AUSTRALIAN AND NEW ZEALAND GEOMORPHOLOGY GROUP

FOURTH CONFERENCE

Buchan, Victoria, February 1989

ABSTRACTS OF PAPERS

Compiled by D.L. Dunkerley

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Monash University
Clayton, Victoria 3168
Australia

SUMMARY CONFERENCE SCHEDULE

SUNDAY 5 February	Registration desk open at Buchan Hall ~ noon onwards. Sydney - Buchan excursion arrives (leader: Dr R.W. Young, University of Wollongong).
MONDAY 6 February	Registration desk open 8:30 a.m. 9:15 a.m. welcome to delegates, Buchan Hall. 9:30 - 1 p.m. Paper presentations: Fluvial Geomorphology 2 p.m. - 5 p.m. Paper presentations: Fluvial Geomorphology 8 p.m. onwards: Techniques workshop on Thermoluminescence dating. Keynote speakers: Assoc. Prof. G. Nanson and D.M. Price, Dept. of Geography, University of Wollongong.
TUESDAY 7 February	9 a.m.- 10 a.m. Paper presentations: Fluvial Geomorphology 10 a.m. - 1 p.m. Paper presentations: Karst Geomorphology 2 p.m. - 3 p.m. Paper presentations: Karst Geomorphology 3:30 p.m. onwards: Guided walk of Buchan area including cave tours. 8 p.m. onwards: Techniques workshop on radiometric dating. Keynote speaker: Prof. J.M.A. Chappell, A.N.U.
WEDNESDAY 8 February	All day: Gippsland Lakes excursion. Packed lunch provided. Buses leave from outside the Hall at 7:45 a.m. and return ~ 5 p.m. Excursion leader: Dr E.C.F. Bird, University of Melbourne. 8 p.m. onwards: Business meeting (energy permitting!) in the Caves Hotel lounge.
THURSDAY 9 February	9 a.m. - 12 noon. Paper presentations: Process Geomorphology 12 noon - 4:30 p.m. Paper presentations: Coastal Geomorphology 7 p.m. for 7:30 p.m.: Conference Dinner, Willow Cottage restaurant. Guest speaker: Dr M.J. Crozier, Victoria University of Wellington.
FRIDAY 10 February	9 a.m. - 1 p.m.: Paper presentations: Evolution of the eastern highlands 2 p.m. onwards: caving.
SATURDAY 11 February	8 a.m.: Buchan to Melbourne excursion departs Homeleigh. Arrives Melbourne ~ 5 p.m. Excursion leader: Dr B. Finlayson, University of Melbounre.

MONDAY 6 FEBRUARY

TIME	SPEAKER	CHAIRPERSON
09:15	Prof. Martin Williams- Welcome address	
	FLUVIAL GEOMORPHOLOGY SESSION:	
09:30-10:00	Wayne Erskine Channel-forming discharges on sand-bed streams of the northern Sydney Basin, N.S.W. (p. 7)	Martin Williams
10:00-10:30	Rob Warner Channel changes, regime shifts and their implications in the upper Hawkesbury River, NSW (p. 9)	"
10:30-11:00	Paula Douglas, David Outhet & Peter Stuckey The application of fluvial geomorphology to river channel management in New South Wales (p. 12)	"
11:00-11:30	MORNING TEA	
11:30-12:00	Sandra Brizga Post European settlement river metamorphosis on the Thomson and Avon Rivers, Gippsland, Victoria: an explanation based on stream power (p. 15)	Ken Page
12:00-12:30	Jacky Croke Floodplain variability within some glaciated valleys in Wicklow, Ireland (p. 16)	"
12:30-1:00	Brad Pillans Topography of ridge crests in relation to drainage density and stream network evolution in N.Z. (p. 17)	"
1:00-2:00	LUNCH HOUR	
2:00-2:30	Axel von Krusenstierna River bank erosion by boat generated waves on the lower Gordon River, southwest Tasmania (p. 18)	Rob Warner
2:30-3:00	Bruce Coates, David Outhet & Kevin Roberts Measurement of bed material discharge in rivers of NSW (p. 21)	"
3:00-3:30	Hugh Stockbridge Stream power/bedload characteristics of the Waingawa River (p. 24)	"
3:30-4:00	AFTERNOON TEA	
4:00-4:30	Trevor Hoey Bedload transport rate fluctuations and channel patterns in gravel bed rivers: a laboratory study (p. 25)	Brian Finlayson
4:30-5:00	David Dunkerley Grain interaction during bedload transport: a neglected aspect of stream behaviour? (p. 26)	"
8:00 pm >	Techniques workshop: thermoluminescence dating. (Keynote speakers: Assoc. Prof. Gerald Nanson & David Price).	

TUESDAY 7 FEBRUARY

TIME	SPEAKER	CHAIRPERSON
	FLUVIAL GEOMORPHOLOGY SESSION (CONT.)	
09:00-09:30	Ken Page, David Price & Gerald Nanson Thermoluminescence chronology of Late Quaternary sediments of the Riverine Plain, south-eastern Australia (p. 28)	Brad Pillans
09:30-10:00	Gerald Nanson, Bob Young, David Price, Brian Jones & Jon East Alluvial evidence of Quaternary environmental change from the tropics of northern Australia (p. 31)	"
	KARST GEOMORPHOLOGY SESSION:	
10:00-10:30	David Dunkerley Mechanisms and chronology of travertine deposition in the Chillagoe karst, Queensland (p. 32)	"
10:30-11:00	John Webb The age and development of the Chillagoe karst, north Queensland (p. 34)	"
11:00-11:30	MORNING TEA	
11:30-12:00	Sue White Relationships of karst landform development to dune limestone diagenesis (p. 36)	Mike Crozier
12:00-12:30	Mia Thurgate Water-filled karst features of the lower South East of South Australia (p. 38)	"
12:30-1:00	Li Shu & Brian Finlayson Some observations on rimstone dam genesis (p. 40)	"
1:00-2:00	LUNCH HOUR	
2:00-2:30	Bernie Joyce Weathering features on limestones of the Buchan area, Victoria, Australia: variations with rock type, within and beneath soil cover, and on bare rock (p. 41)	Prof. Jane Soons
2:30-3:00	D. Fabel & Li Shu Longterm landscape evolution: interpretations from Buchan, East Gippsland (p. 42)	"
3:00-3:30	AFTERNOON TEA (early today!)	
3:30 >	Guided walk, Buchan, and cave tours	
8:00 pm >	Techniques workshop: radiometric dating (p. 43). (Keynote speaker: Prof. John Chappell).	

THURSDAY 9 FEBRUARY

TIME	SPEAKER	CHAIRPERSON
	PROCESS GEOMORPHOLOGY SESSION	
09:00-09:30	Mike Crozier, E.E. Vaughan & J.M. Tippett Relative instability of colluvium-filled bedrock depressions (p. 44)	Wayne Erskine
09:30-10:00	Paul Augustinus Development of the high-level glacierized landscape, McMurdo dry valleys, Antarctica (p. 47)	"
10:00-10:30	D. Brunsden & Jane Soons An exploration of the equilibrium concept: the example of abandoned cliffs on Banks Peninsula (p. 48)	"
10:30-11:00	Mike Clarke & Martin Williams Soil creep: problems raised by a recent study in Australia (p. 49)	"
11:00-11:30	MORNING TEA	
11:30-12:00	Brian Lees Lake segmentation and lunette initiation (p. 50)	Bob Young
	COASTAL GEOMORPHOLOGY SESSION:	
12:00-12:30	Andrew Short N.S.W. beaches - science, surf and safety (p. 52)	"
12:30-1:00	John Chappell, Eric Wolanski, Colin Woodroffe, & Bofu Yu The effect of sea level rise and sediment inputs on lowland floodplains (p. 53)	"
1:00-2:00	LUNCH HOUR	
2:00-2:30	Errol McLean Geomorphic zonation in an evolving estuary- process implications (p. 54)	Gerald Nanson
2:30-3:00	Ted Bryant, Bob Young & David Price Late Quaternary coastal landforms along the Illawarra N.S.W. coastline (p. 56)	"
3:00-3:30	Patrick Hesp & Robert Hyde Dynamics and geomorphology of a trough blowout (p. 58)	
3:30-4:00	AFTERNOON TEA	
4:00-4:30	James Schulmeister Dunefield stratigraphy of Groote Eylandt (p. 59)	"
4:30-5:00	Tony Dare-Edwards & Grant McTainsh Dust accession onto Australian soils: a review (p. 62)	"
7:00 for 7:30	Conference Dinner: Willow Cottage Restaurant.	

FRIDAY 10 FEBRUARY

TIME	SPEAKER	CHAIRPERSON
	EVOLUTION OF THE EASTERN HIGHLANDS	
09:00-09:30	Bob Young Evolution of Tertiary landscapes in southeastern Australia (p. 64)	Lisa Worrall
09:30-10:00	Ian Household Age of the landforms or age of the highlands? - evidence from karsts, basalts and valley fills (p. 67)	"
10:00-10:30	Brad Pillans & Pat Walker Basalt and Bulldust: soils and landscape evolution near Nimmitabel, southern Monaro, NSW (p. 71)	"
10:30-11:00	Mark Stirling The Old Man Range and Garvie Mountains, Central Otago, New Zealand: tectonic geomorphology of the peneplain (p. 73)	"
11:00-11:30	MORNING TEA	
11:30-12:00	Mark Mabin The eastern highlands of north Queensland (p. 74)	Brian Lees
12:00-12:30	Bofu Yu & Keith Fitchett Fractal nature of the eastern highlands (p. 77)	"
12:30-1:00	Jonathan Nott The alluvial history of an Australian river system from 45 million years to the present (p. 80)	"
1:00-2:00	LUNCH HOUR	
2:00 >	Caving	

CHANNEL - FORMING DISCHARGES ON SAND - BED STREAMS OF THE NORTHERN SYDNEY BASIN, N.S.W.

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INTRODUCTION

Recent work by Pickup and Warner (1976), Neller (1980) and Erskine and Melville (1983) has demonstrated that two sets of flows are responsible for determining the channel morphology of streams in the Sydney Basin. In particular, large floods have been shown to be significant in controlling channel capacity and smaller events, the bedforms on the floor of the trough (Pickup and Warner, 1976, Erskine and Melville, 1983). The purpose of this paper is to identify channel-forming discharges on sand-bed streams of the northern Sydney Basin by documenting the response and recovery of Wollombi Brook and Goulburn River to large floods recorded since European settlement.

STUDY SITES

The Warkworth gauging station on lower Wollombi Brook (basin area 1848 km^2) was installed in February 1908. The record flood of 17-18 June 1949 had a peak discharge 26.85 times greater than the mean annual flood but a return period of only 87 years. This event is the largest ever recorded in this area for a comparable catchment area, one of the largest ever recorded in N.S.W. but has been greatly exceeded overseas.

Three long-term river gauging stations on the Goulburn River demonstrate that the flood of 23-27 February 1955 is the largest since at least 1913. The peak discharge was between 33.2 and 43.4 times greater than the mean annual flood and had a return period of between 40 and 130 years. Both Wollombi Brook and Goulburn River have high Flash Flood Magnitude Indices (after Baker, 1977) (>0.71) which means that the annual series flood frequency curves are very steep. Therefore, the probability of experiencing large floods on such streams is much greater than on rivers with relatively flat flood frequency curves, such as those investigated by Leopold Wolman and Miller. The return period of a large flood is not necessarily great on streams with steep flood frequency curves and should not be used as an index of flood magnitude. It should also be stressed that Pickup's (1976) claim (repeated by Neller, 1980) that Sydney Basin floods are castastrophic by world standards is demonstrably false. Envelope curves of extreme flood events for N.S.W. (N.S.W. Department of Water Resources data) and the United States all plot above Pickup's maximum world floods. A detailed air photo, survey and river gauging record has enabled the documentation of river response and recovery to these two large floods.

CHANNEL RESPONSE AND RECOVERY TO LARGE FLOODS

Documented channel behaviour on both rivers was identical. Bankfull stage corresponds to a flood return period in excess of 7 years on the annual series. Floods greatly exceeding the floodplain level are very large events which mobilise the channel boundary sediment and remove all obstructions, thus maintaining a large capacity channel. They clean out the channel by eroding the high banks and by destroying in-channel benches and nearly all of the riparian vegetation, especially trees. The resultant large capacity channel is not obliterated by subsequent sedimentation because of the episodic recurrence of large floods.

During these large floods the river becomes overloaded with sediment, resulting in substantial aggradation (up to 4m). Small to moderate floods after the large event are not high enough to modify the floodplain but transport the flood-deposited sediment. Degradation occurs because the supply of bed-material sediment is an episodic process contingent upon infrequent bankfull floods. This degradation only affects a relatively small part of the enlarged flood channel bed, leaving the higher sections as potential nuclei for later bench formation. As continued incision produces a better defined low flow channel, progressive deposition on the higher stranded sections of the flood channel bed leads to bench development. Benches are temporary sediment storages constructed by small to moderate floods within the void left by the large flood. They are, therefore, a recovery landform.

CONCLUSIONS

The compound channel is a morphological response to the different geomorphological effectiveness of moderate and large floods. Substantial channel enlargement by major floods maintains large channel capacities but succeeding smaller events control the bedforms at the base of the trough by excavating the flood-deposited sand and forming benches within the flood-scoured void.

REFERENCES

Baker, V.R., 1977. Stream-channel response to floods with examples from central Texas. Geol. Soc. Amer. Bull., 88: 1057-1071.

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CHANNEL CHANGES, REGIME SHIFTS AND THEIR IMPLICATIONS IN THE UPPER HAWKESBURY RIVER, NSW

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ABSTRACT

In 1890 Josephson produced a very detailed hydrographic survey of the Upper Hawkesbury between Richmond and Sackville. This data source has seldom been used, perhaps due to datum problems (50ft below a nonexistent Sackville wharf). Thousands of depths below mean low water were recorded but also included were: a detailed long profile, a very meticulous survey of the river near Windsor (plus three cross sections with banks) and a cross section at Lower Crescent which showed the channel, floodplain, bluffs, the 1890 flood height and a measure of peak discharge (>7.5 mill ft3 min-1 or 3560 m3 s-1).

These detailed cross sections can be matched against 1987 PWD surveys near Windsor and that at Lower Crescent has been resurvyed by the Geography Department. In recent years PWD has completed a survey of many cross-sections in the tidal reaches (1978-1887). Parts of their work have been resurveyed in 1986 and 1988.

The main aims of this paper are to show what changes have been revealed, both over the longer (nearly 100 yr) and shorter (up to 10 yr) periods, and to relate these where possible to regime variations and to human impacts on the channel.

Comparisons between 1890 to 1988 show generally a decrease in width and an increase in depth, whilst changes up to 10 years (1978-1986 and 1980-1988) shown increases in both width and depth. Five cross sections near the former Windsor ferry, before the bridge was built, show a narrower and much deeper channel than in 1890.

The flood-stage record at Windsor (1795 to present) has been used extensively in recent times (Josephson, 1885; Riley, 1980 and 1981; Warner, 1987; Erksine and Warner, 1988). This has revealed what are now termed flood- (FDR) and drought-dominated regimes (DDR), as well as mean flood stages (MFS) and mean annual flood stages (Q2.33) (Table 1).

Table 1 Windsor Bridge: FDRs and DDRs, MFS and Q2.33 Stages

Period	Regime	MFS(m)	Q2.33(m)	Floods>6m	per year
1799-1820	FDR	13.0	13.2	14	0.6
1821-1856	DDR	9.2	<6.0	7	0.3
1857-1900	FDR	9.0	9.0	51	1.2
1901-1948	DDR	8.0	6.3	24	0.5
1949-1978	FDR	8.9	9.3	48	1.6

Josephson's (1885) largely qualitative record shows:
30 floods in 26 years (1795-1820)
10 floods in 36 years (1821-1856) and
112 floods in 25 years (1857-1881)

Since the floodplain at Windsor seldom exceeds 10m, it would appear that the first FDR floods were about 3m above the surface. This frequent and high-level ponding may have due in part to the great narrowing of the floodplain (and then densely timbered) as the river enters its gorge through the Hornsby Plateau. Even today steep flood profiles persist (PWD, 1979; GHD, 1980) with lower floodplain roughness and probably larger channels.

From limited data at Windsor ferry, it would appear that the first DDR was characterised by a deep, narrow channel. Q2.33 levels dropped by at least 7.2m. while MFS decreased 4.2m and flood frequency was about 1 in 3 years. The FDR which followed saw MFS drop (?), Q2.33 levels rise by more than 3m and frequency increase to 1.2 or more per year. The channel at Windsor was much wider and shallower.

This century started with a DDR where the channel narrowed and got deeper at Penrith (Warner, 1987). No evidence for this period at Windsor has yet been found. MFS dropped by only 1m, while Q2.33 stages fell by 2.7m and flood frequency was much lower (0.5 yr). In the succeeding FDR, which still persists, the channel again increased in width but depth decreases have only been noted where there are local supplies of bedload. Between 1890 and the present and between 1978-1980 and the present depths have increased downstream of Windsor. The MFS was only up by 0.9m, but Q2.33 stage was up 3.0m and the frequency increased threefold, in spite of the Warragamba Dam (1960).

The reasons for deepening probably reflect human-induced sediment starvation of three kinds: general land conservation, closure of Warragamba Dam (65% of the catchment area above Windsor) and large scale sand and gravel extraction between Penrith and Windsor.

The Hawkesbury today is a sand-bed and therefore mobile stream channel, adjusting rapidly to the impacts of floods and extractive industries. This is supported to some extent by the observations of Josephson (1885) who said: "Many of the recent Hawkesbury floods produce little or no change in the river bed, but there are many indications of change in the past." These thoughts were made 28 years into what was probably the most effective FDR. Changes in the present regime are more frequent and probably result from human-induced actions aided by the bigger and more frequent sediment-starved floods.

The implications of such observations are fairly straight forward. The actual channel is very dynamic responding rapidly to regime shifts and human actions. These need to be considered in any activity concerned with the present channel. Future modifications involving more general changes in climate may well be anticipated from such studies.

REFERENCES

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THE APPLICATION OF FLUVIAL GEOMORPHOLOGY TO RIVER CHANNEL MANAGEMENT IN NEW SOUTH WALES

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ABSTRACT

This paper is a summary of the current policies and principles used by the New South Wales Department of Water Resources (DWR) in managing the State's non-tidal stream channels in regard to erosion/sedimentation advice and control of river excavations. It is important that this information is presented to the geomorphologists at this conference in order to allay any concern that the DWR is not using the latest fluvial geomorphological research results in its management decisions. The former engineering-based approach used by the DWR was the cause of some concern among fluvial geomorphologists in the past and most likely prompted the criticism contained in a recent paper by Warner (1988). The information presented here also illustrates the practical problems of implementing the results of research in the real world where management decisions directly affect people's livelihood, property values, safety, public assets and the environment.

Prior to the 1980's, the DWR used an empirically derived approach (developed historically for irrigation canals) to manage river channels. The Department's River Improvement Branch was using regime equations to design "stable" channel widths. There was no legislative control over excavation activities in river beds which were also considered to be stable. In adopting a geomorphological approach in the 1980's, it was recognised that most river channels are unstable for many reasons and that some channel changes are caused by short term climatic variations. Geomorphologists newly employed during this period assisted in the revision of the river channel management policies and principles. These new policies acknowledge that river channels are dynamic and subject to complex hydraulic and hydrologic interrelationships governed by thresholds. The Rivers and Foreshores Improvement Act was changed in 1982 to include control over river bed activities. At about the same time, federal and state funding for "river improvement" works was cut off, forcing a new policy on erosion control. State-funded works can now only be done in critical locations to protect public assets and not to control whole river reaches as was done in the past. Over the following years, policies and principles were evolved that took into account the latest research results. The new policy for excavation activities based on the dynamic channel concept was used on a trial basis for a few years and was officially adopted on a state-wide basis in May 1987. These new channel management policies are now part of a "river basin management" program by the Catchment Management Unit (CMU) using the expertise of engineers and five applications-orientated fluvial geomorphologists from widely varied backgrounds, a situation unique in Australia.

This evolutionary process was necessary as it takes time to critically review and convert research results into a practical policy that is based on things that can be readily seen in the field, readily measured and readily understood by the people enforcing the policy and those affected by it. The policy must be flexible to allow it to be implemented at specific sites and allow it to be changed as new research results become known or there is evidence that some aspect of a policy is consistently causing major damage. In addition, any policy must fit into the new DWR corporate policy of impartially satisfying the needs of all river users, namely resource consumers, riparian land holders and the environment. The state government must balance the needs of these users and make sure that the benefits of a proposed activity are not outweighed by predictable and significant detrimental effects on the river's usefulness.

On gaining control of river-bed excavations in 1982 a general policy was formulated based on maintaining the location of the existing low flow channel, pool water levels, maintaining or improving bank "stability" and minimising detrimental effects to adjacent riparian landowners. Excavations of pits in bars to great depth was allowed on the condition that underwater slopes were stable and that unexcavated buffer zones were left separating the pits. This implied that the bars were static and that the pits would be refilled by the next flood. Excavations within the low flow channel itself were discouraged except where there were permanent controls.

Because this policy was the first step in initiating control over the industry, it allowed for maximum extraction while the sites were monitored to assess the rivers' short term adjustments. The effects on bedload transport were soon apparent. Where significantly more material was removed from extended reaches than was being transported from upstream, substantial bed degradation occurred. This was often followed by increased bank erosion. The Cockburn River at Tamworth is an example. Degradation there was so severe it directly threatened public utilities and resulted in the Department placing a total ban on extraction of any active bedload. Burra Creek near Moruya and the Urumbilum River near Coffs Harbour are other examples.

Widespread bed degradation has been recorded in other rivers where it could not be attributed principally to extraction, but is also due to changes in hydrologic regime. Thus, whilst the Department can and has stated publicly that continued extraction in rivers such as the Hunter and the Nepean will increase the "natural" rate of degradation, the industry, of itself, cannot be blamed for the present circumstances.

With definite evidence of the major detrimental effects that can result from incorrect methods of extraction, a new, more conservative set of policies was adopted in May 1987. As well as limiting bed degradation caused by extractive industries, the policies also provide for the least impact on the biotic environment and water quality. They are designed for five general situations. Site specific conditions are also applied where necessary. In brief, extraction below normal low flow water level is allowed only in either very controlled situations such as between bedrock bars and in backwater pools or in streams where there is objective evidence of recent bed aggradation. In the latter case, excavation is allowed only to the pre-aggradation bed profile. Where there are no controls to prevent degradation, excavation is limited to harvesting the tops of bars and islands above low flow water level. Where there is objective evidence of bed degradation, no excavation of active bed material is allowed and extractors are directed to inactive terrace or floodplain deposits.

The above excavation policies are an interim step in the evolutionary process of channel management. The latest step has been to initiate a bedload measurement project on nine rivers of the state close to major centres of development (see Coates et al, this volume). Crucial to the management of river sand and gravel extraction is an approximation of the amounts of bedload being transported. This data will provide a more objective basis for better excavation management in the future. It is recognised that any removal of bedload from a fluvial system will produce some response. However, under the present economic and political circumstances, a minor response that does not significantly affect other users, cannot be used as grounds to sterilise the sand and gravel resource of rivers.

The Department of Water Resources is also responsible for providing erosion or sedimentation advice to landowners and other government authorities. Any person may construct control works on their land without permission unless excavations are involved. However, most people usually seek advice from the DWR before proceeding. Although the cost of the works are borne by the landholder involved, officers in the CMU advise clients on river erosion and sedimentation problems on request. During site inspections, a causal assessment is made and the potential for continued or accelerated erosion is considered. The subsequent recommendations are based on the type and causes of the erosion; whether it is fluvial, gravity induced or as a result of general degradation. Historical data from parish maps, survey plans and photographs may be used in the assessment. Advice is also based on a cost/benefit analysis of the works required and the likelihood of success. Potential impacts on other users, some of whom may have conflicting interests, are considered. However, the basic aim of the policy is to provide the least expensive solution to the client with minimal detrimental effects.

It is recognised that many of the causes of erosion and sedimentation are due to the dynamic nature of river systems. Removing the causes of erosion and sedimentation problems must take that into account. Because of this, a recommendation may be made to take no action. This is especially appropriate where structural control works themselves would cause serious detrimental effects on other users or where the cost of works greatly exceeds the value of the asset to be protected.

Where there are significant long-term benefits to be gained from taking action, two courses are available. The first is to direct attention to the catchment in a river basin management program. Such a program is being developed in the Lake Illawarra catchment where riparian buffer strips, land use controls and bank erosion control works will be used to help solve water quality and sediment problems which affect the lake. Where public assets are endangered, a second course of action is recommended in the form of structural works. These may involve bank protection, and/or velocity reduction works. Construction of weirs, drop structures and re-alignment of low-flow channels may also be considered. As a matter of policy, these structures are recommended for critical points in the stream and not for whole river systems. Where such works are undertaken, the performance of the structure and its effects on the stream are monitored. Alterations to the structure or further remedial works are directed where undesirable effects result. With such a wide range of river users represented as well as the difficulty of determining precise cause and effect relationships, a very cautious approach is taken in recommending structural control.

In conclusion, the DWR uses the latest research results from the field of fluvial geomorphology in its channel management policies and principles. It now employs five geomorphologists expressly for the purpose of converting results into practice. This has led to new policies based on the dynamic channel concept. The need to obtain evidence to convince politicians and the public resulted in a time lag between research results and their practical application. These present policies are based on limited available data that is relevant to practical management problems. Unfortunately, public concern arises only when their own property is threatened which is why there is little funding for research. The DWR encourages more research on these problems and would like easier access to the research results so that it can continue to improve channel management in New South Wales.

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POST EUROPEAN SETTLEMENT RIVER METAMORPHOSIS ON THE THOMSON AND AVON RIVERS, GIPPSLAND, VICTORIA: AN EXPLANATION BASED ON STREAM POWER

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This paper explores the causes of post European settlement channel changes on two of Gippsland's rivers. River metamorphosis has occurred on some segments of the alluvial reaches of the Thomson and Avon Rivers during the period of European settlement, but other segments have changed little in character during this period. River metamorphosis has occurred on these streams in the absence of any major extrinsically controlled change in the discharge or sediment load supplied by the catchment, and in the absence of any significant change in base level.

The pattern of change on these two streams suggests a link between river metamorphosis and changes in stream power. The reaches where river metamorphosis has occurred coincide with the reaches where stream power has increased dramatically while no major change in stream power has occurred on the reaches where the channels have retained their pre European settlement characteristics.

Different factors were responsible for the increases in stream power and thus river metamorphosis on different reaches of the Thomson and Avon Rivers. A model which categorizes potential causal factors in terms of their effect on stream power is proposed on the basis of the observed pattern of change. At the core of the model lies an intrinsic sequence of channel and floodplain development. Assuming an arbitrary starting point of a channel incised into the lowest part of the floodplain and thus subject to high energy conditions because of the concentration of floodwaters into the channel, floodplain widening would lead to a decrease in stream power as a result of the energy of floodwaters becoming dissipated over an increasingly large area. Floodplain development would lead to a redistribution of energy, with the floodplain eventually being subject to greater energy than the stream channel. The sequence culminates in avulsion which returns the channel to a lower position on the floodplain, therefore leading to a return to higher energy conditions and thus causing river metamorphosis. Three categories of disturbance, distinguished by their effect on stream power, may be superimposed on this sequence. The first category encompasses disturbances which cause river metamorphosis by altering the channel - floodplain relationship, thus short circuiting the intrinsic sequence. The second category consists of disturbances which cause metamorphosis without short circuiting the intrinsic sequence. For example, an increase in sediment load may force a stream to steepen its slope, thus leading to an increase in stream power. The third category comprises disturbances which have no major effect on stream power and therefore do not cause river metamorphosis although they may have a minor effect on channel characteristics.

FLOODPLAIN VARIABILITY WITHIN SOME GLACIATED VALLEYS IN WICKLOW, IRELAND

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This paper illustrates that there is a variety of geomorphological processes responsible for the formation of floodplains. Furthermore, as evidenced here, these processes can produce a considerable range of floodplain types even within morphologically and lithologically similar environments.

Specifically four floodplain types have been identified within the glaciated valleys of the Avonmore-Avonbeg catchment in the Wicklow mountains south-east of Dublin, Ireland. Type 1 occurs within the headwater or source zone and is a relatively shallow feature composed primarily of a coarse bedload and colluvial material with only a thin veneer of fine overbank deposits. These basal boulders form a lag deposit along a laterally stable channel. In contrast,the fines may be periodically removed during extreme flow. In contrast, type 2 is characterised by the dominance of overbank deposition coincident with downvalley floor widening. This change is a result of a combination of the effects of previous glacial deposits and present low gradient stream hydraulics. In particular, the resistance of pre-existing glacial deposits prevented lateral migration thereby promoting overbank deposition. Type 3 is a product of lateral migration, reworking the glacial and fluvioglacial materials as a result of an increase in stream power and discharge associated with a major tributary input. Type 4 within the lower most reaches is anomalous, it consists of an incised channel within terraces of truncated outwash material. The formation of these terraces is reminiscent of that described for bedrock terraces elsewhere. The examples presented here illustrate a variety of floodplain types throughout a series of glaciated valleys.

TOPOGRAPHY OF RIDGE-CRESTS IN RELATION TO DRAINAGE DENSITY AND STREAM NETWORK EVOLUTION IN NEW ZEALAND

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ABSTRACT

The elevation of new land along an actively rising coastline has long been recognised as an initial surface upon which subaerial drainage networks are formed (e.g. Horton, 1945). Flights of marine terraces in New Zealand show progressive dissection of terrace surfaces with increasing age, until whole terrace surfaces are completely dissected. In South Taranaki, where stream networks are initiated and grow by headward sapping, terrace surfaces are completely dissected in c. 500,000 years (Pillans, 1985, 1988). Once dissection of the initial surface is complete, drainage divides develop as knife-edged ridge crests. Erosion in headwater regions of first order streams produces a characteristic notching of the ridge crests; the spacing of these notches is related to drainage density.

On sloping ridge crests, the notches resemble steps, with a semi-regular spacing. Bull & Cooper (1987) have interpreted similar ridge crest notches as shoreline remnants in the South Island of New Zealand. Seemingly convincing age/height relationships can be established for the notches (Bull & Cooper, 1987), based on comparison with marine terraces in New Guinea (Chappell, 1983). However, the existence and spacing of such notches can be explained entirely in terms of drainage densities and stream network evolution, and the correlations of Bull & Cooper (1987) may be spurious. It may yet turn out that the rounded quartz pebbles of supposed marine origin that are associated with the notches, are nothing more than Moa cropstones (Ward, 1988).

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RIVER BANK EROSION BY BOAT GENERATED WAVES ON THE LOWER GORDON RIVER, SOUTHWEST TASMANIA.

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ABSTRACT

The estuarine section of the Lower Gordon River is approximately 38km long and has been used as a navigable waterway since its discovery in 1815. Early usage was concerned with the extraction of valuable timber growing in the area, particularly Huon Pine. But as that resource was exhausted tourist cruises took over as the dominant use of the river. The river based tourist industry received a major boost from the widespread interest generated in the area during the river blockade by conservationists protesting against the construction of the Gordon Below Franklin Hydro-electric Scheme in 1983. The two cruise operating companies responded by purchasing new, high speed cruise boats that enabled them to operate two return trips per day along the river during the summer tourist season. This produced a sudden increase in both the size of waves and the frequency of impacts on the banks which resulted in the rapid erosion of many kilometres of previously stable riverbank. As the banks retreated the temperate rainforest vegetation lining the river toppled into the water, significantly degrading the aesthetic qualities of this world heritage area and drawing unfavorable comments from tourist and other visitors.

The aim of this study, which was commissioned by the Tasmanian National Parks and Wildlife Service (now the Department of Lands, Parks and Wildlife) was:
(1) To determine the type and processes of bank erosion, as well as its distribution and severity.
(2) To examine ways of preventing further erosion by regulating boat traffic and monitoring the effectiveness of imposed regulations.

Although strongly indicated by the circumstances already mentioned, field investigation of the distribution and processes of erosion confirmed that boat generated waves were the primary cause. The present bank erosion on the lower Gordon was found to follow a three stage sequence:
(1) Exposure of living plant roots on the bank surface through the removal of surrounding soil particles by wave action.
(2) Breaching of the protective rootmat on the bank surface followed by undercutting of the bank at the point of maximum wave attack or minimum bank resistance (generally just above low water level) to produce a distinct notch.

(3) Increase in the size of the notch to the point where the upper part of the bank and its supported vegetation collapse into the river.

Further wave action removes the collapsed bank material and the process of undercutting and collapse is repeated.

Bank materials were grouped into 7 different types on the basis of probable varied response to wave attack. These were:

(1) Bedrock; mainly limestone and fine grained sandstone and shale.
(2) Colluvial slopes of large boulders with no visible fine matrix.
(3) Colluvial slopes of small rock fragments and gravel set in a clayey matrix.
(4) Coarse sandy levees 1 to 4 meters above low water level overlying finer, more compacted silty sands.
(5) Coarse sandy levees 1 to 4 meters above low water level overlying river gravels.
(6) Low banks (less than 1 meter above low water level) of fine silty alluvium.
(7) Pebble and gravel beaches.

An erosion severity assessment was made for each section of different bank type and expressed as the percentage of total bank length affected. This assessment was initially done in three categories of increasing severity of erosion:

(1) Fresh root exposure.
(2) Bank undercutting and notch formation.
(3) Tree fall.

For easier comparison these three categories were then combined into an erosion severity index for each section of each bank type. In addition the location of any fresh landslips on colluvial slopes was noted.

The bank survey showed that only three bank types were affected by wave erosion; however, these bank types comprised about 80% of total bank length. The three eroded bank types in order of decreasing severity were; levees, colluvial slopes of small rock fragments and low, fine grained alluvium.

The second part of this study involved relating the wave characteristics produced by the tourist launches at different speeds to the amount of bank erosion produced in order to determine if a speed restriction could be imposed on the boats that would prevent further erosion of the banks. This part of the study was carried out in collaboration with Drs. G. Nanson and E. Bryant of Wollongong University and Dr. M. Renilson of the Australian Maritime Collage. Two different methods were used to measure the wave characteristics of the tourist launches at different speeds. These were minor adaptations of methods used by Bhowmik et al. (1982), and consisted of;

(1) A video camera and surveyor's staff.
(2) A capacitance probe and chart recorder.

Both methods proved satisfactory, though the probe and chart recorder were more accurate. For each wave train generated by the boats traveling at different speeds three independent erosion indices were measured.

(1) The amount of retreat of a section of sandy uncohesive bank was measured using fine wire pins.
(2) The amount of sediment transport in the swash zone was measured using a trap placed on the river bed adjacent to the bank.
(3) The amount of fine material brought into suspension during the period of maximum turbulent activity associated with each wave train was measured.

The results indicated that there is a significant jump in the erosional energy of waves above a height of about 20cm to 30cm and below about 12cm erosional energy is negligible.

Based on these measurements a speed limit of nine knots was imposed on boats over 8m in length on about 90% of the length of the lower Gordon River. At this speed each of the three tourist boats would produce waves around 20cm high. In addition to the speed restriction each boat was only allowed one return trip per day.
A monitoring program using erosion pins inserted into the bank face was set up to check the effectiveness of the boat restrictions. The measurements indicate that the new regulations have effectively reduced erosion rates to the point where little further damage to the river banks by boat waves is expected.
Monitoring is continuing as it is uncertain whether a stabilizing vegetation cover will be quickly re-established, or if other erosive factors will come into play on the now exposed bank sediments.

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MEASUREMENT OF BED MATERIAL DISCHARGE IN RIVERS OF NEW SOUTH WALES.

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ABSTRACT

The New South Wales Department of Water Resources is the state government authority responsible for the formulation of policies and environmental management options for aggregate extraction within the state's riverine environment. This paper outlines the rationale and methods behind the Department's 'Bed Material Discharge Project'.

Sand and gravel bed material contained within river systems is utilized by the construction industry. Current areas of high demand for this resource correspond closely to population centres undergoing expansion (refer Fig.1).

It is recognized that inappropriate policies and poorly managed extraction of bed material has had significant effects on channel dynamics and on the environment. As an example, the Cockburn River at Tamworth has degraded by up to 2 metres over a period of 10 years. During this period, uncontrolled extraction from the bed of the river was in the order of 160 000 tonnes per year.

Whether the upstream or downstream effects of bed material extraction are significant or whether they are considerably dampened by the fluvial system depends on the ratio of the rate of extraction to the bed material discharge. Several attempts at predicting bed material discharge in N.S.W. have been made using equations developed in various studies overseas. However, these formulae appear to be inherently unreliable under natural field conditions, giving results that differ widely at similar sites and in similar situations (Hean and Nanson, 1987). Rates of bedload and suspended load determined by direct measurement methods are therefore required to provide the data base for the establishment of predictive equations for bed material discharge.

Several methods have been developed for measuring bed material discharge. These include the use of pits or slots, site surveys, sampling during an event, particle tracers, and scour chains. All methods have inherent advantages, limitations and inadequacies. For gravel bed rivers, the Department has adopted a technique which combines surveys and a post event scour chain/magnetic tracer method (Hassan et.al.,1984).

Sites selected for bed material measurement are initially surveyed to establish the general morphology of the river channel. Scour chains are installed vertically in the river bed to measure the depth of activation of bed material movement at a cross-section. The chains enable the determination of both the amount of scour and fill during an event(refer Fig.2).

Magnetic tracers are used to measure the distance and distribution of gravel transport. Small ceramic magnets are placed in holes drilled into the gravels and sealed off with epoxy resin. Each particle is painted, numbered and the length of the A,B,C, axis recorded. The size distribution of the magnetic particles is matched to the site and the particles are placed on the cross section with their exact locations surveyed and recorded.

Following a flood event the site is resurveyed to identify changes in channel morphology. Scour chains are measured to determine the zone of activation. The magnetic particles are detected using a fluxgate magnetic locator and

their positions surveyed. The site is then reset with chains in the vertical position and a new series of particles ready for the next event. Particles are left in the channel for several events so that they are mixed into the bed material. The sample size therefore, increases after every event.

The technique has several advantages over other methods. These include:(1) direct means of measurement with a quantifiable data base.(2) post-event method, it is not essential to be at the site during a flood event.(3) magnetic particles can be detected up to 1 metre below the bed and in water up to 1.5 metres deep.(4) enables spatial variations in transport to be assessed.(5) relatively inexpensive.

The disadvantages of the method are:(1) limited to gravel bed rivers (it is necessary to employ other methods in conjunction with this technique to measure bed load in sand or mixed bed rivers).(2) limited to channels that have periods of shallow water levels during low discharge periods.(3) does not provide temporal information for a flood event.(4) there is some loss of particles.

Combining information from the scour chains and the magnetic particles the volume of sediment moved in an event can be calculated. The threshold of motion can be established from the discharge which initiates particle movement and the bed material supply rate can be calculated.

After one year there have been several significant (i.e. gravel transporting) events over the established sites.

The Department is aware that both hydrologic and sediment supply rates are influenced by variables which are undergoing changes both temporally and spatially. Because of this, bed material discharge/duration curves calculated using a short term data base will only be relevant provided conditions influencing these variables remain constant. It is therefore intended that this will be a permanent ongoing project to provide a mechanism for the monitoring of any long term changes in the river system. The information collected will be stored on a computerized data base which will be made available to other researchers and the public at a nominal cost.

Management decisions for aggregate extraction based on the results of the project will also take into account factors such as channel modifications, regulatory structures (e.g. weirs), recent channel changes and evolution, periodic natural regime shifts, possible climatic changes, and past aggregate extraction. The information obtained from the project will be used along with inputs from other government departments and recent relevant research findings to formulate 'River Excavation Management Plans'. In this way, policy decisions will resolve the complex management issues while recognizing the highly dynamic or 'unstable' nature of N.S.W's river systems.

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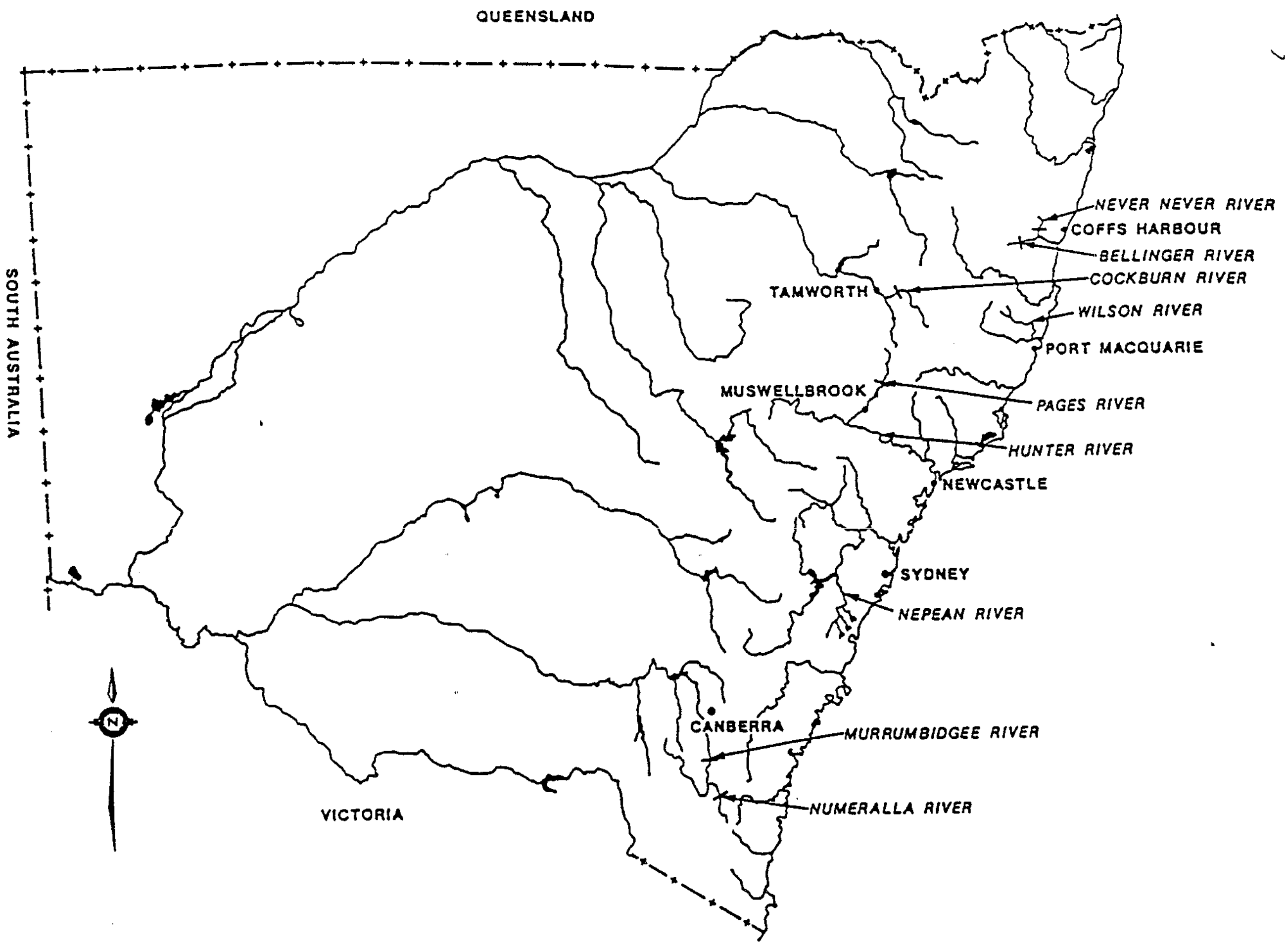

Figure 1 : Monitoring sites and major centres demanding sand and gravel resources.

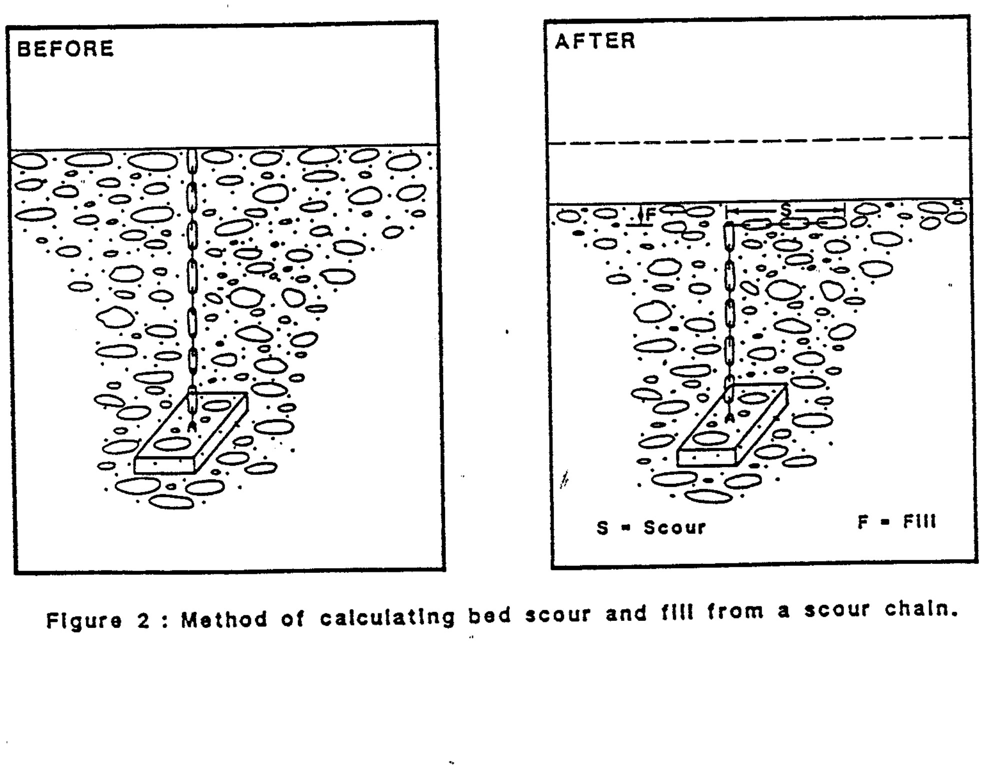

Figure 2 : Method of calculating bed scour and fill from a scour chain.

STREAM POWER/BEDLOAD CHARCTERISTICS OF THE WAINGAWA RIVER.

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This paper examines the degree of relationship between bed material size and the stream power of the Waingawa River, Wairarapa, New Zealand.

The drop in bed material size in the downstream direction can be explained by a similar drop in stream power. The average rock size drops from 45cm diameter at the foothills of the Tararua Range to 18cm diameter near the confluence with the Ruamahanga River. Similarly, stream power drops from 90Watt/m^2 to 15Watt/m^2.

The critical power required to move bed material at the lower reach is approximately 15% of the stream power available at bankfull discharge, compared to the upper reach with critical power at half the stream power at bankfull discharge. The upper reach has a lack of stream power at bankfull discharge in comparison to the lower reach.

It appears that the drop in bed material size down the Waingawa River is due to the preferential transport of smaller rocks, as determined at bankfull discharge.

BEDLOAD TRANSPORT RATE FLUCTUATIONS AND CHANNEL PATTERNS IN GRAVEL BED RIVERS: A LABORATORY STUDY

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Numerous recent studies have identified irregular fluctuations in bedload transport rates in gravel-bed rivers and flumes. These have been documented over a range of timescales, associated with which is a range of spatial scales. The timescales extend from the micro (0 - 10^{-2} years), through the meso (10^{-2} - 10^{1}) years, to the macro (10^{1} - 10^{3} years). Micro scale fluctuations can be explained by bedform migration and particle sorting effects, and macro scale ones tend to reflect adjustment to long term river disequilibria, such as post-glacial relaxation. The meso-scale fluctuations, which are manifested in the river systems as 'bed waves', have been associated with discrete inputs of material into river systems since the pioneering study of Gilbert (1917) into hydraulic mining debris in the Sierra Nevada. More recently, it has been suggested that such phenomena can also result from processes operating entirely within the river channel i.e. with constant rate of supply of material from both upstream and slope inputs to the river, waves of material are still able to develop. Ashmore (1987) interprets variations in bedload output from a laboratory gravel-bed river model in terms of this sort of wave development.

Wave genesis with constant sediment and water inputs to a river system has been tested in a laboratory gravel-bed river model. A generic, process-similar model was used, with Froude and Reynolds Number similarities being obtained between the model and prototype rivers, as indicators of model representativeness of field conditions. The model rivers were classified as braided. Variations in sediment output rates from the model of up to 5 times were observed in the same experimental runs. These variations had a periodic form, and were closely related to changing channel geometries. The explanation for variation in bedload transport lies in the cause of these changes in channel geometry. Different cross-sectional geometries are associated with different planform channel patterns. A link between planform pattern and sediment transport can be suggested on *a priori* grounds. Comparison of this *a priori* model with the laboratory data suggests a strong functional relationship between channel pattern and sediment transport and storage.

Variations over time in channel patterns, sediment storage volumes and sediment transport rates appear to be normal features of active gravel rivers. This reflects the dynamic nature of the equilibria in such rivers, whereby the equilibrium condition involves repeated aggradation, incision and avulsion, as the channels evolve. The switch from aggrading to incising states seems to be caused by the crossing of a slope threshold, above which channel incision can occur.

Extension of these interlinkages to prototype rivers suggests that downstream channel pattern variations observed in such rivers can be associated with variations in sediment storage volumes and in sediment transport capacities. Thus waves of gravel can be identified and described, and observed to migrate using sequential measurements of channel patterns.

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GRAIN INTERACTION DURING BEDLOAD TRANSPORT: A NEGLECTED ASPECT OF STREAM BEHAVIOUR?

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ABSTRACT

The transportation of bed material in streams has been relatively widely studied in recent years, with a particular emphasis on the conditions applicable to gravel streams and to poorly-sorted bedload sediments. It has been clearly established that in such streams, natural segregation of the bed sediments occurs to produce coarse surface layers which have been labelled in a diversity of ways but which are best simply described as *armour*. The development of these segregated layers has in turn attracted considerable attention and has most widely been studied experimentally in the laboratory flume.

Early work on the development of armour layers was carried out in reaches of rivers which had been affected by dam construction. Sediment trapping in large dams results in clear-water release and a tendency for downstream scour. In such situations, the development of armour was considered to occur by the removal (*winnowing*) of finer clasts leaving a lag of coarser grains. This process was then modelled in the laboratory by setting flow conditions in the experimental flume in such a way as to mobilise only the finer fraction of the model sediment.

However, armour is a prominent feature even in streams where flows of a magnitude able to transport all available grains sizes are experienced. The development of coarse surficial layers in such situations is still problematical. Parker & co-workers (e.g. Parker & Klingeman 1982) have set out a model incorporating *vertical winnowing*, in which finer grains are worked down into the bed beneath larger clasts at the bed surface. This process occurs within an *active layer* of much more than one grain diameter in thickness. Details of this process have not been explained in the literature and it remains speculative.

Field evidence from the Tambo River presented elsewhere (Dunkerley, in press) however has suggested that in some situations, armour develops not from an initial body of bed sediment, but by the accumulation of large mobile clasts from the bedload. This requires a mechanism by which large mobile grains can be brought to rest at the bed surface overlying finer materials.

A similar situation arises in the case of the transport of material through riffle and pool sequences. In order that riffles remain coarser than pools, areal sorting of bed sediment must occur. What causes coarse material scoured from an upstream riffle to come to rest in a similar location further downstream? Beschta (1987) suggests that there may be lower bed shear stresses at riffles because of differences in channel geometry there. However, following this line of argument develops rapidly into unsatisfactory circular reasoning. We would reason that because of altered channel geometry, coarse grains are found on riffles; but the geometry is only different because the coarse grains *have* accumulated. Clearly, even the origin of such common features as these remains incompletely understood.

A common theme in the context of armour development by the accumulation of coarse grains and in the maintenance of coarse sediment at riffles may well be the nature of the interaction among grains during active bedload transport. In particular, we may need to consider further the conditions which can bring about the deposition of coarse grains during mobile bed conditions.

A number of hypotheses may be advanced to account for the accumulation of segregated coarse grains. However, fundamental to these is the possibility that the conventional treatment of sediment transport oversimplifies the true situation. It seems probable that since coarse grains move spasmodically and in essentially continuous contact with the bed, that there will be extensive interaction between grains. A clast temporarily in movement may be involved in a collision with a clast which is temporarily at rest on the bed; the simple cluster so produced may act as a seed, if conditions are appropriate, for the accumulation of further grains. Alternatively, there may be collision processes between a large moving clast and one or several smaller clasts, or between two or more moving clasts. The outcome of collision processes at the bed surface

where, because of high shear stress most of the bed surface is in active transport, is not known. Moss (1963) had envisaged the operation of a process called *traction clogging* in which interaction between mobile clasts and large stationary grains results in reduced mobility for large grains along the streambed. These would thus accumulate as a channel lining. Laronne & Carson (1976) found that up to 25% of the bed surface area in a Canadian gravel stream was composed of isolated protruding grains or those grouped into imbricate, locked, or boulder shadow structures. Similarly, Brayshaw (1984) has described the formation of *cluster bedforms* around an initial seed clast or obstacle, and has indicated that such features occupy typically 5-10% of the channel floor in coarse-grained alluvial channels. These clusters were considered to be primarily the result of hydraulic effects around large clasts exceeding the D_{95} diameter.

The collapse and re-development of cluster bedforms in the traction carpet may be associated with the phenomenon of pulsing in the delivery of bedload material. In addition, grain interaction during traction appears to be important in the development of grain segregation as found in certain armours, and perhaps in the formation of the riffle-pool texture contrast. Thus this is an area of bedload movement which appears to warrant additional study.

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THERMOLUMINESCENCE CHRONOLOGY OF LATE QUATERNARY SEDIMENTS OF THE RIVERINE PLAIN, SOUTH-EASTERN AUSTRALIA

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The Murray Basin is a low-lying, saucer-shaped, intracratonic basin of thin flat-lying Cainozoic sediments which extend over an area of 320,000 km^2 in south-eastern Australia. In the eastern part of the basin fluvial sediments up to 300 m thick underlie a flat and topographically almost featureless landscape known as the Riverine Plain. The present rivers (the Murray and its tributaries) typically flow within a belt of a alluvium whose surface is incised a few metres below that of the surrounding plain.

The geomorphic map of the Riverine Plain (Butler et al., 1973) shows that is consists of coalescing alluvial fans which emanate from gaps in the bordering ranges. These fans were largely produced by ancient rivers which bear little relationship to the modern drainage system. Butler (1950) called these rivers prior streams and noted that they were characteristically leveed bed-load channels of low sinuosity. The prior streams formed a criss-crossed distributary pattern and generally peter out towards the western margin of the plain. Pels (1964) showed that even the younger prior streams were beyond the then limits of C^{14} dating (36,000 years).

Pels argued that the demise of the prior streams was followed by a phase of incision by large sinuous suspended-load channels. Because these streams were the true precursors of the modern drainage network Pels called them ancestral rivers. Remnants of these channels are well-preserved along the margins of the Murrumbidgee floodplain between Darlington Point and Carrathool and also on the Cadell Tilt Block south of Deniliquin where faulting diverted the westward flow of the ancestral Murray and Goulburn and also created a series of lunette bordered lakes on the downthrow side of the fault. The largest of these was Lake Kanyapella.

Although the later phases of ancestral river activity were C^{14} dated by Pels (1969) and Bowler (1967) (Table 1) the inability of this technique to date events beyond about 30 000 years old presented a major impediment to further research on the chronology of Riverine Plain sedimentation.

Recent developments of thermoluminescence (TL) dating have, however, enabled the dating of fluvial and aeolian sediments up to almost one million years old. Last year 13 samples from prior streams, ancestral rivers and associated aeolian deposits were dated in the TL laboratory at the University of Wollongong and taken together provide the basis for a reappraisal of the history of Riverine Plain sedimentation [Table 1]. Although much more field and laboratory work is required before a firm chronology can be established these first dates display a high level of internal consistency and permit us to draw three initial conclusions.

1. The last phase of prior stream activity dates back to before 90 000 years and probably terminated about 45 000 years ago when the Northern Prior Stream near Hay aggraded its channel with sand and gravel.

2. Given that the ancestral Green Gully was active at the same time as the Murrumbidgee prior streams it is difficult to maintain the rigid morphological and chronological separation of prior streams and ancestral rivers. Bowler's (1978) misgivings about the ancestral river-prior stream dichotemy appear to have been well founded.

3. The formation of Lake Kanyapella as the result of tectonic activity took place about 30 000 years ago. Five TL dates on channels and dunes associated with this event show a strong clustering. The close agreement between dune and river based dates is particularly encouraging for the future of TL dating in Quaternary research.

Less straightforward is the construction of hydrological environments associated with Riverina Plain sedimentation. If Green Gully and the northern prior streams were simultaneously active it is difficult to reconcile the apparently arid climate, low discharge conditions responsible for the latter with the high discharge conditions demanded by the large Green Gully channel. Clearly, a great deal of work remains to be done before it will be possible to establish a sequence of Riverine Plain flow regimes and place these within the broad Australian regional context as evidenced elsewhere for the inland lakes (Bowler, 1983), Cooper Basin (Rust and Nanson, 1986) and coastal rivers of New South Wales (Nanson, Young and Stockton, 1987).

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TABLE 1
COMPARISON OF C^{14} AND TL DATES FOR RIVERINE PLAIN SEDIMENTS

PRIOR STREAMS

C^{14}		TL	
All > 36 000 years (Pels, 1964)		Central PS	83 500 years
		Central PS	86 600 years
		Northern PS	46 800 years
		Murray PS	90 100 years
		Cadell PS	94 200 years

ANCESTRAL RIVERS

C^{14}		TL	
Pre-diverted phase			
Green Gully	> 28 600 years (Pels,1969)	Green Gully	93 900 years [terrace]
Tallygaroopna	28 700 years tn	Green Gully	85 500 years [pt bar]
Channels	20 300 years (Bowler,1967)	Goulburn Tributary	84 200 years [terrace]
Post-diverted phase			
Edwards River	24 650 years (Pels,1969)	Kotupna Riv	34 400 years [McCoy Pit]
Kotupna	16 150 years to	Kotupna Dune	33 100 years [near McCoy]
Channels	13 000 years (Bowler,1967)	Kanyapella	30 500 years
		Dune	27 300 years
		Little Kanyapella	29 800 years

Alluvial Evidence of Quaternary Environmental Change from the Tropics of Northern Australia.

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There is scant information about the response of tropical and subtropical river systems to the climatic and eustatic perturbations of the Quaternary. In this paper, evidence is examined for environmental change in the last 300,000 years in three large river basins in northern Australia. In contrast to high latitude and high altitude rivers, those studied here show almost no evidence of distinct terracing that could be attributed to climatic and associated flow-regime changes. However, they do provide buried alluvial sequences that identify significant changes in flow regime.

The Cooper and Diamantina Rivers of Western Queensland are fed largely by the monsoon of northern Australia. In their headwaters subdued terraces are present which, along with buried sandy alluvium in the central basin, are related to interglacial climatic episodes at 120 Ka and 240 Ka B.P. The last 80 Ka have been characterised by a uniform period of mud transport and deposition.

The Gilbert River in the Gulf of Carpenteria shows a similar pattern of longterm mud deposition. The well-defined anastomosing channels that traverse this fan-delta confine sand to narrow stringers inset within a widespread and relatively thick mud sheet. A sand sheet (or set of coalescing sand ribbons) beneath the mud is evidence of a sand-dominated phase of deposition dated about 100-120 Ka B.P. The onset of the present mud regime has been dated at prior to 80 Ka B.P. (T.L.).

Along Magela Creek, a tributary of the East Alligator River in the most northern part of Australia, there has also been a period of last-glacial and Holocene fluvial stability. A dominantly late-Pleistocene floodplain (with a basal T.L. age greater than 40 Ka B.P.) appears to be still forming. Here the major perturbation in the late Pleistocene has not been a climatically induced change in flow and depositional regime, but instead is due to the trenching of the Pleistocene floodplain during the last period of glacial low sea-level.

The tropical rivers of northern Australia reveal no dramatic shift in flow regime associated with the major Pleistocene-Holocene transition of the high latitudes, but there is clear evidence that at about 240 Ka and again at 100-120 Ka B.P. there were pronounced changes in tropical climate and associated river regime. It appears that the present interglacial (Holocene) has not yet culminated in a period of pronounced fluvial activity so characteristic of previous interglacials in tropical Australia.

MECHANISMS AND CHRONOLOGY OF TRAVERTINE DEPOSITION IN THE CHILLAGOE KARST, QUEENSLAND

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ABSTRACT

The Chillagoe karst area, located inland from Cairns, is seasonally arid but contains many small perennial streams which are spring-fed. The water chemistry of a number of these springs has been investigated by sampling at intervals down the channel and examining carbonate concentrations, saturations levels, pH, etc. Information on the chemistry of the groundwater has been supplemented by analysis of water samples from deep bores in the limestone. Results from this work are summarised in the table below:

WATER CHEMISTRY - SPRINGS AND BORES - CHILLAGOE

Samples included	pH	Cond.	Total hardness	Ca hardness	Mg hardness	pCO_2	SI_c	SI_d
All data	6.86	711	284	257	31	1.22	0.10	-0.54
Bores	6.97	709	289	253	36	1.39	0.16	-0.23
Springs	6.82	738	294	269	29	1.13	0.10	-0.64

The spring waters evidently carry about 80% calcium carbonate and 20% magnesium carbonate, and are very close to saturation with respect to calcite. The slight mean oversaturation (0.10) probably reflects the fact that water samples were collected after some contact with the atmosphere had already occurred. Mean theoretical equilibrium carbon doxide levels in the spring and bore waters was 1.22, corresponding to about 6% CO_2.

Waters with this composition clearly undergo rapid degassing and equilibration on reaching the surface at a spring site. All of the streams show signs of secondary carbonate deposition, either as tufa encrustations on bed and banks, or as more substantial cascades of tufa barriers. Rates of carbonate deposition have been examined at several sites. Ryans Creek at Mungana, in the central part of the Chillagoe karst, is typical. The spring here has a total hardness in the range 280-300 ppm as calcium carbonate, a pH close to 7, and SI_c of 0.05. In the form of a major sequence of tufa barriers, it precipitates carbonates over a distance of 1-2 km below the spring; the deposited material is almost entirely calcium carbonate, so that the magnesium hardness actually *rises* downstream. Precipitation of the carbonates here is believed to be largely an inorganic process driven by degassing and aided by evaporation (Dunkerley 1987) but the role of alge and bacteria remains to be tested.

The loss of calcium carbonate amounts to about 130 ppm, or about 50%, over the first kilometre. At an estimated flow rate of 5 l/minute, this amounts to about 1 kg per day, or about 1 m^3 of tufa in about 6-7 years. Thus a deposit 2 km long, over a depositional surface 50 m wide, and built up to a depth of 1 m, could form in about 16000 years. This can be taken as no more than an order-of-magnitude rate estimate, and accumulation processes would certainly have been changed during the Quaternary. However, it is sufficient to suggest that the cascades of tufa barriers along the Chillagoe creeks need be no older than postglacial.

In addition to the cascades of tufa barriers forming at the present day, there are extensive relict deposits of travertine within the Chillagoe karst. These involve volumes of material much greater than are involved with contemporary (i.e. postglacial) deposits. The travertines are generally located on and near geologic boundaries where conduits for water upwelling must have been exploited in the past. The deposits are generally undergoing breakdown and erosion at present, and typically lie well above present stream levels, forming travertine benches and terrace remnants.

A number of the relict travertines have been sampled by diamond drill coring, with a view to establishing a chronology of travertine deposition, and hence, by inference, a chronology of major episodes of solutional development in the karst area (Dunkerley 1988). One such deposit flanks Chillagoe creek, and runs for some kilometres along it. The material is a horizontally bedded, cream to buff coloured travertine with a bulk density of about 2.36 g/cm^3. Samples from 100 mm diameter drill cores were washed, slab cut, and crushed in tungsten carbide mills for dating by the uranium-thorium method. This work was carried out at the Institue of Nuclear Sciences, DSIR, New Zealand.

Owing to the cost of this dating method, only two samples have at present been dated. These were taken from near the base and near the surface of a large travertine bench flanking Chillagoe Creek. Results of the isotopic dating are as follows-

TRAVERTINE AGES - CHILLAGOE CREEK (thousands of years)

Isotope pair	Upper sample	Lower sample
$^{230}Th/^{234}U$	78 ± 3	260 ± 20
$^{231}Pa/^{235}U$	79 +11/-9	210 +200/-70
$^{231}Pa/^{230}Th$	76 +12/-11	260 +50/-30

The upper unit of travertine therefore appears probably to have accumulated during the last interglacial, and to have ceased accumulating as conditions became colder; the lower unit appears to have begun accumulating in the preceeding interglacial, and probably ceased as glacial conditions were established. Further intermediate dates within the travertine column are required to verify this. However, it appears from the dates avalibale that the relict travertines are the product of interglacial conditions when increased solution in the unsaturated zone is likely to have resulted from greater plant growth and soil microbial activity and their effects on the composition of the soil atmosphere. Given that the lower unit dated from Chillagoe Creek appears to sit on bedrock, it is possible that partial re-solution of the travertines takes place during glacial phases. The dating of travertines appears to be a useful way of approaching the development of a chronology of karst development; it could usefully be supplemented through the parallel use of pollen analysis (e.g. Weinstein-Evron 1987) and stable isotope analysis (e.g. Turi 1986). It is hoped to pursue these possibilities in the Chillagoe area.

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THE AGE AND DEVELOPMENT OF THE CHILLAGOE KARST, NORTH QUEENSLAND

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ABSTRACT

During recent years evidence has begun to accumulate that the karst landscapes in Australia may be considerably older than previously imagined, e.g. Osborne (1984), and some (e.g. Buchan, eastern Victoria) certainly had their origins in the mid-Tertiary (Webb et al. in press). Thus a reassessment of other karst areas is in order, and a close examination of the Chillagoe Karst in north Queensland indicates that it may be very old indeed.

The Chillagoe area lies about 180 km west of Cairns, and the karst has developed in a belt of limestone generally only around 5 km in width, but extending discontinuously north from Chillagoe for almost 200 km.

The limestone landscape is characterized by spectacular towerkarst development; individual towers rise well over 100 m above the surrounding landscape, and can be up to 4 km long and 1 km wide. The surfaces of the towers are covered by extremely well developed rillenkarren, and all significant towers contain caves, which are typically enlarged joint systems, occasionally reaching down to the water table (Ford 1978; Jennings 1982; Pearson 1982).

The limestone in which the karst is developed, the Chillagoe Formation, is Early Silurian to Early Devonian in age (B.G. Fordham, pers. comm.), and was affected by a major deformation in the Late Devonian - Early Carboniferous (Day et al. 1983). This episode of thrusting forced the limestone into a subvertical orientation. From the mid-Carboniferous to the Permian a series of ignimbritic caldera-forming eruptions occurred in the Chillagoe area, accompanied by high level granite intrusions. The presence of the ignimbrites indicates that the area was dry land at the time, so the limestones of the Chillagoe Formation had been exposed to weathering by the mid-Carboniferous.

Since this period of intrusive and extrusive activity, sufficient erosion has occurred to unroof the granites. However, as these intrude the ignimbrites in places, they must have come within 2 km of the surface (the maximum thickness of the ignimbrites). Therefore the amount of erosion since the Carboniferous may only have been of the order of 2 km or less. As the granites are directly overlain by Early Cretaceous sediments (see below), the erosion must have occurred prior to this.

Since the Permian, the only significant depositonal episode to affect the Chillagoe Limestone was in the Early Cretaceous, when the Gilbert River Formation was deposited. This formation has a basal fluviatile unit of ferruginous and quartzose sandstone, overlain by shallow marine glauconitic sandstone (Smart et al. 1980). The basal unit directly overlies and partially obscures the Chillagoe Formation in the Bellevue area, about 80 km north of Chillagoe. In the Chillagoe area small outcrops of ferruginous and quartzose sandstone occur commonly around the bases of the towers, and these are correlated with the Gilbert River Formation at Bellevue (De Keyser & Wolff 1964; Robinson 1980).

The Chillagoe outcrops of Gilbert River Formation are at elevations of 345-380 m asl. However, the limestone towers in the Chillagoe area are up to 437 m asl in height. Thus the conclusion appears inescapable that the Chillagoe towerkarst had at least 60 m of relief around 130 million years ago. Erosion since then has added only about 40 m to the local relief.

There has been small scale movement along faults in the area since the Early Carboniferous, but this is unlikely to have been sufficient to invalidate the above conclusions. An outcrop of Gilbert River Formation along the major fault line to the west of the Chillagoe Formation (the Palmerville Fault), within the Chillagoe area, apparently showed evidence of folding due to fault drag (Jennings 1982; this outcrop has since been removed by quarrying). However, this has not affected most of the Gilbert River Formation outcrops in the area, which are found in amongst bluffs that show no evidence of recent faulting.

Thus the towerkarst at Chillagoe, and by implication the caves, were well developed in the Early Cretaceous, and have probably been forming since the Carboniferous.

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RELATIONSHIPS OF KARST LANDFORM DEVELOPMENT TO DUNE LIMESTONE DIAGENESIS

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ABSTRACT

The relationships between the development of karst landforms and the lithification of the host rock are especially interesting in soft limestones. Karst features are traditionally regarded as being most well developed in limestone which is "pure, hard and compact, with well developed fissures along which solution takes place, while the rock itself is impermeable" (Sweeting, 1973) The ability of the roof in a cave to resist collapse under the weight of the rock above is an important characteristic in karst landscapes and is usually related to the composition and lithification of the rock itself. Karst processes are evident in less than the optimum conditions described above.

Extensive aeolian calcarenite deposits are to be found in the Pleistocene calcareous ridge systems of the Otway Basin, described as Bridgewater Formation. These include areas of karst features, such as Bats Ridge, Mumbannar, Strathdownie and Puralka. Detailed studies of Bridgewater Formation at Bats Ridge near Portland, indicate that shallow, linear horizontal cave systems have formed under a hardened cap rock or kankar layer in the imperfectly lithified dunes.

Bridgewater Formation at Bats Ridge is a well sorted, fine to medium grained bioclastic carbonate sandstone which is commonly laminated and characterised by large scale dune crossbedding. It is variably cemented by calcite as a meniscus cement, the kankar layer being somewhat more cemented than the underlying limestone. Even so, the cementation is relatively low when compared to Palaeozoic limestones of Eastern Victoria, and the rocks can be regarded as only partially lithified with high primary porosity and high permeability. Bridgewater Formation has a chemically variable composition ranging between 73.8% and 92.7% $CaCO_3$ at Bats Ridge, with 1.5% to 17.0% insoluble residues. Comparison to other published data (Coulson, 1940) indicate that this area contains more soluble material than other areas of Bridgewater Formation.

The dune ridges are thought to have been deposited during the early Pleistocene (Kenley, 1971) and the caves are thought to be initially excavated during the mid Pleistocene during times of higher sea levels and therefore higher water tables. However this must have taken place in rocks which are not well lithified. The presence of a better cemented, relatively hard kankar or caprock layer in the dunes is important.

Measures of rock strength of both the more indurated caprock and the softer less indurated layer have been taken and compared to the chemical composition and position in the dune, and other published data (Day, 1981). The variable cementation of the caprock shows that although it is harder and has more compressive strength, it is still a relatively soft rock with high primary porosity and high permeability, factors which are important for the development of cave systems.

Cementation of such dunes is controlled by the rate of percolation and runoff of water and the availability of CO_2 and the partial gaseous pressure of CO_2. The lithification processes involving limestone solution by CO2 enriched percolating waters and the redeposition of low Mg calcite has resulted in this caprock which is necessary for the strength of cave roofs to resist immediate collapse.

Karst development on this aeolianite ridge is dependent on the lithological conditions such as the purity of the limestone, its porosity and its ability to support a cavity as well as the availability of aggressive water capable of solution. There is insufficient time for diagenesis to have occured prior to major solution, so the solutional features have formed simultaneously to the cementation and diagenesis of the limestone dunes.

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WATER-FILLED KARST FEATURES OF THE LOWER SOUTH EAST OF SOUTH AUSTRALIA

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ABSTRACT

The Lower South-East of South Australia is well known for its volcanic craters and lakes, as well as its extensive karstlands. Previous studies of the karst features of the area have tended to describe only one type of water-filled karst feature - the cenote. Cenotes are defined as collapse dolines, which usually extend below the water table, are circular in shape and, have steep vertical or near-vertical walls (Bogli, 1980; Monroe, 1972). The distribution of the major cenotes in the South East are shown in Figure One. Similar features have been described in the Yucatan and Florida Peninsulas, Turkey and the Nullarbor.

Not all the water-filled karst features in the South East conform to the definition of a cenote. At least 14 sites exist along the southern coastline (Figure One), which possess a morphology indicative of solution rather than collapse. Typically, these features have gently sloping concave walls, are fed by sublacustrine springs and, are surrounded by karst fens. Thus, the term "karst spring lake" has been adopted by the author to differentiate a second type of water-filled karst depression.

Previous studies of the karst landforms of the South East have tended not to recognise the existance of the karst spring lake, but have instead labelled such sites as "drowned cenotes" (e.g. Marker,1976). The purpose of this paper therefore, is to describe the water-filled karst depressions of the South East in some detail and, to differentiate between the cenote and the spring lake. A disscussion of the geomorphological origins of both of these landforms will also be outlined.

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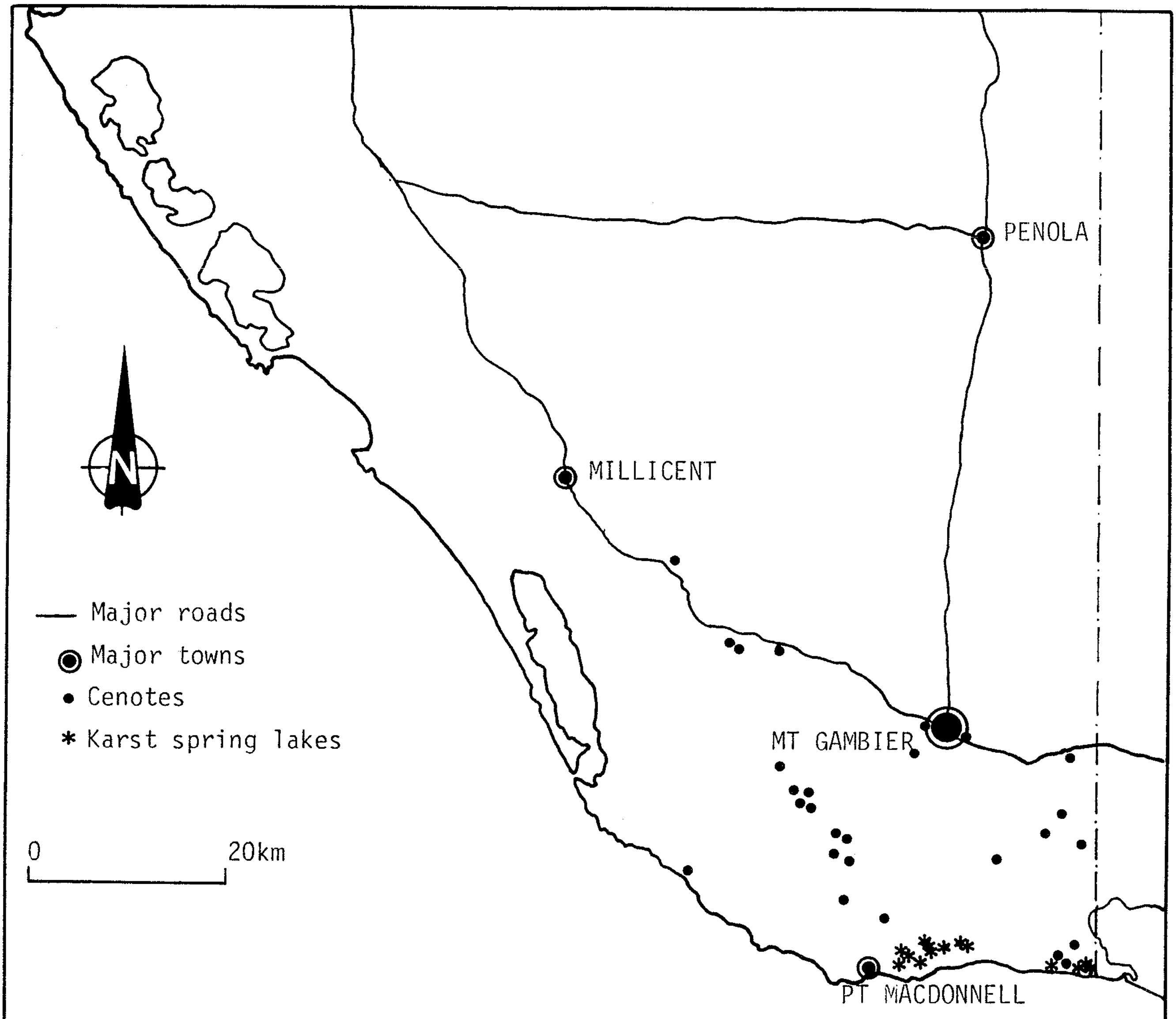

FIGURE ONE : DISTRIBUTION OF CENOTES AND KARST SPRING LAKES IN THE LOWER SOUTH EAST OF SOUTH AUSTRALIA.

SOME OBSERVATIONS ON RIMSTONE DAM GENESIS

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ABSTRACT

Rimstone dams and gours from the Buchan Caves, East Gippsland, Australia, have been investigated in order to evaluate the mechanisms controlling their formation. Surveys of the morphology of gours were made in Fairy Cave, Royal Cave and Federal Cave, and included length, width, depth and inclination of the cave floor on which they were developed.

It was found that the inclination of the cave floor is not important for the initiation of gours, even though it can affect their size. The preexistence of irregularities in the floor is not crucial but is a favourable precondition for gour development.

A preliminary theory concerning rimstone dam and gour development is proposed in this paper, in conjunction with survey data and some field observations which suggest that the tendency of crystallites to coalesce and the intermittent flow inside gours are two major factors pertinent to the rim development.

Abstract for Fourth Conference of the Australian and New Zealand Geomorphology Group, held at Buchan, Victoria, 6-10 February, 1989.

Weathering features on limestones of the Buchan area, Victoria, Australia: variations with rock type, within and beneath soil cover, and on bare rock.

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Several major rock types can be mapped within the limestones of the Buchan area. Each rock type has distinctive landforms and slope morphology, and generally a distinctive soil cover, varying from Terra Rossa to darker Rendzina-type soil.

In many parts of the area, soil cover is irregular, and red-stained limestone outcrops showing only minor solutional features appear to mark recently stripped areas.

With time the exposed rock surface develops minor solutional features, including pitting and solutional flutes, and these can often be correlated with rock type.

Within some deeper soils, detached pieces of limestone, or "clints", develop sharpened and bevelled edges, giving unusual and distinctive shapes. These clints may occasionally be observed in position in the soil, e.g. in road cuttings. Removal of the soil by erosion leads to accumulation of these clints on the exposed limestone surface.

The accumulation of clints, and progressive changes in sub-aerial weathering of exposed limestone surfaces, may be useful parameters for the study of rates of soil erosion in the Buchan area.

28/10/88

Longterm landscape evolution: interpretations from Buchan, East Gippsland

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Broad scale surface landform development in the Buchan valley has been largely determined by structure and the lithologies the Buchan River has had to erode. The river emerges from a narrow V-shaped valley cut into the resistant Snowy River Volcanics and enters the more easily eroded Buchan Group. Here lateral erosion has outstripped vertical erosion resulting in the formation of a broad valley. The local baselevel for this valley is provided by the Snowy River Volcanics downstream of the Buchan Group. The formation of the valley and the excellent preservation of terraces in it is directly related to the slower incision of this baselevel.

The caves at Buchan can be separated into two broad groups on the basis of their topographic location, morphology and age. These three criteria are interrelated, as the oldest caves consist of phreatic networks situated high above present baselevel. They were formed under a broad valley which traversed the limestone area from north to south during the early Tertiary and represent the first group. Eocene basalt flows disrupted the drainage north and west of the Buchan area at around 42 Ma. The phreatic caves are thought to predate this disruption. Lowering of the local baselevel by subsequently developed drainage networks led minor to vadose modification and eventual draining of the phreatic caves.

The second group consists of extensive epiphreatic caves which have been cut through existing phreatic caves located at lower elevations. One U/Th date has been obtained from the lowest level in one of these caves giving an age of 99 Ka. It is these epiphreatic caves which provide more detailed information about landscape development in the area.

The development of the Buchan valley and the epiphreatic caves within it provides an extensive record of periods of erosion, stillstand and deposition which is not found in non-karst areas. Correlations between the surface and subsurface features is possible. This and the length of record available allows for more detailed interpretation of landscape development for this area and possibly for the southeastern highlands in general.

ABSTRACT

DATING TECHNIQUES WORKSHOP

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In order of increasing time range, radiometric dating techniques useful in geomorphology include Cs-137 (40 years range), Pb-210 (150 years), C-14 (50ka), U-series (1 my), ESR and TL (1 my), and long-range methods widely used in geology such as k-Ar. These provide continuous time scales. A discontinuous scale with well established horizons is provided by the geomagnetic reversal chronology. Other radiometric methods under development, using accelerator mass spectrometry (AMS), include Cl-137 (1.5 my) and Be-10 (10 my).

Each technique is applicable to particular types of materials, and each is most reliable with a smaller subset of materials. Precision depends strongly on geochemistry and physical state of samples in each case, and the achievable time range often is substantially less than the general range for the method. Measurement technique also affects achievable range. This contribution to the workshop deals with these matters, with particular reference to C-14, U-series, certain aspects of ESR, and certain applications of AMS. Alternative laboratory techniques in each case are reviewed, as are limitations of widely-used sample materials.

RELATIVE INSTABILITY OF COLLUVIUM-FILLED BEDROCK DEPRESSIONS

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ABSTRACT

Regolith landslides are commonly found to be located in colluvium-filled bedrock depressions (CBDs). The conventional explanation for this preference relates to the ability of these sites to concentrate shallow groundwater and develop positive porewater pressures (Dietrich and Dorn, 1984; Reneau et al. 1984). However, observations indicate that this mechanism does not provide a sufficient explanation for the relative instability of CBDs compared to surrounding terrain.

A more satisfactory explanation is achieved by invoking the concept of critical depth. Depth becomes a limiting factor for stability if the material possesses cohesive strength. By employing infinite limiting equilibrium analysis and assuming the water table reaches the surface, critical depth can be derived as follows (Crozier, 1986):

$$Zc = \frac{\dfrac{C' \sec^2 \beta}{\alpha}}{\tan\beta - \dfrac{(\alpha - \alpha w)}{\alpha} . \tan \varphi}$$

Where: C' is effective cohesion
φ is the angle of internal friction
β is the angle of the shear plane
α is the bulk density
αw is the unit weight of water

Strength parameters determined from drained direct shear tests (Table 1) can be employed in this equation to determine critical depth at given slope angles.

Table 1 Shear Test Results

Location		φ'p	φ'r	C'p	C'r	Strain rate mm/min
		(degrees)		(kPa)		
Interdepression		32		8		6.0
CBD	Kelburn	40	39	1.3	0	0.06
CBD	Makara (1.2m)	37	32	2.4	4.4	0.06
CBD	Makara (0.5m)	44	35	1.2	4.6	0.06

p = peak r = residual

When these are compared with field conditions (Fig. 1) most CBDs are close to or exceed critical depth and all interdepression regolith is not thick enough to become unstable. It appears that the relative instability of CBDs is a function of the depth of accumulated colluvium.

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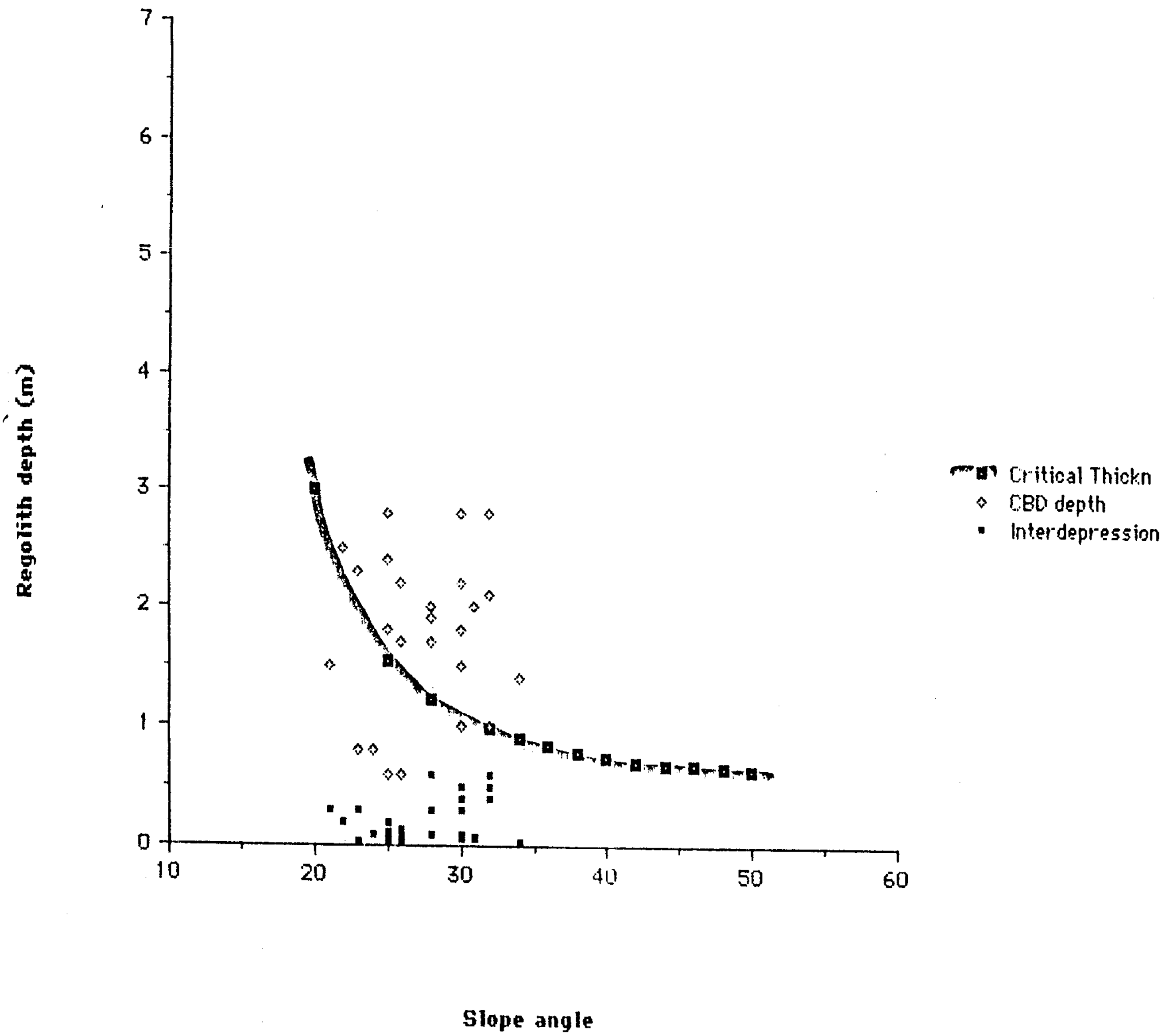
Fig 1 Regolith thickness vs. slope angle (Belmont)



DEVELOPMENT OF THE HIGH-LEVEL GLACIERIZED LANDSCAPE, McMURDO DRY VALLEYS, ANTARCTICA

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ABSTRACT

The McMurdo Dry Valley landscape developed under a temperate glacial regime, and has been essentially ice-free since the Pliocene. Considerable subaerial modification of the slopes has occured, much of which has been attributed to salt weathering and the progressive development of Richter denudation slopes (Selby, 1974).

The rock mass strength (RMS) classification of Selby (1980) was applied to the interpretation of the development of some high-level erosional landforms in the Dry Valleys. Two and three layered finite element models were developed to enable the study of stresses and displacements in the erosional landform remanents as they deformed under their own weight.

The McMurdo Dry Valley landscape preserves remanent features of Miocene glacial erosion, although the details of the present morphology are dominated by subaerial erosion and stress-relief induced erosion effects. The release of residual and overburden-induced stresses is indicated by the pervasiveness of sheeting joints. The in situ rock stresses contribute to rock weakening, enhancing rock slope failure and erosion. Significant differences in rock strength were found between the slope forming units. However, the RMS properties of the slope rock control the final slope form and future directions of erosion.

Thus, many of the Dry Valley landform no longer owe their detailed morphology to glacial erosion. This suggests that care must be taken when attemting to interprete the high-level erosional morphology as evidence of Miocene Ice-Sheet overriding, as was done by Denton et al. (1984).

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AN EXPLORATION OF THE EQUILIBRIUM CONCEPT: THE EXAMPLE OF ABANDONED CLIFFS ON BANKS PENINSULA

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ABSTRACT

As part of a 3rd year geomorphology course profiles were surveyed along a sequence of basalt cliffs ranging in age from 0 to about 7 000 years, with the object of identifying changes with time since abandonment by the sea, and if possible establishing a relaxation curve. As a teaching exercise the project was very successful; however, the large number of sources of error made the contribution to knowledge less convincing than might have been expected. Nevertheless a relationship between change of cliff form and time was determined. This involved much consideration of definitions, and a conclusion that it is doubtful whether the conditions for establishment of a relaxation curve in hard rock could ever be met in this geographic location.

SOIL CREEP: PROBLEMS RAISED BY A RECENT STUDY IN AUSTRALIA

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ABSTRACT

In October 1965 and February 1966, 55 Young-pits were installed in tropical Northern Territory (NT) and temperate New South Wales (NSW). Pits were monitored in 1968, 1971, 1974 and 1988 (NT only). In each region, half of the pits are on weathered granite, and half on sandstone. Local relief is 30 m or less, and slopes are up to 20°. Annual rainfall is evenly distributed in the NSW sites (800 mm yr^{-1}), but is confined to the 5-month wet season in NT (1200 mm yr^{-1}).

Analysis of 160 rods in 49 undisturbed pits shows:

(1) vectorial movement generally not downslope parallel to the ground surface, but dominated by a vertically downward component;

(2) significant uphill and vertically upward components of movement for many rods;

(3) a weak correlation between total movement and sine of slope;

(4) rapid movement during 1965-68, and slow movement thereafter;

(5) significantly higher creep rates on the NT granites than on all other sites, perhaps because mound-building termites and burrowing marsupials are especially active there.

(6) The 1988 observations in Northern Territory are not yet fully analysed. Provisional data indicate continued widespread bioturbation on the granite slopes, and low overall rates of rod movement during 1974-1988 relative to 1965-1974.

We conclude that creep models which assume that all movement is downslope and slope-parallel may need revision, and stress that repeated long-term measurements are essential to distinguish long-term creep rates from short-term disturbance effects.

LAKE SEGMENTATION AND LUNETTE INITIATION

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ABSTRACT

The creation and segmentation of dune lakes, and the associated development of lunettes, is occurring at the present time in the Olive River dune field of northeastern Australia. It is thus possible to observe a number of intermediate steps in this process which offer clues to the processes responsible. The environment is humid tropical, characterised by strong, persistent, uni-directional winds. The oscillatory motion due to surface waves induces oscillatory motion of bottom sediments when the shear stresses exceed the critical shear stress for the sediment. Net drift of the sediment in the direction of the waves then results due to the mass transport velocity. The resultant ripples migrate in the direction of the waves with the faster moving ripples catching up with the slower moving ones to, ultimately, form an emergent shoal. Further accretion to this shoal forms a partial barrier across the lake. Lake segmentation occurs following barrier formation and sand lunettes form on the barriers, further separating the lakes.

A variety of other lunette stratigraphies have been reported. In many of these a sand core with a clay drape is common. Examination of the process of lake formation suggests that some lunettes with sand or gravel cores form as a consequence of lake basin evolution. A five stage model of lake-lunette co-evolution is proposed (figure 1). Field checking of stages III to V of the model on the Lake Victoria, NSW, lunette and the checking of stages I and II on features in Lake George, NSW, showed strong support for the model and confirmed that some features previously ascribed to shoreline processes have formed sub-aqueously as predicted by the model.

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DIAGRAMS

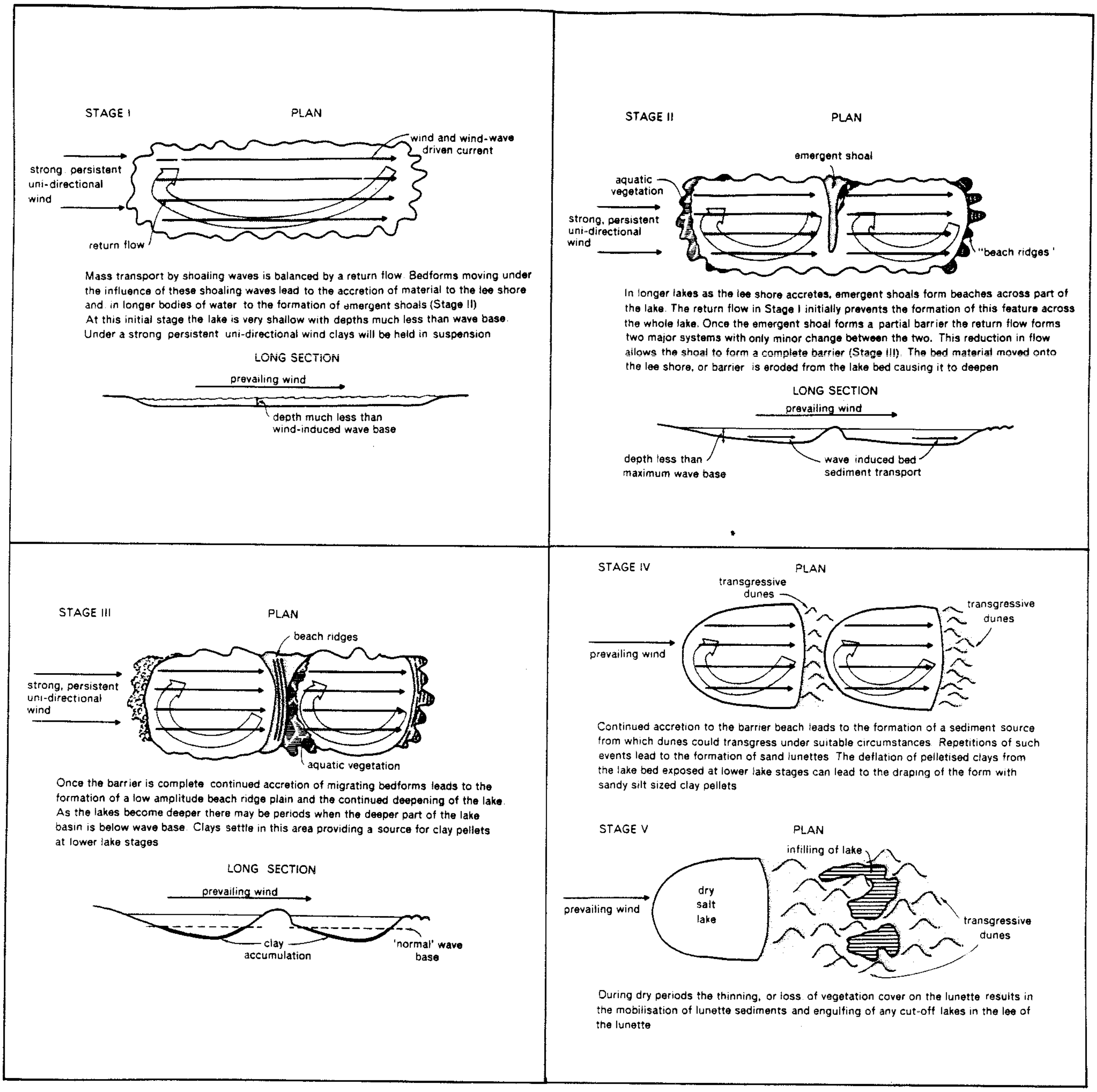

Figure 1; Simplified model of the co-evolution of lakes and lunettes based on the lake segmentation and lunette initiation model of Lees (in press). If the lake is initially short, then segmentation will not occur and bedforms will migrate to the lee shore. The environmental conditions prevailing during stages I and II are (a) a strong, persistent, uni-directional wind and (b) lake full conditions. It must be emphasised that water level fluctuations are not required by the model at this stage, if they do occur the model is robust enough to cope with them. At stage III either a variation over time in wind strength or water depth is necessary for clay accumulation.

N.S.W. BEACHES - SCIENCE, SURF AND SAFETY

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The 1740 km long N.S.W coast contains 550 beaches which occupy 67% of the coast. The scientific understanding of the behaviour of these beaches has been greatly enhanced by the recent development of a globally applicable 'beach model' based on research on S.E.Australian beach systems. The scientific knowledge of beaches has however lagged considerably behind their public use. The public use unfortunately proceeding in often blissful ignorance of surfzone dynamics has resulted in several thousand surf rescues being performed each year and the construction of 124 surf clubs along the coast. In an effort to bridge the gap between beach science and beach safety the N.S.W. Beach Safety Program was launched in October 1988. The program is a cooperative venture between the Coastal Studies Unit, the N.S.W. Surf Life Saving Association, the Department of Sport, Recreation and Planning and the Australian Beach Inspector-Lifeguard Association. Its aims are to enhance our scientific knowledge of all N.S.W. beaches and circumstances of all rescues and use this information to both assist beach management and resuce procedures as well as improve and expand public education on beach safety. Information for the program will be derived from existing aerial photographs, literature and site investigations, together with input from all cooperating agencies including the Public Works Department (online wave rider data), all surf clubs, all 28 coastal shire councils and lifeguards, all coastal National Parks and State Recreation Reserve officers, and amateur and professional boardriding associations. Information will be stored in a textural-graphics data base and results will be designed to best suit the needs of each beach and each of the above organisations.

This paper will address some of the more scientific aspects of the program as well as the mechanism for converting science/geomorphology into publically useful information.

ABSTRACT

THE EFFECT OF SEA LEVEL RISE AND SEDIMENT INPUTS ON LOWLAND FLOODPLAINS

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Sedimentation and dynamics of lowland basins and floodplains are sensitive to sea level changes. Their response to post-glacial sea level rise is preserved stratigraphically. This provides a basis for testing models of the effects of anticipated future sea level rise. Effects of sediment inputs can be assessed by comparative Holocene studies from several basins.

With rising sea level, principal mechanisms of change are (i) increased frequency of flooding, and (ii) changes of channel dimensions, which is particularly important in tidally-influenced systems. Least-affected areas are those where sedimentation keeps pace with rising sea level. The distribution of such areas within a given river system depends on sediment inputs including those from fluvial and marine sources. An additional source is sediment mobilised by widening of tidal rivers, which can occur as the tidal prism increases with tidal flooding. We present a simple model which predicts patterns of sedimentation as a function of tidal and fluvial parameters and sediment inputs.

The model is tested using present-day process data and Holocene stratigraphic information from several tidal river and floodplain systems. For systems with strong tides and small fluvial sediment inputs (eg in northern Australia) we predict that estuarine floodplains can keep pace with rising sea level, once they become tidally flooded. We also predict that sedimentation keeps pace more readily nearer the coast then the tidal limit, and that there is a lag between the onset of tidal flooding and dynamic adjustment of the system. Sedimentation patterns and relative duration of the lag are a function of tidal parameters. We support these predictions with data from the South Alligator and Norman rivers and examine application of the model to other cases.

GEOMORPHIC ZONATION IN AN EVOLVING ESTUARY-PROCESS IMPLICATIONS

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INTRODUCTION

The evolutionary model for drowned river valley estuaries proposed by Roy(1984) has been largely determined from sedimentological and stratigraphic studies of selected NSW estuaries. Process variations are usually inferred from sedimentological evidence with the bulk of available process information being restricted to estuarine entrance studies (Wright,1977, Nielsen and Gordon, 1981, PWD,1983). While the mechanisms for estuarine infill from fluvial and marine sediment sources have been generally understood for some time (Bird,1967, Jennings and Bird,1967), documentation of the processes involved has lagged the conceptual models. This study has focused on the processes operating in identifiable morphologic zones during periods of high fluvial discharge and tidal domination of estuarine circulation. Morphodynamic relationships and the existence of thresholds separating estuarine segments have been examined to explain the nature of estuarine evolution and the pattern of stability/instability under different process regimes.

METHODOLOGY

Bathymetric and morphologic surveys were used to determine the major geomorphic components and sediment collection and analysis outlined the sedimentary environments and boundaries. The bulk of the field programme involved the collection and analysis of hydrodynamic data under varying tidal and fluvial conditions to obtain representative patterns of fluvial/tidal interaction over as wide a range of conditions as possible. The installation of four Aanderaa recording meters at different locations along the estuary for a period of five weeks provided data on salinity, temperature and current velocity and direction at 10 minute intervals, 1 metre above the channel bed. These data were used to calculate near-bottom fluid power and potential transport gradients. In combination with the hydrodynamic patterns evidenced by insitu profiling, the work gradients at the channel boundary provided information as to the importance of the hydrodynamic factors to the potential sediment movement and the contemporary pattern of evolution of the estuary.

RESULTS

Three distinct morpho-sedimentary environments were identified:

1. Mud basin
2. Fluvial delta
3. Tidal river channel

The morphodynamic processes in the estuary are directly related to the interaction of the tides and fluvial flows with the existing morphological features. The fluvial delta region is the most dynamic of the three zones since it is subject to an injection of sediment during river floods and effective tidal velocities during periods where tides dominate the estuarine circulation. Morphodynamic adjustments are most evident in this zone, while the tidal river channel remains river dominated and the mud basin tide dominated in the longer term. The transition areas between the zones exhibit morphodynamic thresholds which reinforce the morpho-sedimentary zonation within the estuary. Subsequent studies in other estuaries have indicated that similar patterns exist and that such conceptual or process models are useful in conjuction with mathematical modelling especially in initial model construction and the evaluation of predictions of the numerical model.

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Late Quaternary coastal landforms along the Illawarra, N.S.W. Coastline

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Along the Southeast corner of Australia there exists Late Pleistocene coastal deposits from the Last Interglacial ~125,000 years B.P or older. Barrier dune deposits extend continuously back through the Quaternary in the Gippsland basin of Victoria, are present for at least the last 2 interglacials in northeast Tasmania (Bowden and Colhoun, 1984), and represent most of the Pleistocene in South Australia (Schwebel, 1984). In New South Wales, only Last Interglacial deposits appear to be present and then only north of Newcastle. Along the south coast of New South Wales, Last Interglacial deposits have always been perceived as missing, with sediments swept north along the shelf over successive phases of sea-level oscillations in the Late Quaternary (Roy and Thom, 1981). Extensive field reconnaissance of coastal landforms in the Wollongong-South coast region of N.S.W. indicates that this view is overly simplistic and that Last Interglacial aeolian deposits and raised platforms are preserved in certain settings.

We have 3 lines of evidence for believing this. Firstly, we have identified the presence of cliff top dune deposits at Red and Fisherman Points that give Thermoluminescence dates up to 275,000 years older than the Last Interglacial (Table 1). Similar types of deposits appear to be present on other headlands in the area. Further dating is required to ascertain whether or not these deposits were formed at times of interglacials.

Secondly, we have also identified well developed raised platforms on larger headlands between Stanwell Park and the Shoalhaven River. On Red and Bass Points, these platforms are stratigraphically associated with clifftop aeolian sediments. These platforms are twice as large as modern day platforms, evidence 2-3m high, 20m wide drainage channels on the landward end suggestive of a northeasterly wave approach, and appear at a common 5-7m height above existing sea-level. This elevation is in agreement with heights for platforms found along the west Victorian coastline and dated as Last Interglacial (Gill, 1972). Uranium-Thorium dating of crystalline iron derived from terrestrial groundwater and deposited on Illawarra platform surfaces within 2 meters of existing high tide, indicates that platforms, considered to be modern, are pre-Holocene and relict from a previous higher sea-level (Table 1). The mapping of platform morphology presents a unique opportunity for defining weather and wave conditions that affected the New South Wales coastline during the Last Interglacial. This wave climate contained higher wave energys than those presently affecting the coast and was most likely generated by the more frequent southward passage of tropical cyclones. There is even evidence from one U-Th date of 347ka years from a siliceous crust on Red Point that some platform surfaces were formed even further back into the Quaternary.

Finally, Roy and Peat (1976) have identified several separate layers of Late Pleistocene marine and estuarine sediment under Lake Illawarra and Lake Macquarie. We believe that these sediments represent the estuarine equivalent of interglacial dune sediments deposited on adjacent headlands along this coast.

Table 1 Thermoluminescence and U-Th dates from aeolian coastal dunes and raised platforms

REF	Date	Limits	Method	Location	Comment
1	290ka	±85ka	TL	Red Point dune N.	carbonate enriched surface layer 1-2m thick
2	>399	±66ka	TL	"	sand underlying sample 1
3	45.5ka	±10ka	TL	Red Point dune S.	overlaps western side of sample 1
4	240ka	±70ka	TL	Fisherman Pt. dune	on headland 1km north of sample 1, in 2-3m thick humate rich horizon, 3-4m below the surface
5	9.2ka	+2.3ka -2.4ka	U-Th	Wombarra, Wollongong	iron crust in crevice on rock platform 2m above HT
6	– ±3σ	<46ka >20ka	U-Th	Bulli Point	iron crust on platform remnant 2m above high tide
7	347ka	+∞ -47ka	U-Th	Red Point	siliceous crust on raised rock platform

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DYNAMICS AND GEOMORPHOLOGY OF A TROUGH BLOWOUT

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The dynamics, sand transport, morphology and evolution of a small trough blowout is examined. Trough blowouts are narrow, deep, elongate erosional hollows which commonly occur within established foredunes along the east Australian coast. Analysis of the aerodynamics of one such blowout utilising an array of Rimco miniature cup anemometers shows that the surface and near-surface wind flow is dominated by high-speed jets within the entrance and throat region, and rapidly decelerating expanding flow in the downwind depositional lobe region. For transverse approach winds, the jet flows operate to erode sediment from the throat base and lateral walls, and this sediment is deposited in a symmetrical, arcuate lobe within the leeward deceleration zone. Jet flows are highest down the blowout centreline axis and decelerate in a Gaussian fashion laterally. Thus deflation basins formed in the throat region are ovoid and concave, and depositional lobes parabolic in shape. Oblique approach flows result in erosion of the facing lateral wall, 70-90° deflection of the flow by the wall and flow escape over the adjacent lobe section.

Medium-term observations indicate that blowout expansion occurs via lateral wall deflation and wall slumping. Blowout extension takes place via throat basin deflation and erosion of depositional lobe windward faces. The implications for equilibrium development and the long term evolution of blowouts is examined.

DUNEFIELD STRATIGRAPHY OF GROOTE EYLANDT

by

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Groote Eylandt is a large island, circa 5,000 sq km., in the western Gulf of Carpentaria. It is situatated at 14°S 136°40'E in the North Australian Monsoon belt. A location map is displayed in Figure 1. The Quaternary history of the island is poorly understood, though some geomorphological work has been carried out in the heavy mineral analyses of coastal sands (Roarty,1976). Extensive investigation of the hardrock geology has been carried out because of the presence of a substantial Manganese deposit (Slee,1980; Bolton and Frakes, in press).

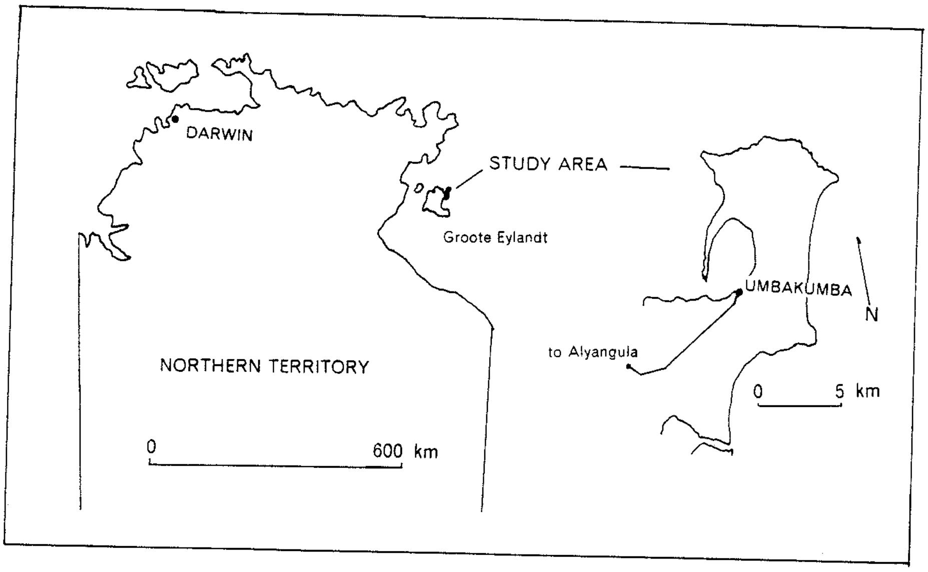

Figure 1. Location Map.

The Quaternary environmental history of Groote Eylandt is investigated in this project. It involves multidisciplinary studies of a dunefield in the northeastern corner of the island and biostratigraphical analyses of an adjoining lake. It is expected to generate a detailed lithostratigraphy for the dunefield, identifing periods of dunefield activation and / or emplacement, and to relate these to an analytical pollen record from the lake. Dating control will be provided by coarse fraction thermoluminescence dating in the dunefield and C^{14} dating from lake sediments and other suitable environments. The dunefield stratigraphy presented here provides the contextual framework for future work.

Examination of the dunefield has resulted in the identification of five major horizons. At no site, however, are all five events represented. Two geographically separate stratigraphies are constructed. These stratigraphies can be shown to correlate with considerable confidence. The first of these is an horizontal stratigraphy stretching from the east coast as far as the main Umbakumba/Angurugu road and locally reaching the Umbakumba Lagoon (see figure 1). This stratigraphy is composed as follows;

Coastal System: An active series of blowout dunes are migrating off east facing beaches. These have penetrated up to two kilometers inland.

Deflation Surface: Behind the beach dunes in a discontinuous belt up to about 200m wide lies a deflation surface. This is composed of low angle tabular cross-stratified, slightly indurated red sands. This unit is providing the source material for the next system.

Draa System: A series of active draas up to 4km inland and up to 1 sq km in area. These are notable for their lack of vegetation and have dunes migrating over them. The draas are encroaching on an older series of dunes.

Uburamudja System I: This is a series of large (up to 3 km long, 30m high) stabilized elongate parabolics. These dunes display strong podsolization in the top 50 cm. The core of the system, however, is composed of low angle tabular cross-stratified red sands.

Uburamudja System II: This is the oldest series of dunes with surface expression. They are clearly overridden by Uburamurdja system I dunes near the Umbakumba road. Podsolization is indicated by strong A horizon development and the dunes have a pisolithic horizon starting at 4.9m depth.

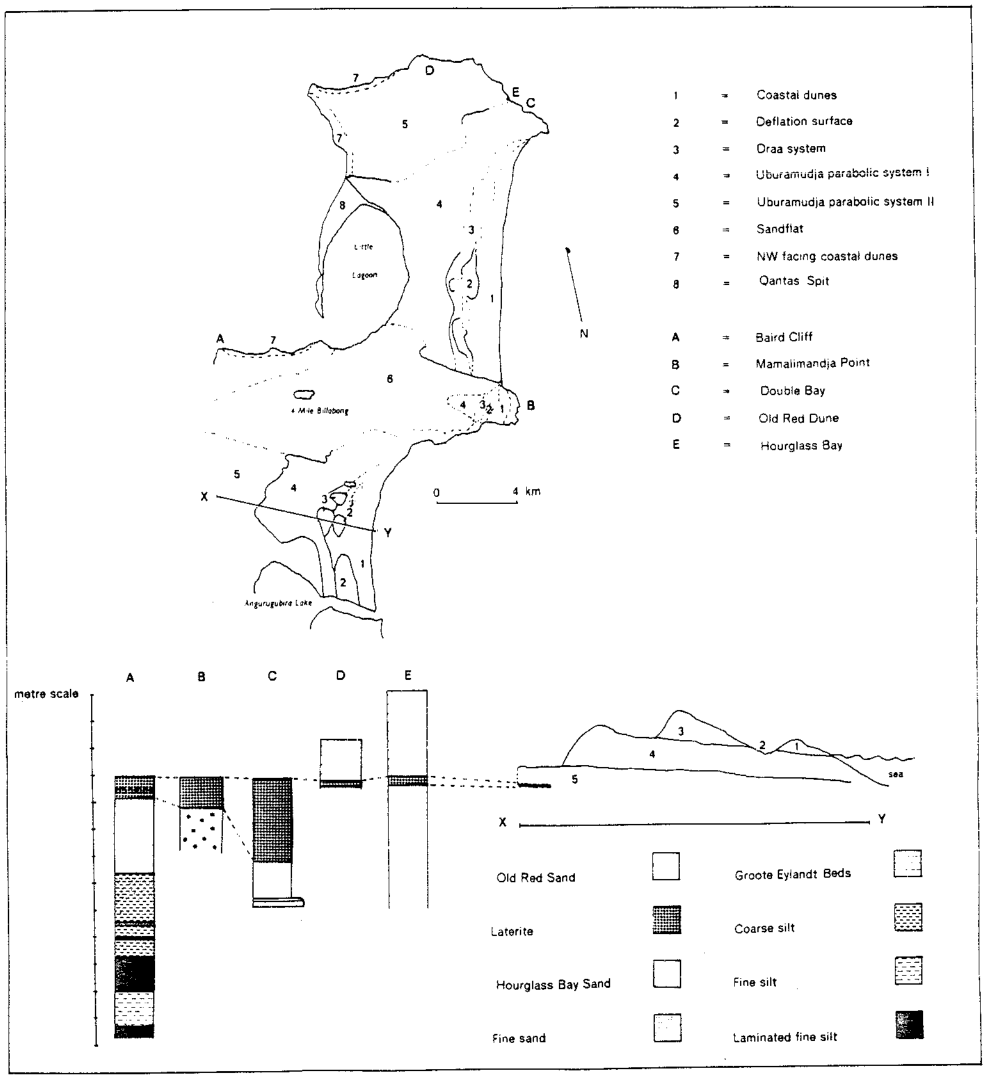

Figure 2. Stratigraphy of the Umbakumba Dunefield. The sections derived from five coastal exposures (bottom left) are integrated into the surface dune complex shown in cross-section (bottom right) and mapped above.

The horizontal stratigraphy is displayed in idealized form in Figure 2. The deflation surface is identified as part of the Uburumurdja I system and the Draa and coastal systems are combined as a modern active system. This gives a simplified stratigraphy as follows;

1. The modern coastal and Draa system.
2. The Uburumudja I system and
3. The Uburumudja II system.

The horizontal stratigraphy is replaced in the northern and western parts of the field area by a vertical stratigraphy exposed in coastal sections. As these sites are distal to the modern sediment source, the sections lack a modern dune cover, but at least two dune sands and a laterite horizon are represented. There are many coastal exposures but the best sections are at Baird Cliff and Hourglass Bay (Figure 2). The idealized stratigraphy, from youngest to oldest, is;

Old Red Sand Unit: A surface unit of low angle tabular cross-stratified sand. This sand is strongly indurated and displays a classical dune sedimentology. Maximum exposures are up to 15m deep.

Laterite Horizon: A laterite horizon ranging from 0.30m to 2.00m in thickness, is extremely extensive along the coast and always underlies the red sand (where present).

Hourglass Bay Sand Unit: A fine white, possibly aeolian and underlies the laterite at several sites. This may be pisolithic (Mamalimandja Point, Baird Cliffs) or homogenous (Hourglass Bay). This unit in extremely indurated. The maximum exposure of this unit at Houglass Bay is 4m.

Bedrock: The underlying bedrock over most of the field area is Proterozoic sandstone of the Groote Eylandt Beds though Cretaceous Marine silts and fine sands outcrop in the Baird Cliffs.

Linking the Stratigraphies: The Old Red Sand Unit of the vertical profile is tentatively identified as the same unit as the Uburumudja II system. This is proposed on the basis that;

1. Both are composed of a fine red aeolian sand.
2. Where present as a dune in coastal sections, the Old Red Sands trend E.S.E. to W.N.W. as do the dunes of the Uburumudja System but not the other systems.
3. Like the Uburumudja II system the Old Red Sand is underlain by a pisolithic laterite.

On this basis an integrated dunefield stratigraphy is proposed.

1. The Modern Coastal and Draa Systems.
2. The Uburumudja I System.
3. The Uburumudja II / Old Red Sand System
4. The Laterite Horizon
5. The Hourglass Bay Sand System.

Samples for TL dating have been recovered from several sites in the Uburumudja I, II, and Hourglass Bay Sand Systems. The laterite is unsuitable for dating and the active Systems are too young for this technique. If dates in the Old Red Sand prove to be comparable to those from the Uburumudja II System, the stratigraphy will be confirmed.

The assumptions involved in generating the stratigraphy are firstly that significant episodes of activity can be identified across a dunefield. This is not a problem in this dunefield as many units are very extensive. The laterite horizon in particular is traceable for over 10km on the north coast. A second assumption that is inferred in all stratigraphical investigations but causes particular problems in dunefields is the question whether real events on the dunefield are applicable to the more general environment. Dunes are particularily vulnerable to disturbance, which may not be siginificant in even a local context. It is hoped that the integration of biostratigraphical data from the adjacent lake will minimise this problem.

This stratigraphical work has provided the context for the further studies and it is hoped that an integrated and detailed Quaternary record will emerge from Groote Eylandt over the next few years.

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Dust Accession onto Australian Soils: A Review

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The importance of aeolian dust processes and their sediments in the evolution of the Australian landscape during the Quaternary has been recently described (McTainsh,1988). What effect has this aeolian dust accession had on the soils of Australia? Most "modern" Australian soils are over 20 000 years old and have been in receipt of varying amounts and contrasting types of aeolian dust during this time.

Accession rates and the character of aeolian dust have varied through time: there is clear evidence of periodicity in the timing and amounts of aeolian material (Butler,1959); while the dust varies from being calcareous (Crocker,1946), to saline (Blackburn, 1980) or both. The widespread windblown clay deposits in the Murray Basin and the western foothills of the Eastern Highlands -termed Parna by Butler (1956) and Loessic Clay by Dare-Edwards (1984))- were transported into the area as silt-sized, saline, calcareous, subplastic clay pellets, in association with some mineral grains of the same size range. These windblown sediments are draped over the landscape as blanket which can be 2-3 metres thick.

The high levels of calcium and more importantly sodium ions in these loessic clay sheets (and dunes) will, we suggest, have had a significant effect upon soil development. Saline dust accession onto stable soil surfaces would modify pre-existing soils.The high sodium content would cause sodicity values to increase leading in turn to clay dispersion, formation of duplex profiles,and soil pippng. Perhaps the widespread nature of saline and sodic soils, as illustrated in the maps of Northcote and Skene (1972), are the result of aeolian sodium accession.

These ideas are not new: Downes(1957) suggested that soils of southern Australia, which are currently classed as podzolics, were actually formed by solonization. However, he proposed that the sodium ion was derived form cyclic salt dumped onto the area 5 000 years ago during the "Recent Arid"-a widely accepted arid phase in the literature of the 1940's (Crocker, 1946). Clearly, the salt accession mechanism (marine) and the dates (5 000 BP) are no longer tenable but the problem of explaining the high levels of sodicity and salinity in podzolic soils is still there. We suggest that saline aeolian dust was indeed the cause of the abnormal characters recognized by Downes. Only the mechanism and the timing are different.

The classic mechanism for the production of loessic clay dunes and sheets requires the presence of abundant sodium salts in specific environments in the landscape (Bowler,1973). Similarly, the timing of these events is related to discrete phases in the environmental history of southern Australia. (Bowler et al,1976). The extensive nature of the loessic clay sediments produced has been recorded by a number of workers (eg Jessup,1961; Chuchward,1963; Beattie,1972). Altogether this produces a scenario for salinization, followed by solonization, and even solodization in the soils of southern Australia. A pattern which has been recorded in detail at one major site on dunes of the Willandra Lakes, New South Wales (Dare-Edwards, 1979). In turn this sequence of events,which we suggest is widespread, should be incorporated into models for Australian pedogenesis

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EVOLUTION OF TERTIARY LANDSCAPES IN SOUTHEASTERN AUSTRALIA

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Extensive remnants of ancient landforms which are preserved under Tertiary basalts over some 1200 km of the highlands of Southeastern Australia provide a perspective on longterm denudation that is at odds with widely accepted models which have provided the basis not only for the interpretation of many landscapes, but also for numerous tectonic histories. Three fundamental tenets of those models are challenged. The first is that, given tectonic stability and adequate runoff, the passage of several millions of years will result in stream profiles declining in gradient and becoming increasingly independent of lithological constraints. The second is that general rates of erosion are such that 10 to 30 Ma are sufficient for an area of continental extent to be reduced to a surface of low relief. The third is that, apart from regional epeirogenic warping, landscapes of this age will be essentially the product of exogenetic rather than endogenetic processes, and that the effect of deep-seated crustal constraints on topography will have long ago been eliminated.

Detailed studies of the origin and dissection of landforms preserved beneath Eocene to Miocene basalts have demonstrated six fundamental morphological features (Young, 1977; Bishop et al., 1985; Bishop, 1988).

1. Landforms of this region cannot be explained simply in terms of cycles of erosion graded to migrating nickpoints initiated near sea level. Erosion has occurred simultaneously above and below nickpoints, and geological constraints are no less important than regional base levels.
2. Rather than showing evidence of longterm decline of gradients, modern stream profiles are roughly parallel to their Tertiary counterparts.
3. Local adjustment to variable lithology is as evident on modern channels as it is on Tertiary channels.
4. The amount of incision throughout drainage systems are more closely linked to variations in stream power than to any regional base level.
5. Despite the passage of 15 to 30 Ma the local relief in some large catchments has tended to remain static or increase, rather than decrease.
6. Drainage patterns have been remarkably stable over this period of time and show no evidence of largescale capture or derangement.

Despite substantial elevations (200-300m) and humid climates throughout much of the Tertiary, rates of erosion have been much slower than the modal rates cited in most textbooks (Young, 1983; Young and McDougall, 1985; Bishop et al., 1985).

1. The large coastal escarpment south of Sydney has retreated at an average rate of about 170m/Ma.
2. Sandstone cliffs in upland valleys have retreated at rates ranging from about 10 to 25m/Ma.
3. Stream incision in upland valleys(Shoalhaven, Lachlan, Murrumbidgee, Hunter, Murray) on varied lithologies has ranged from about 4 to 12m/Ma.
4. The most prominent erosion has been caused by the headward extension of deep canyons below the upland surfaces, but even there rates have been slow. The 600m Shoalhaven canyon, for example, has retreated at less than 5Km/Ma and its mean cross-sectional depth gives a rate of only 10m/Ma of denudation.

So far from being reduced to planation surfaces in 10 to 20 Ma these valleys have not even passed from one stage of the classical cycle to another. At these rates of erosion, probably more than 100Ma would be needed for planation, even without isostatic compensation.

Perhaps the most striking feature of the Eastern Highlands is that the position of the continental divide shows clear, though previously unrecognised, evidence of crustal constraint (Young, in press).

1. For 80% of the 3800 km between Melbourne and Cairns the divide follows the alignment of major negative Bouguer anomalies.
2. Regional Bouguer gravity patterns of this scale are dominated by the effect of the crustal root.
3. The origin of the gravity anomalies is the key to the drainage pattern. The competing theories are (a) crustal roots of Palaeozoic mountains that were deeply denuded and isostatically uplifted to form the modern highlands (b) igneous underplating caused by continental extension prior to the opening of the Tasman and Coral Seas at the end of the Mesozoic (c)igneous underplating of Early Tertiary age triggered by the opening of these seas. Whatever the case, the divide is clearly of great antiquity.

The evidence reviewed here supports and extends the reports of very slow rates of change from other cratonic areas, and certainly prompts caution against the uncritical application of traditional models of longterm landform evolution either locally or in intercontinental comparisons. Indeed, rather in searching for a generally applicable model, we should now recognise that there have been fundamental differences between landform evolution in the stable and in the mobile parts of the world.

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Age of the landforms or age of the highlands? - evidence from karsts, basalts and valley fills.

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Accurate dating of Tertiary basalt flows in the eastern highlands has led to often unfounded assumptions that the age of landforms in the vicinity of these flows are of a corresponding age (Young 1982). Other sources of evidence such as sub-basaltic landforms and palaeokarst features have all presented a *prima facie* case for the extreme antiquity of many southeast Australian landforms (Osborne 1984, Taylor *et al* 1985). However, independent dating of other features, particularly karst and younger basalt flows, often presents a picture of significant landforms of a much more recent origin superimposed on an ancient geomorphic pattern.

Dated cave sediments and interpretation of younger Plio/Pleistocene basalt flows indicate a much younger age for certain highlands valleys than has recently been proposed in the literature, with rates of erosion often an order of magnitude or more greater than those commonly accepted. Evidence suggests that constant downcutting of southeast highlands river valleys has been the exception, rather than the rule, throughout the late Tertiary and Quaternary. The effects of two major variables:

i) Rates of nickpoint retreat
ii) Effects of valley infilling by basalt, colluvium and alluvium

ensure that local changes in base level within catchments have exhibited great variability, the significance of which has in the past been underestimated by geomorphologists.

There is little doubt that the majority of southeast highlands rivers, from southern Tasmania to at least the Barrington Tops area, have been eroding in the sense of a series of nickpoint retreats, as opposed to constant incision, throughout the long profiles of streams. Bishop (1987) found the majority of highland rivers to be significantly oversteepened at present in their lower reaches, or on the highlands margin. This fits well with Ollier's (1982) Great Escarpment model, and is equally applicable in the highly dissected Victorian Highlands as the in places comparatively less dissected Tasmanian and SE NSW Highlands.

Ages of significant landforms are, therefore, determined by the passage of a nickpoint through a study area, its timing and intensity, rather than by assumed constant incision rates. Nickpoint retreat is controlled by two factors:

i) Tectonics
ii) Effects of valley fills.

Large scale tectonics, such as those invoked by researchers of the mode and timing of the initial uplift of the highlands (Lambeck & Stephenson 1986, Wellman 1979, 1987), rifting and the formation of the Great Escarpment (Ollier 1982), would set in motion retreat of large scale nickpoints. The filling of valleys either with basalt, alluvium or colluvium would have had the effect of temporarily perching local base levels; the incision of which would set in motion retreat of other nickpoints, their magnitude depending primarily on the depth of the initial fill.

The great depth of some valley flows of basalt, and also of alluvial/colluvial fills, ensure that landforms resulting from their incision are of a significant scale and, more importantly, not necessarily of great age. In the less incised valleys of the tablelands only a relatively shallow depth of fill would be necessary to completely mask pre-existing landforms and substitute a landsurface of considerably younger age.

Deep valleys such as those of the southern Blue Mountains, the southern Great Escarpment and to a lesser extent parts of the western incised zone, the Snowy Valley and many of the deeply incised river valleys of the eastern Victorian and Tasmanian highlands margins all show evidence of considerable valley filling by late Tertiary-Quaternary alluvium/colluvium. These are often related to large areas of outwash gravels such as the Pliocene Haunted Hills gravels in Victoria, gravels in the vicinity of the Snowy River floodplain, and glacial outwash in the Tasmanian Highlands valleys, often several hundred metres thick (Kiernan 1984).

In fact, the effects of valley filling on landforms in the Highlands are continuously greater towards the south. This is interpreted as evidence for a predominantly climatically controlled factor in the origin of these valley fills and their effects on surrounding landforms.

Incision rates, calculated by assuming constant downcutting of Tertiary basalt filled valleys, as compared with incision rates calculated by dating of karst features related to younger fills, and younger basalt flows (eg Gibbo R - Morass Ck) are shown in Fig 1. The apparent dichotomy between the two may possibly be explained by the effects of valley fills on stream profiles or the timing of nickpoint retreat. The younger ages and faster incision rates may be explained by the buffering effects of fills on incision.

There is a spectrum of ages for significant Highlands landforms, some possibly reaching back to the Early - Mid Tertiary, but they probably not as ubiquitous as we have recently thought. Landforms of a comparable scale may be very old or very young, or somewhere in between. Base levels may move *up* as well as *down* to a significant degree.

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Study area	Age of basalt (Ma) (Wellman et al 1974)	Average incision rate (mm/ka)	Dated site (Ka)	Incision rate from dated site (mm/Ka)	Difference in rate (X)
Judd's Cavern (Tas)			189+6-12 (U/Th)	106 max	
Kubla Khan Cave (Tas)	?		172±9 (U/Th)	190 max	
Exit Cave (Tas) (Goede et al 1983)			> 400 (U/Th)	63 max	
Sheehans Cave (NE Vic) Houshold (in prep)	?		29±.6 (14C)	~180	
Gibbo R - Morass Ck (NE Vic)	?		2200	~70	
Buchan (E. Vic)	22	12	?	?	
Mill Swallet Cave (S. NSW)	23	11	< 25	Present	
River Cave (S. NSW)	23	11	< 50	320 max	29
Castle Cave (Lower)(S.NSW)	23	11	< 50	700 max	63
Castle Cave (Upper)(S.NSW)	23	11	< 150	299 max	27
Jillabenan Cave (S.NSW)	23	11	> 700	120 min	11
Jersey Cave (S. NSW) Houshold et al (in prep)	23	11	< 700		
Punchbowl Cave (S. NSW) Schmidt et al (1984)	23	6	1200	~75	12.5
Bushrangers Cave			19.400 (14C	~315	98
			33.600 (14C	~181	56
Grove Cave			14.800 (14C	~171	53
Abercrombie Frank et al (1978)	19	3.2			
Arch Cave	11	1.7	27 (14C)	~370	217
Tunnel Cave Borenore (C.W. NSW) Frank (1972, 75)			27 (14C)	~160	94

Table 1. Incision rates from E. Highlands basalts and karsts

BASALT AND BULLDUST: SOILS AND LANDSCAPE EVOLUTION NEAR NIMMITABEL, SOUTHERN MONARO, NSW

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ABSTRACT

A significant proportion of the landscape on Monaro basalt in Southern NSW is a gently undulating upland at approximately 1000 m. South of Cooma, this upland forms a broad divide between rivers flowing to the east coast and those draining west to the riverine plains of the Murray-Darling Basin. Wellman & McDougall (1974) reported K/Ar ages on Monaro basalt of 36-54 Ma, and concluded that several volcanic episodes were involved. Taylor et al. (1985) reconstructed the pre-basaltic surface and proposed that the earlier drainage systems, along which the basalts flowed, were little different from the present, indicating prolonged tectonic and erosional stability of the divide since the basalts were erupted. Prolonged erosional stability of the upland on Monaro basalt south of Cooma is also evidence from the weak dissection of much of the landscape, and from the occurrence of numerous enclosed depressions and lakes, particularly west of Nimmitabel.

Despite the abundant evidence of prolonged landscape stability summarised above, the soils and weathered zones of the area are unexpectedly thin, and do not have properties consistent with prolonged Tertiary weathering and pedogenesis. In places, the thickness of weathered zones between basalt flows is greater than that at the present surface. Sediments of 31 small lakes west of Nimmitabel range in thickness from 0.4 to 3.7 m, with a mean of 1.6 m, which is much less than expected from the size of the lakes and their closure (up to 10 m from lake floor to lowest overflow point). Low depositional features associated with modern wind erosion have been documented on the eastern perimeter of some of the lakes by Pillans (1987). These are termed "lake shadows", and consist of clay pellets blown from the floors of the lakes during periods of drought. Lake shadows are morphologically distinguishable by their sheet-like character, in contrast to the dune form of lunettes which are generally absent in the Nimmitabel area.

We conclude that the Nimmitabel landscape is highly sensitive to climatic changes, and that much of the Tertiary soil cover on Monaro basalt was stripped by wind (and water) erosion during the Quaternary. As a result, the present soils and associated surficial deposits relate to Quaternary processes. These findings are consistent with Costin's (1954) interpretation that the modern soil cover in the area strongly reflects the modern climatic pattern.

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THE OLD MAN RANGE AND GARVIE MOUNTAINS, CENTRAL OTAGO, NEW ZEALAND: TECTONIC GEOMORPHOLOGY OF THE PENEPLAIN.

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The late Cenozoic tectonics and geomorphology of a 700 square kilometre area of remnant peneplain topography comprising the Old Man Range, Obelisk Range and Garvie Mountains, Central Otago, have been investigated. This study combined with existing data from Otago show that the peneplain was originally devoid of significant relief (maximum paleo-relief = 500m/10km, in west) and is underlain by a broadly low angle schistosity (c. 0-20°). Tertiary sediments in the area indicate that the peneplain surface has been vertically offset by up to c. 1500 metres. Quartzose Potters Gravels (new name) have a palynologically determined Waipipian maximum age, and were reworked from Manuherikia Group sediments during early uplift of the schist ranges.

Mapping has revealed a consistently low angle relationship between schistosity and peneplain attitude, and dominance of distributed deformation (flexure) over fault displacement deformation. Undulations in topography are thus mirrored by equivalent undulations in underlying schistosity, and the study area has been divided into nine fault bounded blocks. Three fault provinces are also recognised. Tabulation of joint orientations shows D (ESE) sets to dominate in the west and C and D (ENE-ESE) sets to dominate in the east. They are geometrically and genetically related to pre-Cenozoic faults (Nevis-Cardrona and Old Man fault systems, the latter of which does not displace the peneplain significantly), and reactivated according to flexure of blocks. Fold axes of blocks trend north-northeast in the west and north-northwest in the east. Heterogeneous strain distribution is evidenced by variable shortening percentages/axes of blocks and contrasts with bordering tectonic basins. Shortening by folding is calculated through measurement of angular spread of poles to topography and schistosity attitudes on stereonets. Shortening values of 3.1% (schistosity derived) and 3.8% (peneplain derived) on an axis 081 are calculated for the study area. The axis is similar to previously determined geodetic PHS directions and plate convergence vectors for Central Otago. A transpressional en echelon folding model has been developed with the aid of Surface II graphics and Fourier analysis. Regional peneplain and schistosity derived values of 1% shortening are calculated in the east (Taieri Ridge area), and up to 26% in the west (Cardrona-Moonlight block). Considerable shortening is indicated by steep schistosity attitudes in west Otago/northern Southland, where the peneplain is not preserved. Schistosity attitude could be used in late Cenozoic strain analysis outside Central Otago.

Landform studies show the upland peneplain to have suffered minimal degradation in the late Cenozoic. Tors have been formed by erosion of a weathered zone of irregular depth (0 to 10 metre depth at the Potters depression, southern Old Man Range), and are thus genetically inseparable from lower altitude tors. They occur where jointing is well developed (i.e. dependant on degree of flexure) and in areas relatively sheltered from the southwest. XRD analysis of clays from the study area and from Quaternary-late Tertiary sediments in the upper Clutha Valley has constrained kaolinite age as pre dating deposition of the Maori Bottom Formation (Plio-Pleistocene). Additionally, erosion of the peneplain has been limited to removal of the weathered zone. A degradation rate (3-10 mm/1000y) is calculated, based on known thicknesses of the weathered zone. This degradation rate is similar to rates determined in tectonically inactive cold temperate and arctic environments. Clay and landform studies could be used for identification of the peneplain surface outside Central Otago.

THE EASTERN HIGHLANDS OF NORTH QUEENSLAND

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In north Queensland the Eastern Highlands reach their highest elevations outside of the much discussed Southeastern Highlands of the southern New South Wales - eastern Victoria region. Although a variety of contrasts is noted along the highland belt, it is generally considered as a single morphotectonic region. Examination of the north Queensland sector reveals some unique features, and it is suggested that this region may have undergone a different evolution.

Wellman (1987) considered the Eastern Highlands to be of two basic types: i) asymmetrical highlands in north Queensland, and southern Queensland - New South Wales - eastern Victoria; ii) an intervening symmetrical highlands area in central Queensland. Bishop (l988) reiterated these contrasts, and drew attention to the wider continental shelf associated with the central Queensland sector. Closer examination of the topography of the Eastern Highlands and the western Tasman Sea floor reveals some interesting patterns along the margin of this Australian continental block.

The southern portion of the Eastern Highlands extends south for 1600 km from southern Queensland. Here the highland belt is about 250-300 km across and contains much land above 1000m. The east-west watershed divide is l00-250 km from the coast, and the highlands are asymmetric in cross profile being higher to the east. Further to the east, the edge of the continental landmass is only 75-l30 km offshore. The sea floor spreading that created this continent-ocean boundary was active from 80-55 Ma. (Veevers, 1982).

The central section of the Eastern Highlands extends for 1100 km through central Queensland, and exhibits many contrasts with the southern section. The highland belt is wider, - some 450 km across, but much lower being mostly less than 800 m. The watershed divide is up to 400 km inland and the highlands are symmetrical in cross profile. Offshore the edge of the continental landmass is 300-500 km to the east. This submerged part of the Australian continental margin consists of a plateau and troughs formed by rifting and subsidence during the late Mesozoic - early Cainozoic (Mutter and Karner, 1980). The seafloor spreading that created the present continent-ocean boundary was active from 62-56 Ma. ago (Veevers, 1982).

The northern segment of the Eastern Highlands, from 18°S latitude in north Queensland has been likened to the southern section by Wellman (1987) and Bishop (1988), while Jones and Veevers (1983) included it with the central Queensland sector. The highland belt in north Queensland is up to 250 km across, has an asymmetrical cross profile, and rises to over 1000 Ma. Offshore the edge of the continental landmass is 350-950 km to the east, and consists of a plateau and troughs that apparently developed in the same manner as those in the central Queensland sector. (Mutter and Karner, 1980). Clearly the north Queensland segment of the Eastern Highlands forms a separate section, morphologically distinct from the central Queensland sector, and in a different structural setting from the southern highland belt.

Along the axial crest of the highlands in north Queensland are various plateau remnants cut across Paleozoic granites and volcanics. The highest of these is the Herberton Tableland rising to 1296 m. However, the highest elevations in the area occur some 40 km east of the Great Divide in the granitic mountains of the Bellenden Ker Range which reach to 1622 m on Bartle Frere South Peak. Progressive erosion of the Great Escarpment is leaving these ranges standing high above the coastal plains and corridors. Stephenson (1986) notes that rocky plateaus and gentle summit ridge lines on these ranges may be inherited from old erosion surfaces.

Late Cainozoic basalts of the Atherton Volcanic Province are widespread in the area with ages ranging from 7.1 - 0.01 Ma. (Stephenson, in press). While most of the activity has been on the Atherton Tablelands, some lavas have flowed over the Great Escarpment and several volcanic vents have been identified on the coastal plains. Unfortunately no old lavas have yet been found in suitable areas that would help develop a chronology of major landforming events. However flows dated by Stephenson (in press, and pers comm) allow determination of river incision rates. A reach of the North Johnstone River that passes through the Great Escarpment has cut a gorge at least 270 m below a 1.60 Ma. old lava flow, while on the Tablelands the Barron River has cut a 70 m deep gorge through a 1.80 Ma. old lava flow.

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FRACTAL NATURE OF THE EASTERN HIGHLANDS

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ABSTRACT

Fractals have been widely used to describe and simulate a variety of topographic features in the landscape (Mandelbrot,1982), e.g. mountain ranges, the geometry of caves and lakes, the length of coastline and river channels. The term 'fractal' refers to any spatial and temporal phenomena having a Hausdorff-Besicovitch dimension D_H greater than its topological dimension. For a Brownian surface, $D_H = 2.5$, and a 'white noise' surface, $D_H = 3.0$ (Culling, 1986).

Four sites in the Eastern Highlands were selected to study the fractal nature of the landscape and the effect of scale on fractal dimensions. For each area, three transects were digitized from the 1:100,000 topographic maps (Figure 1). Three transects at Gunning are shown in Figure 2 as an example. These transects were then linearly interpolated at 0.1 km interval to generate elevation series at equal distance. Among five methods available, semi-variogram was used to estimate the fractal dimension of the landscape in the Eastern Highlands. The unbiased estimation of a semi-variogram is given by (Oliver and Webster, 1986):

$$\gamma(h) = \frac{1}{2(N-h)} \sum_{i=1}^{N-h} [z(i) - z(i+h)]^2$$

where z(i) is the elevation at point i, N is the sample size, and h is the lag. The slope, b, on the log-log plot of $\gamma(h)$ versus h is related to D_H by :

$$D_H = 3 - b/2$$

Such a plot for Gunning site (Figure 3) shows that there seems to be a break in the slope, indicating that at a smaller scale, less than 0.8 km in this instance, the landscape is smooth, while at a large scale it is highly irregular. This observation may well be a result of a long and complicated evolutionary history of the Eastern Highlands; and the scale-dependence was also noted elsewhere (Mark and Aroson, 1984). Semi-variograms are useful to identify landscape features which may not be so obvious, and models based on the concept of fractal dimension have been proved to bear at least a strong visual resemblance to the landscape (Goodchild and Mark, 1987). Such models, however, fail to explain the vertical asymmetry in the landscape because there are definitely more mountain peaks than depressions.

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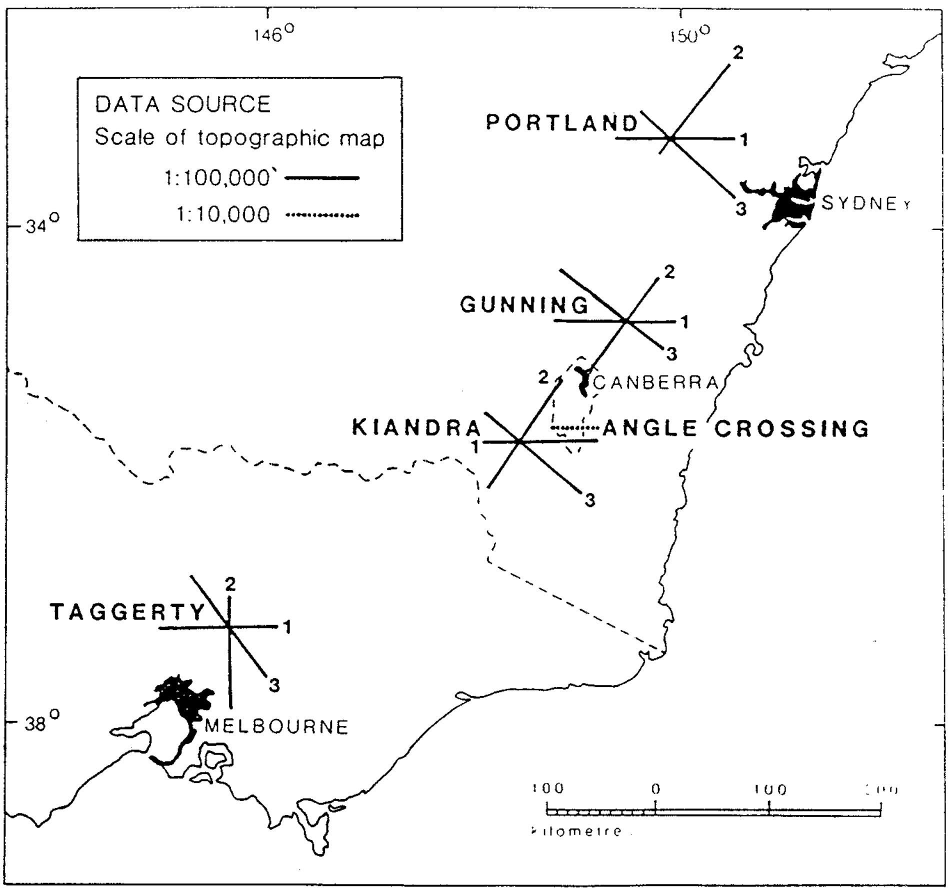

Figure 1 Location and orientation of the digitized transects.

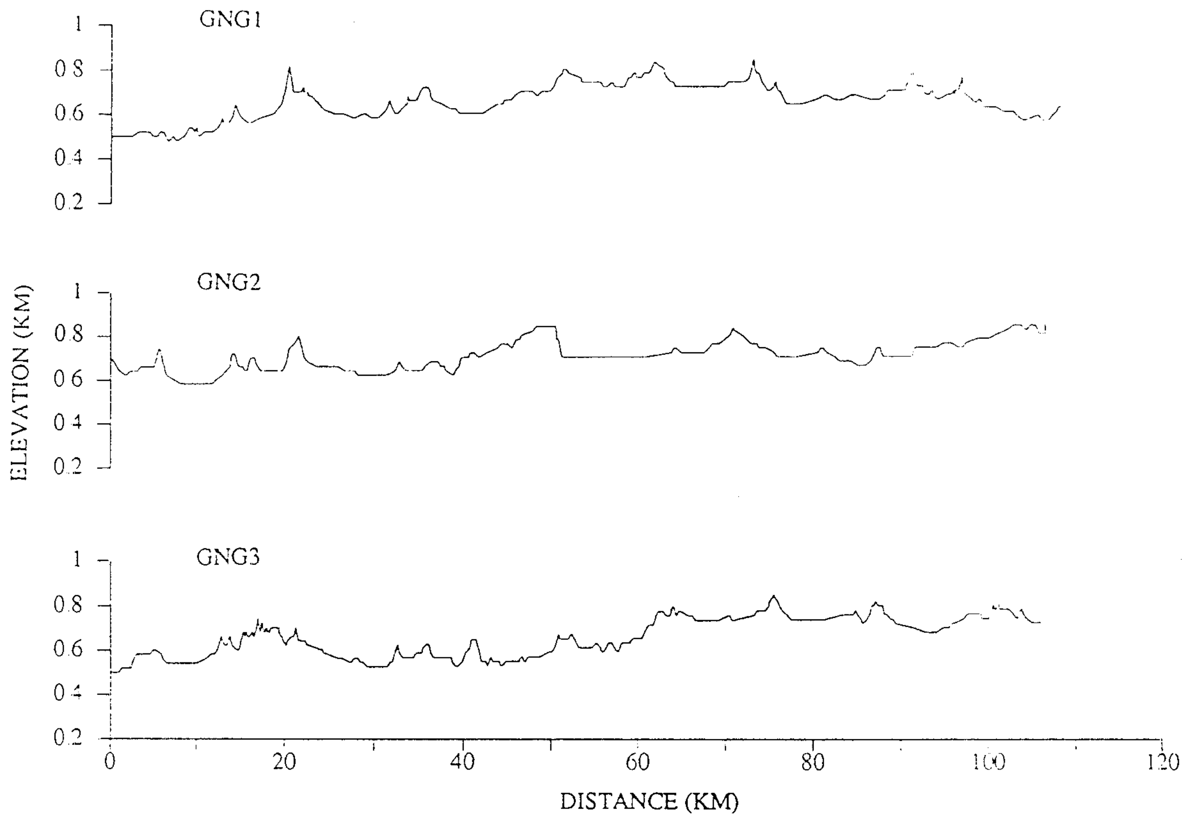

Figure 2 Transects of the Gunning site.

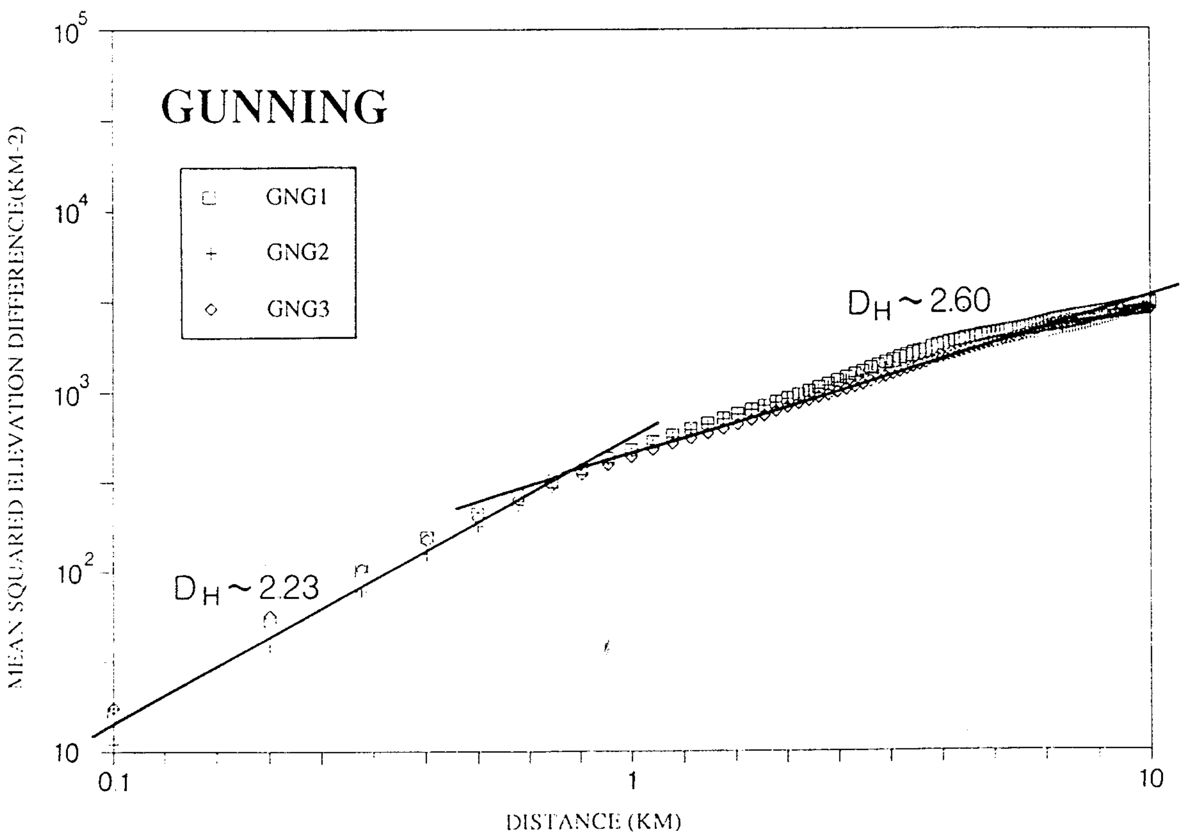

Figure 3 Semi-variograms of elevation series at Gunning site.

THE ALLUVIAL HISTORY OF AN AUSTRALIAN RIVER SYSTEM FROM 45 MILLION YEARS TO THE PRESENT

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ABSTRACT

Extensive alluvial deposits adjacent to the contemporary Shoalhaven River and tributaries in South Eastern N.S.W. reveal a unique record of fluvial activity over a period of at least 45 million years. These deposits extend to depths of 100 metres and cover an area of several hundred square kilometres across a tableland surface 600 metres above sea level. Their stratigraphy is complex, often with thick clay layers overlying bedrock which in turn are overlain by gravels and sands.

Earlier proposals of basalt damming and tectonism to account for this aggradation are not supported by detailed field evidence. Furthermore, eustasy and Pleistocene glacial and peri-glacial activity have also had no influence in this environment. It is proposed here that deeply weathered Devonian granites and Ordovician metasediments within the catchment provided an abundance of material for deposition.

Data from bore holes, seismic refraction and the identification of ancient channel boundaries in bedrock indicate that the Shoalhaven and its tributaries have maintained a single sinuous channel morphology since at least the late Eocene. Palynological evidence and stratigraphic associations with dated basalts show the earliest sediments laid down by the Shoalhaven River to be at least mid Eocene in age. Subsequent deep incision into bedrock occurred and infilling of this channel began during the Oligocene. Avulsion relocated the Shoalhaven to its present position where it has downcut to within 10 metres of its early Tertiary depth. Exposures within both the ancient channel infill and in Quaternary terraces show stratigraphies evidencing changes in flow regime. This variable sedimentology allows interpretations to be made of fluctuations in climate for this region throughout nearly the entire Cainozoic.