Perhaps the most significant result from Louie Creek concerns Phase II deposition. Although the fluvial evidence favours an increase in sedimentation (possibly at the expense of discharge and assisted by a reduced vegetation cover), the persistence of deposition throughout the Last Glacial Maximum indicates steady moisture availability in the catchment at this time. Whilst this may reflect true regional moisture levels, one must also consider the importance of groundwater capture in karst terrains and how, under relatively drier conditions, springs may feed karst streams long after non-karst streams have ceased flowing.

Acknowledgements

We gratefully acknowledge the support of the following: University College, The University of New South Wales; Quaternary Dating Research Centre, The Australian National University; Queensland National Parks and Wildlife Service (in particular Lawn Hill National Park); Gulf Gorges Pty Ltd. This is contribution number 8 of the Barkly Karst Project and contribution number 30 of the Geomorphology and Quaternary Science Research Unit.

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Channel Adjustment to Extreme Floods in Arid Central Australia

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Introduction

The major impacts of climate on the Australian environment result from extremes: severe droughts, large floods, extensive fires and intense winds. It is likely that many aspects of Australia's environment are adjusted to these extremes, and that periods between are times of much slower change, often following dramatic responses to extremes. As extremes dominate much of the hydrology and fluvial morphology of the Australian arid zone, it is essential that we have a clear understanding of the process response of river systems.

Previous work on the region's highly variable hydrological regime and paleoflood record (Pickup *et al.*, 1988; Pickup, 1991; Patton *et al.*, 1993; Bourke, 1994; Bourke, 1995a; Bourke and Pickup, in press) has concluded that vast areas of the landscape are periodically inundated by high magnitude floods. Much of this work has concentrated on event paleohydrology and chronology (Baker *et al.*, 1983; Baker *et al.*, 1985; Pickup *et al.* 1988; Wohl *et al.*, 1994). Paleoflood studies have focused on the gorge reaches of river systems where evidence of flood stage, such as slack water deposits and high stage gravel deposits, are preserved. This work has led to the acknowledgement of the importance of high magnitude events in determining gorge channel morphology and sedimentology (Pickup *et al.*, 1988; Wohl, 1992a, 1992b).

Beyond the confined gorge reaches of the Todd River evidence of large flood events include an assemblage of sand sheets, sand threads, ripple fields, overflow channels (Pickup, 1991), large-scale paleo-braid channels, levee deposits and broad, low relief bars (Patton *et al.*, 1993). These flood forms are associated with a series of high magnitude floods which occurred between approximately 1500 and 700 BP. More recent work (Bourke, in prep) has established that extreme flows have occurred in the Todd catchment since at least 15 ka.

Study Area

The Todd River drains from the MacDonnell Ranges in central Australia (Figure 1) (133° 50' E, 23° 40' S) passing through the town of Alice Springs. In this semi arid region, rainfall events occur infrequently with maximum rainfall receipts between October and March, and a mean annual rainfall about

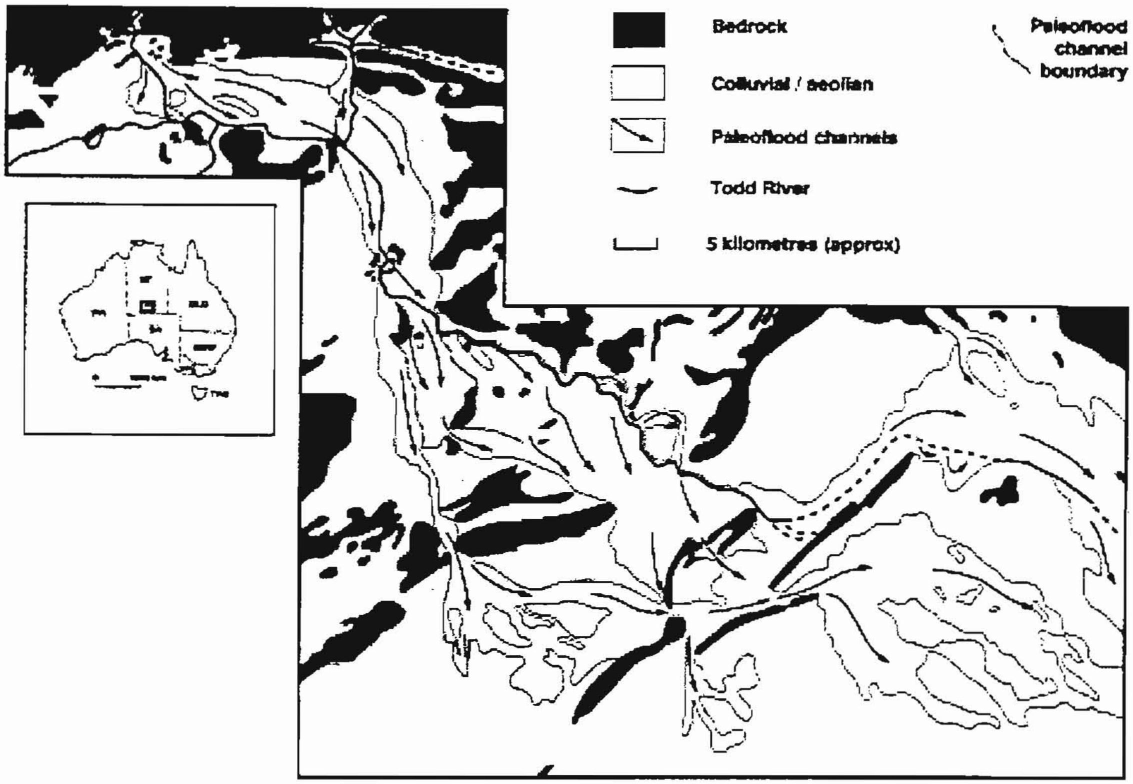


Figure 1. Extent of paleoflood inundation in the Todd River Catchment.

the ranges of 274.4 mm. The river is ephemeral with infrequent and sometimes large flows. The catchment has a drainage basin area of approximately 9,300 km^2, with two large tributaries draining from the north (Figure 1).

The channel pattern of the Todd River is essentially a single thread, straight or gently winding channel which changes to a distributary pattern in the intermediate and terminal floodouts. Channel gradients vary from approximately 0.00266 m/m in the Ranges to 0.00150 m/m further downstream. The landscape through which the Todd River and its tributaries flow is characterised by a range of topographies, from the strike-ridge-dominated MacDonnell Ranges, through Pleistocene piedmont fans and wide alluvial plains until the terminal floodout in the longitudinal dunes of the northern Simpson Desert.

This paper will begin by describing the immediate or the first order effects of the paleofloods. It will then describe the way in which the contemporary river system has adjusted to these events, that is, the second order effects.

First Order Effects

The Todd River has been inundated by extreme floods since at least 15 ka (Bourke, in prep). Several discrete flood channels (Figure 1) have been mapped and a chronology produced by Optical Luminescence and radiocarbon analysis. These channels were occupied both synchronously and asynchronously during the Late Pleistocene and Holocene. The activation and formation of channels was dictated by the flow of tributary catchments, the magnitude of the event and the tendency for the paleoflood channels to avulse.

The high magnitude of these events is testified by the erosion of pre-existing landforms, the scale and spatial extent of the flood forms, the coarse nature of the deposits, the distance the flood effects extend from the ranges, the avulsive nature of the flows and the fact that no floods since European settlement of the region have inundated the paleoflood surfaces.

The erosion of existing landforms

The paleofloods inundated large areas which were composed of older alluvium, colluvium and aeolian landforms. In many locations the contact between the surfaces is erosional. Remnant landforms with truncated faces lie adjacent to the paleoflood channels. These include the truncated coarse grained colluvial fans (Figure 4 d), the eroded downstream extensions of older flood channels (Figure 1) and individual longitudinal dunes and large sections of dune fields (Figure 1).

The deposition of large-scale fluvial landforms

The paleofloods have created a hierarchy of fluvial landform scales in the Todd catchment (Bourke and Pickup, in press). These large scale flood channels extend from the ranges to the northern fringe of the Simpson desert in relatively straight paths flowing around obstacles such as outlying bedrock ridges and remnants of aeolian dune fields and plains and through pre-existing gaps in ridges (Figure 1). The channels are of moderate gradient (0.001 m/m), convex in cross-profile and measure several kilometers in total width. They are braided in nature with individual bars and splays extending several kilometres downstream in low relief (<1 m). Sediment size decreases rapidly from cobble and gravel deposits in the confined gorges to gravely sands in the unconfined reaches. Coarse material was emplaced in the northern fringe of the Simpson desert with silts and clays in the terminal and backwater areas. The flow dynamics of the paleofloods has dominated sediment size distribution over large areas of the catchment.

Transmission losses through the porous channel bed in desert rivers results in diminishing flows downstream. The distance downstream that flows travel has been used as a surrogate for flow magnitude (Mabbutt, 1977). Many of the Todd paleoflood

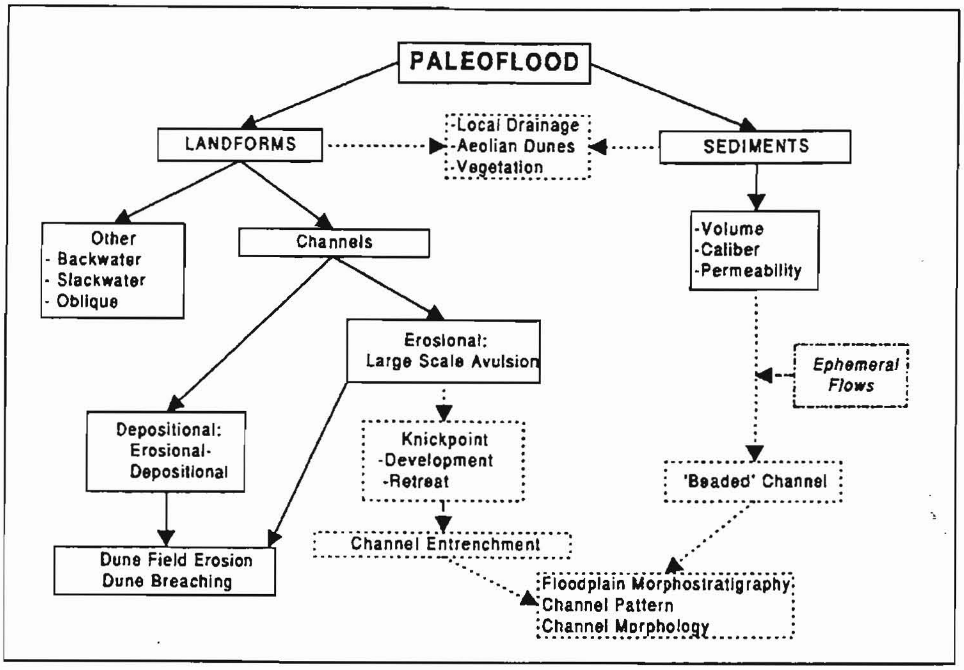


Figure 2. First Order Effects (solid lines) and Second Order Effects (dashed lines) of Large Scale Paleofloods.

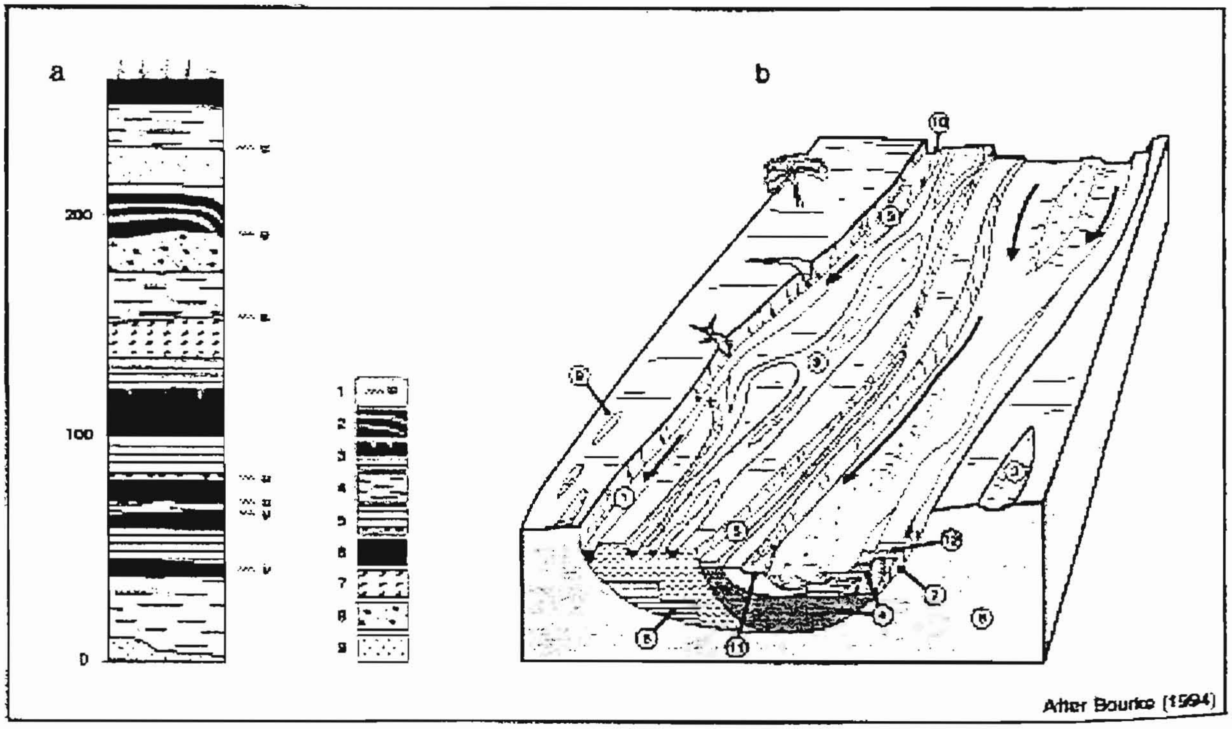
channels extend 100 km from the ranges into the northern Simpson desert emplacing coarse gravel loads across aeolian plains and into dune fields (Figure 1).

In summary, these events changed the catchment landform assemblage and increased the volume and calibre of sediment supply (Figure 2). The river system has adjusted to the change in these catchment characteristics. The following section illustrates some of the flood-forced changes in contemporary river behaviour.

Second Order Effects

One of the major geomorphic effects of the floods was large-scale avulsion where the flow path changed from event to event. In addition to relocating the contemporary channel it changed the depositional end point of the system to a point of lower elevation. This process triggered widespread channel entrenchment in a manner similar to alluvial fan entrenchment. Knickpoints along the channel long profile incise underlying paleoflood and Pleistocene material as they rapidly migrate towards the ranges activating dormant sediment stores.

The weathering history and textural composition of the sediments into which the channel has incised profoundly influences the channel morphology, planform and pattern. Where the boundary sediments are composed of material resistant to erosion, such as indurated Pleistocene alluvium (>59 ka, Patton *et al.*, 1993), channel width is relatively narrow. Floodplain facies in these confined reaches are composed of a 'chaotic' aggradation sequence (Figure 3 a, b) which has been



After Bourke (1994)

Figure 3. a. Schematic floodplain facies in entrenched channel reaches. 1. Erosional unconformity. 2. Terrace veneer deposit. 3. Flood couplet with desiccation cracks. 4. Sand sheet with faint horizontal bedding. 5. Sand sheet with clear planar bedding and rip up clasts. 6. Mud bed. 7. Climbing ripple sequence with truncated crests. 8. Overbank bar with mud clasts. 9. Buried flood plain remnant. b. Schematic block diagram illustrating the variable morphology and morphostratigraphy of floodplains in the Todd River. 1. Back channel 2. Flood channel 3. Swirl pit. 4. Channel inset. 5. Flood plain inset. 6. Buried flood plain remnant. 7. Surface flood plain remnant. 8. Pleistocene alluvium. 9. Overbank bars. 10. Back channel inset. 11. Stripped surface. 12. Terrace veneer deposit.

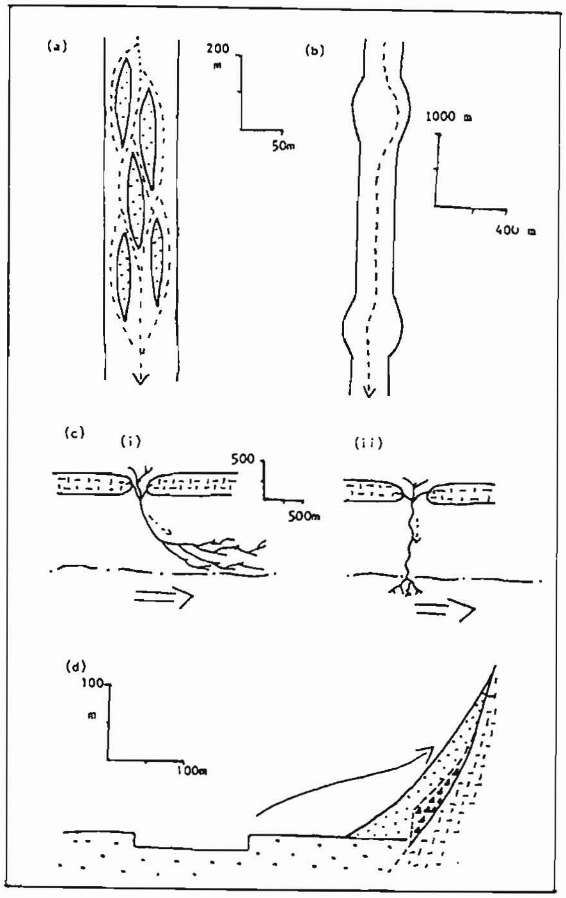


Figure 4. Schematic diagram of channel adjustment to paleoflood: (a) Localised braiding reaches; (b) Channel 'beads', the localised increase in channel width; (c) Small-scale drainage (i) deflection (ii) disintegration. Large arrows indicate paleoflood channel; and, (d) Source bordering climbing dune. Note truncated fan underlying dune (triangle pattern).

emplaced by medium-magnitude flood events. Floodplains are periodically subjected to repeated erosional events which may remove the entire alluvial sequence (Bourke, 1994). This process results in the juxtaposition of young alluvial sediments (<300 BP) (Bourke, 1995b) and Pleistocene age material (Figure 3 b).

Channel boundaries composed of paleoflood sediments are relatively easier to erode. The mobilisation of bank materials and floodplain stores yields an increase in local sediment supply. Ephemeral streams flow infrequently and there is a marked decrease in flow magnitude downstream (Thornes, 1994). Pickup (1985) has modelled the sediment dynamics of arid systems and concluded that sediment travels in pulses down the system and is linked to the rate at which the flood wave decreases downstream. The absolute magnitude of flows affects the ability of the river to entrain large volumes of sediment. Once released from the floodplain store, sediment may travel only short distances and be placed in adjacent stores such as channel bars. In order to compensate for the increase in local sediment supply the channel adjusts its pattern from a dominantly single thread to one of extended braiding sections (Figure 4a). In places, forming large central bar systems composed of a series of coalescing braid bars. The channel may be deflected around these central bar systems locally expanding the total channel width from 100m to 400 m (Figure 4b). These 'beaded' channel patterns are a distinctive feature of the Todd channel and the various mechanisms which lead to their formation will be discussed in detail elsewhere.

In locations where the channel incises coarse calibre paleoflood sediment, the insufficient transport energy of contemporary flows results in paleoflood sediment extending a major influence on contemporary channel and floodplain morphostratigraphy. Large remnant islands composed of cobbles and gravels remain 3 m above the thalweg (Figure 5 A, (i)) and

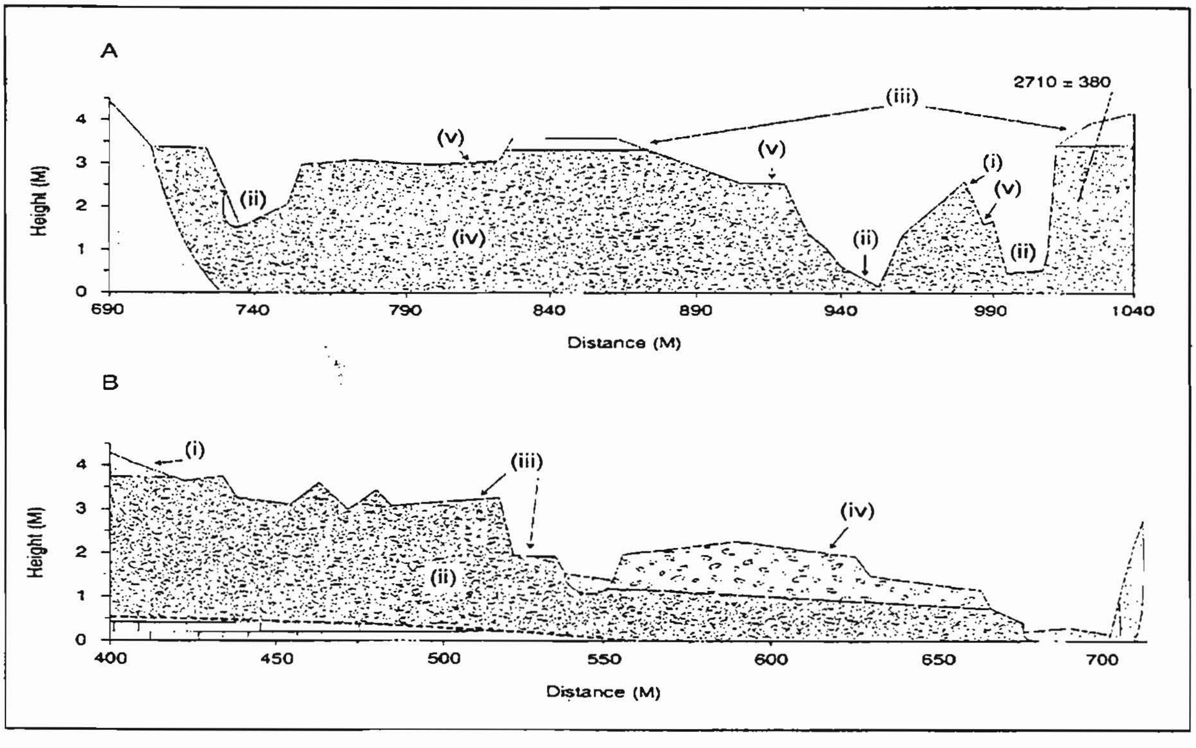


Figure 5. Channel crossections of Todd River (A) Giles Creek, (i) Island composed of remnant paleoflood sediments. (ii) Locally anastomosing channel pattern. (iii) Contemporary floodplain smear. (iv) Floodplain core composed of remnant paleoflood sediments. (v) Stripped surfaces with step morphology. (B) Mosquito Bore, (i) Contemporary floodplain smear. (ii) Floodplain core composed of remnant paleoflood sediments. (iii) Stripped surfaces with step morphology. (iv) Remobilised paleoflood gravels.

Table 1. Radiocarbon age of source bordering climbing dune

Location	ANU Code	Age BP	Age (cal BP)	Geomorphic Environment	Material	Sample Depth (cm)
Jessie Gap Sand Quarry	8835	1430+/-270	1320 +/-250	Source Bordering Dune (top)	Charcoal	86
Jessie Gap Sand Quarry	8836	2830+/-70	2920 +/-70	Source Bordering Dune (flank)	Charcoal in Hearth	75-88

deflect the contemporary channels which form an anastomosing pattern in order to maximise transport efficiency (Figure 5 A (ii)). In these locations the contemporary floodplain is often a thin smear (Figure 5 A, (iii) and B, (i)) over a laterally more extensive paleoflood core (Figure 5 A (iv) and B (ii)). The morphology of exposed paleoflood sediment is often step-like (Figure 5 A (v) and B (iii)) due to the relative resistance of individual sedimentary layers to floodplain stripping. In these reaches active channel bars tend to be coarser in textural composition than further downstream due to locally sourcing the coarse paleoflood materials (Figure 5 B (iv)).

The drainage orientation and patterns of small scale systems (<20 km^2) are altered when they abut the large paleoflood deposits. These small catchments drain the piedmont ranges and outlying ranges and ridges. Where they flow over terrain which has not been emplaced by floods they tend to flow south in a single thread channel eventually terminating in a floodout. In Figure 4 c (i), drawn from a satellite image, the southerly direction of the small channel is deflected eastward along the higher, convex boundary of a paleoflood channel trending west-to-east. In Figure 4 c (ii), the single thread pattern of the small channel rapidly disintegrates into a distributary system. The distance between the beginning of channel disintegration and the disappearance of surface flow is much less that in channels that do not flow over young paleoflood deposits. The relatively high permeability of the paleoflood sediments controls the rate of drainage disintegration.

An increase in sediment supply from the catchment headwaters provided a new sediment source for aeolian transportation (Figure 4 d). Source bordering, climbing dunes are located close to paleoflood channels where adjacent high bedrock ridges trap the mobile sand fraction. Radiocarbon dates from one such dune indicate late Holocene formation (Table 1). In some locations older aeolian dune material (~ 6 ka) has been remobilised by local runoff and reworked into fine grained alluvial fans.

The relatively nutrient and seed rich, permeable paleoflood sediments (Bourke and Pickup, in press) support vegetation which is different from the surrounding older landforms. For example the older Pleistocene alluvial surfaces support *Hakea eyreana* and some *Acacia estrophiolata* and the aeolian surfaces *Micromyrtus flaviflora, Duboisia hopiwoodi, Plectrachne schinzii.* The paleoflood surfaces support *Acacia murrayana, Acacia victoria, Hakea eyreana, Acacia estrophiolata, Eucalyptus camaldulensis* and *Eucalyptus microtheca.* The implications of the change in vegetation distribution after the last glacial maximum, due to an increase in flood frequency and magnitude, on Aboriginal settlement of the arid interior is discussed elsewhere (Bourke, in review).

Conclusion

Large-scale late Pleistocene and Holocene floods have been the dominant fluvial process since the last glacial maximum. These events transformed large sections of an aeolian landscape to a fluvial landscape. The adjustment and recovery of the Todd River is ongoing. As the recovery time most probably exceeds the recurrence interval of these high magnitude floods, the channel is in a constant state of disequilibrium.

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