melbourne, corresponding with Golson's recent arrival in Canberra provided a vital stimulus, one that accelerated the third and critical stage of development.

The third stage saw the establishment of specialised laboratory facilities. Radiocarbon dating became available in a systematic way; laboratories were dedicated to Quaternary palynologic and sedimentologic analyses. This period corresponded to one of increasing appointments, particularly in departments of Geography, of practitioners with training of particular relevance to Quaternary studies. Chappell came to Canberra, Williams to Macquarie, Kershaw to Monash and so on. A new wave of Quaternary systematic studies had arrived.

Although first developed in a consolidated way at Canberra, the growth in number of practitioners and diversity of skills has led to a healthy dispersion of research facilities throughout the continent. A glance through the range of contributions to the Proceedings of the 1981 CLIMANZ Conference provides ample testimony to the strength and diversity of Quaternary research in this country today. We may claim that Quaternary studies has arrived; its present health and impetus is assured.

Despite the substantial progress to date, there remain significant gaps in the state of regional coverage of the continent, imbalances in emphases, imprecision in climatic reconstructions and uncertainties in chronologies.

What of the Future?

This brings us to the point at which we stand in 1984. Where do we go from here? What of the future? How do we become more quantitative? How do we ensure a better range and increased accuracy in dating techniques? How can we address the constant problem of establishing greater precision in our environmental and especially in our palaeoclimatic reconstructions? How do we differentiate between the effects of evaporation, precipitation, run-off and other climatic parameters the interactions of which determine the nature of our proxy evidence, be it through palynology, palaeohydrology or other analytical methods?

These are questions that the concerned community of Australian Quaternary scientists must now address. The occasion of the presentation of these discussion papers through the assistance provided by the Bureau of Mineral Resources offers an opportunity to explore implications and to structure possible responses.