

## **Cyclical construction and destruction of flood dominated flood plains in semiarid Australia**

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**Abstract** The morphostratigraphy of flood plains along unconfined reaches of the Todd River, central Australia, indicate that flood plain formation is dominated by high magnitude floods. Processes of flood plain destruction include channel widening, vertical stripping, flood channel, back channel and macroturbulent scour. Flood plain construction occurs predominantly during high magnitude floods. Overbank aggradational sequences comprise a complex assemblage of depositional units which include channel and flood plain insets, terrace veneer sedimentation and channel fills separated from each other by erosional unconformities. The resultant sedimentary sequences within the flood plain is best described as chaotic. Mechanisms responsible for the construction and destruction of flood plains operate at three scales. These extend from the alteration of individual sedimentary layers to the complete removal of valley bottom aggradational sequences. The highly complex morphostratigraphy of flood plains in this region negates the application of conventional paleoenvironmental reconstruction techniques.

### **INTRODUCTION**

The ability of high magnitude floods to completely alter the geomorphology of a landscape has been well documented (Baker, 1978; Rudoy & Baker, 1993). Similarly, much attention has been paid to the role of floods on river channels and flood plains (e.g. Schumm & Lichty, 1963). While floods have been recognized as dominant forces in arroyo channel morphometry in the semiarid southwest of the US (Graf, 1983), much of the research into the relationship between high magnitude floods and flood plains has focused on the immediate geomorphic response to a single event or clustering of events (Schumm & Lichty, 1963; Schick, 1974; Nanson, 1986). Their findings have shown that high magnitude events, although geomorphically effective (Wolman & Gerson, 1978), are episodic disturbances in the more gradual formation of flood plains. In this paper a series of flood plain characteristics are presented which indicate that flood plains in this region are formed predominantly during high magnitude flood events. A recent classification of flood plains (Nanson & Croke, 1992) identified unconfined vertical accretion sandy flood plains as part of the class of high energy non-cohesive flood plains. Until now little was known of this flood plain type, its stratigraphy, morphology or formation. This study serves to redress this situation somewhat and indicates the need for further research into these flood plains.

## STUDY AREA

The headwaters of the Todd River and its tributaries drain the semiarid MacDonnell ranges located in the Northern Territory of Australia (Fig. 1). Annual rainfall and discharge figures for this ephemeral river display high inter-annual variability (Fig. 2). The largest gauged flood, which occurred in 1988, is reported to have a 1-in-50 annual exceedance probability (Barlow, 1988). Slack water deposits currently under investigation by the author indicate the occurrence of much larger floods beyond the gauged record.

Pickup (1991) and Patton *et al.* (1993) have described the geomorphology of the piedmont reaches of the Todd River. The geomorphic effect of "super floods" on the incised, low angled piedmont fans is seen as essentially aggradational. Distinct landforms assemblages are formed during these events. These include 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). This study examines the geomorphic effects of floods on a 37 km reach of the Todd River below the piedmont zone (drainage basin area of approximately 18 000 km<sup>2</sup>) (Fig. 1). This reach is unconfined in that it does not drain a bedrock gorge. However, the flood plain is inset into alluvium and low angled colluvial aprons of Pleistocene age, which limit the width and lateral extent of flood plain processes.

The alluvium along this reach of the Todd River is divided into three broad units displaying different lithologic characteristics (Table 1). This paper is concerned with the youngest unit ( $A_0$ ), which constitutes the present flood plain. In this reach the Todd River has incised Pleistocene alluvium ( $A_2$ ) to maximum depths of 11 m. This indurated alluvium ( $A_2$ , Table 1) retards the active migration of the channel and provides an alluvial envelope within which the more recent alluvium ( $A_0$ , Table 1) is set (Fig. 3, 8). Channel gradients, recorded from 1:50 000 maps, measure 1:650 for the study reach as compared with 1:790 for a similar length reach immediately upstream. This increase in gradient is influenced by two large tributary entrants, that of the Ross River and Giles Creek (Fig. 1). A highly variable channel width averages at 80 m and mean flood plain width to channel width ratio is 3.6:1 with minimum values of 1.8:1 and a maximum

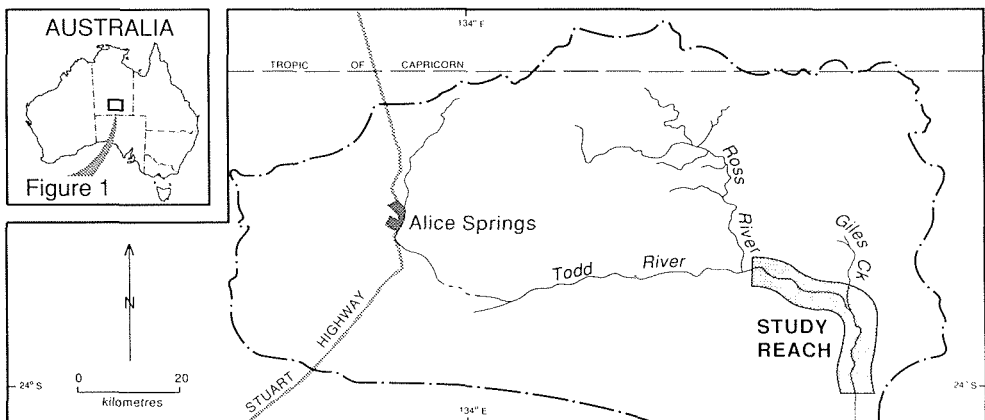
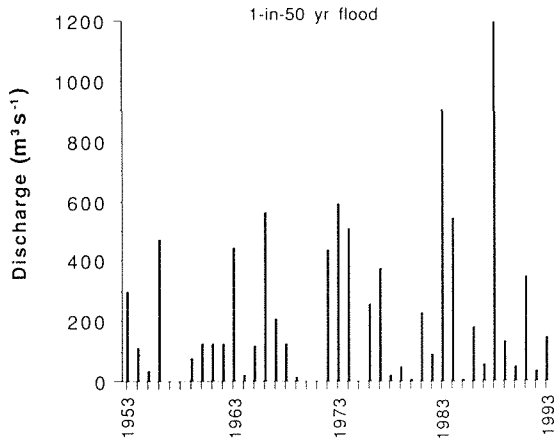


Fig. 1 The Todd River drainage basin and study area.



**Fig. 2** Recorded annual maximum floods on the Todd River (GS0060009), Alice Springs, 1953-1993 (data source: Water and Power Authority, Alice Springs). No data available for 1956, 1957.

value of 6.3:1. The channel pattern displays localized anabranching and meander migration imposed on an essentially straight reach.

Although the incised Pleistocene alluvium has been inundated by recent floods, the term flood plain is used in this paper to describe the alluvial landform which extends from the channel bank to the adjacent, higher Pleistocene alluvial boundary. The flood plain alluvium is believed to be of Holocene age.

**Table 1** Properties of alluvial units identified in the Todd River.

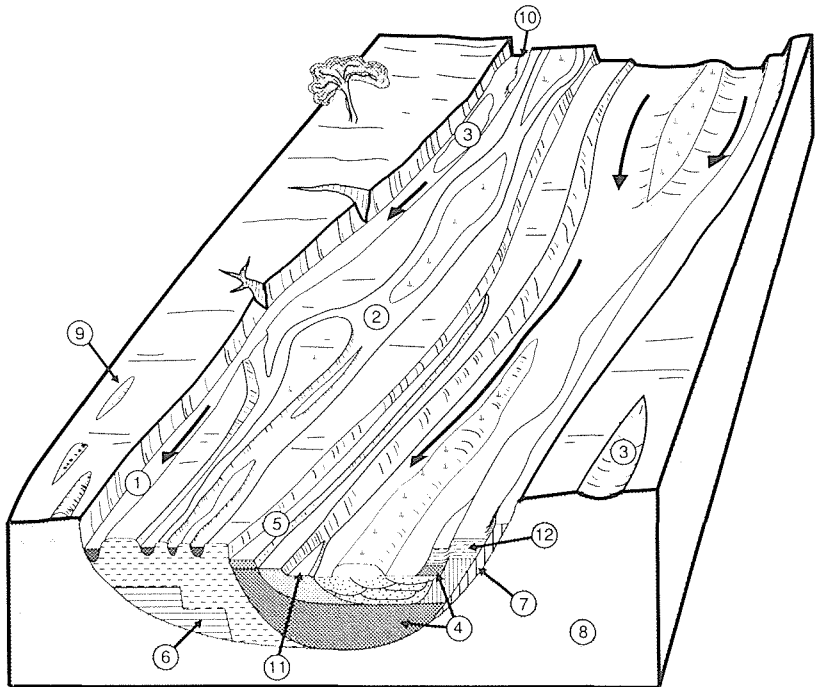
Property	Unit A <sub>0</sub>	Unit A <sub>1</sub>	Unit A <sub>2</sub>
Morphology	Stepped	Some steps	No steps
Colour, Munsell	10yr7/4	5yr5/6	2.5yr5/8
Texture	Clay to gravel	Clay to gravel	Clay to gravel
Degree of pedogenesis	Rare	Common	Abundant
Bioturbation	Occasional	Abundant	Abundant
Oxidation	Absent	Common	Abundant
Induration	Absent	Occasional	Abundant
Secondary gypsum	Absent	Common	Abundant
Sedi. structures	Well preserved	Poorly preserved	Not preserved
Charcoal/organics	Abundant	Absent	Absent
Recently flooded	Yes	Yes	Yes

## FLOOD PLAIN MORPHOLOGY

A notable characteristic of these flood plains is their **stepped** morphology and accompanying abrupt increases in elevation with distance from the channel. Relatively flat surfaces are separated from higher flat surfaces by well defined, steep scarps ( $\sim 1$  m high) (Fig. 3) The number of levels is highly variable, for example, at one site the flood plain cross-section extending from the left bank has six "steps" while the opposite flood plain has three. Individual levels can be traced, sometimes discontinuously, for several kilometres downstream. In addition to a variable number of levels, they are also unmatched in elevation across the channel. The morphostratigraphy of these flood plains, discussed below, indicates that this morphology does not represent conventional flood plain/terrace sequences.

A single **back channel** is located along many of the scarps which separate the multiple levels described above (Fig. 3, <sup>1</sup>). In places, these channels represent up to 25% of the surface area of a level. Localized macroturbulent scouring along the channel bed can increase depth by an order of magnitude. To date, a maximum depth of 4 m has been recorded. Back channel insets ( $\sim 0.75$  m high) are located on the convex bank of these channels where the back channel laterally erodes the scarp of the adjacent, higher level (Fig. 3, <sup>10</sup>).

A braided **flood channel** pattern occurs on the surface of many of the flood plain levels (Fig. 3, <sup>2</sup>). They are of two types, those which scour the surface and those which



**Fig. 3** Block diagram illustrating the variable morphology and morphostratigraphy of flood plains 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.

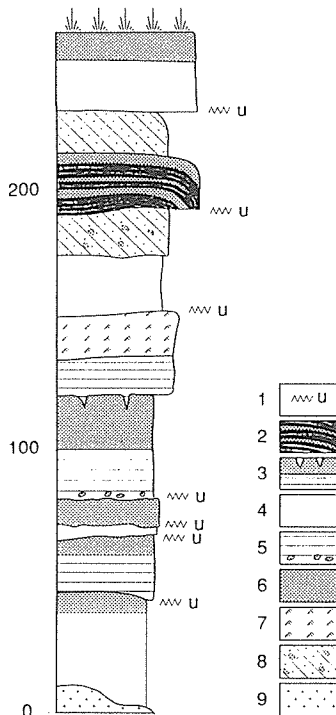
divide around freshly deposited overbank bars. They breach the channel boundary and can extend downstream, parallel to the main channel, for several kilometres. Individual braid channels have average cross-sections of  $1 \text{ m}^2$  and although they have been observed to feed into or out of back channels, they are generally independent flood features.

**Swirl pits** (Gardner, 1977) are found both on the surface of flood plains (Fig. 3, <sup>3</sup>) and in the main channel. Where fully formed, they are elliptical in planform, deepest at their upstream end and can exceed 2 m depth. They usually form close to or around obstacles such as riverine vegetation (most commonly *Eucalyptus camaldulensis*) and adjacent to flood plain scarps.

## FLOOD PLAIN MORPHOSTRATIGRAPHY

The internal stratigraphy of these flood plains is characterized by a complex assemblage of sedimentary fills with distinctive morphologies separated by erosional unconformities (Fig. 3). Below is a brief description of the composition of the fills.

Maximum depths of **back channel** and **flood channel** fills, which sit unconformably in the flood plain sediments, are 1 m. Typical facies display repeated, event-based deposition which grades from matrix supported pebbles to planar sands.



**Fig. 4** Schematic facies of overbank units. 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.

An **inset fill** is a body of alluvial material deposited against an eroded scarp. Two types are identified here. The first are channel insets which are set unconformably against the eroded channel bank and overlie the main channel bed sediments (Fig. 3, <sup>4</sup>). These range in scale from small channel bench-like forms to 3 m thick channel aggradational units (Fig. 3, <sup>4</sup>). The second type are flood plain insets which are set unconformably against a flood plain scarp and unconformably overlie eroded flood plain sediments (Fig. 3, <sup>5</sup>). Insets are generally flat-topped with well defined erosional scarps. Individual fills are up to 3 m thick. Although the internal stratification of insets is typified by the sedimentary facies described below (Fig. 4), composition can be variable. For example, a 1 m high flood plain inset, in the study area is composed entirely of homogenous, massive muds.

A **flood plain remnant** is described here as the eroded core of a previously more vertically and/or laterally extensive flood plain. They have unconformable contact with adjacent alluvial sediments and are of two types, those which are preserved under the flood plain (Fig. 3, <sup>6</sup>) and those which are visible as truncated steps in the flood plain surface morphology (Fig. 3, <sup>7</sup>). Buried remnants display a distinct erosional morphology, both vertically and laterally. In one particular case the scarp of a buried remnant was stepped (Fig. 3, <sup>6</sup>), indicating at least two erosional episodes. Remnants visible at the surface (Fig. 3, <sup>7</sup>) have been truncated by lateral erosion but typically extend vertically through full depths of the flood plain.

The lapping up of younger alluvial sediments onto higher, adjacent surfaces is termed **terrace veneer** (Brakenridge, 1984) (Fig. 3, <sup>12</sup>). In the study area, these fills are identified draping over several of the flood plain scarps at angles of 15°, damping the pronounced stepped morphology. Excavation of these fills indicate that aggradation is episodic and depositional episodes can be separated by erosional unconformities.

## SEDIMENTARY FACIES OF OVERBANK DEPOSITS

Although a detailed facies description of these flood plains will be given in a future paper, a preliminary description of the dominant characteristics of overbank deposits is presented here. Depositional macroforms indicative of high magnitude overbank floods, such as overbank bars and sand sheets occur within flood plain facies sequences, shown schematically in Fig. 4. The following is a description of these and other components of the facies.

Overbank **bars** with steeply dipping (15-30°) large scale (~50 cm) foreset beds occur on flood plain surfaces and in stratigraphic sections. These contain alternating beds of poorly sorted pebbles and coarse sands. The presence of well rounded mud clasts along the dipping foresets indicate stripping of mud beds upstream.

Extensive, horizontally laminated, planar bedded **sand sheets** are found in all stratigraphic sections examined. In places horizontal bedding is disturbed by extensive bioturbation which may extend into adjacent layers making boundaries indistinct. Sand sheet thickness is highly variable and measures between 10 cm and 80 cm, the latter representing a significant aggradational high magnitude flood event.

Uniform dense **mud beds** up to 30 cm in thickness represent the deposition of suspended load during flood recession. Where they lie conformably on sand sheets, the depositional unit is termed a "flood couplet" and reflects the transition from deposition of bed load to suspended load during the flood recession. Cyclical aggradation of flood

couplets, indicative of clustered high magnitude floods, do occur. The boundary between events is distinguished by features such as sand filled desiccation cracks and rip up clasts (Fig. 4). Mud beds are also deposited on bar surfaces and in slack water areas on the flood plain surface, such as along back channels and in the swirl pits described above.

**Other facies characteristics** which indicate overbank deposition by high magnitude floods include the presence of reverse grading. This is most commonly observed in thickly bedded, loosely packed, structureless sands and fine gravel. Upward fining is generally from medium sands to fine gravels supported in a coarse sand matrix.

Textural change between succeeding flood deposits is generally abrupt, a common example is the deposition of a pebbly bar on a massive mud layer (Fig. 4). Aside from bioturbation, the most common cause of post depositional alteration of overbank flood deposits is erosion by the succeeding flow(s). One example of this is the truncation of the crests of climbing ripple sequences observed in a horizontally extensive sandy overbank sheet (Fig. 4).

The suite of flood plain facies and morphostratigraphic units which occur in the study area are more variable than those described for semiarid rivers to date. Previous research (Williams, 1971; McKee *et al.*, 1967) has noted the dominance of parallel laminated sands interbedded with mud layers. Alluvial facies in the study area typically contain a range of depositional macroforms which include overbank bars, channel fills, sand sheets and mud layers. The position of these macroforms in the vertical sequence of the flood plains is best described as chaotic. Overall sequences do not smoothly fine upwards as units of fine and coarse facies may occur in any vertical order. Sequences such as shown in Fig. 4 demonstrate that overbank bar deposition may occur repeatedly and be located in any position in a given section. This reflects a discharge regime where flood plains are constructed by events at the higher end of the flood magnitude spectrum.

## MECHANISMS OF FLOOD PLAIN DESTRUCTION AND CONSTRUCTION

### Flood plain destruction

**Channel widening** In the study reach, channel widening during floods is a significant process of flood plain destruction. Groves of River Red Gums (*Eucalyptus camaldulensis*) which formerly grew on the river banks now stand within channel beds, sometimes 30 m from the present banks, with their roots often exposed. This is probably related to floods of the 1970s and 1980s. The resultant "surface flood plain remnant" (Fig. 3, <sup>7</sup>) appears as a small step on the flood plain surface. A number of surface flood plain remnants indicates destruction of flood plains by repeated channel widening. Although a lack of physical evidence is inherent to the process, the logical extension of the channel widening phenomenon is the complete removal of the Holocene flood plains during the highest magnitude floods, a geomorphic response reported for the Cimarron River by Schumm & Lichty (1963).

**Flood plain stripping** Stripping of flood plains (Nanson, 1986) is a process that removes alluvium from flood plain surfaces. In the study area this mechanism operates at a variety of scales. In one location, a strip of flood plain alluvium approximately 20 cm in depth and 3 m in width was removed from the flood plain surface along its 300 m length. More commonly, flood plains are stripped to depths in excess of 2 m and widths

of 30 m for distances of up to 500 m. The residual flood plain morphology is stepped, with distinct vertical scarps. Similar to the account by Nanson (1986) for the Clyde and Manning rivers of southeast Australia, flood plain stripping terminates at more resistant layers, for example, along dense mud beds and at some sites, within gravel layers forming low channel benches (Fig. 3, <sup>11</sup>). However, this is not always the case as stripping also terminates within sandy layers in the study area. The erosional morphology of flood plain remnants (Fig. 3, <sup>6</sup>) buried under contemporary flood plains indicate that the destruction of flood plains by stripping has occurred repeatedly in the past.

**Macroturbulent scour** Operating at a smaller scale is the excavation of holes on the flood plain surface and within the channel by macroturbulent vortices (Fig. 3, <sup>3</sup>). These "swirl pits" (Gardner, 1977; Baker, 1978) are features associated with the flood peak and are believed to indicate deep high gradient flood flows. They are associated with the development of vortices around obstacles (most commonly the large River Red Gums, *Eucalyptus camaldulensis*) and along irregular flow boundaries such as those created during flow over the multiple level morphology of the flood plains.

**Surface channel scour** During floods, overbank flow is often concentrated in braid-like threads on the flood plain surface. These channels can erode the surface to depths of 30 cm and do not necessarily aggrade during the waning stages of the flow. The confined back channels are more effective agents of both lateral and vertical erosion. The lateral extension of the back channel by erosion of the scarp of the adjacent, higher flood plain level is commonly observed.

### Flood plain construction

Flood plains along the study reach are formed predominantly by vertical accretion. Aggradation generally occurs during high magnitude events where bed load is transported and deposited overbank. Flood plain construction is achieved by a number of mechanism which include the formation of insets, terrace veneer sedimentation, and the aggradation of back channels and flood channels.

**Flood plain and channel insets** The principal geomorphic response to channel widening and/or flood plain stripping is the deposition of alluvial material against the erosional scarp of the flood plain remnant. For example, channel insets are formed by lateral bar accretion during the waning stage of the flood or subsequent lower magnitude flows. Once reconstruction of the flood plain has begun, surface flood plain remnants appear as steps on the flood plain surface (Fig. 3, <sup>7</sup>). Channel widening and inset construction is one of the mechanisms by which the multiple levels on these semiarid flood plains form. Although both channel and flood plain insets are ultimately dominant forms of flood plain construction, flood plain insets initially result in the vertical aggradation of the flood plain surface, while channel insets initially reduces channel width by forming channel benches similar to the narrow berms described by Brakenridge (1984).

**Terrace veneer** Terrace veneer sedimentation is a process of both vertical and lateral accretion. It effectively blankets the flood plain morphology and can be a

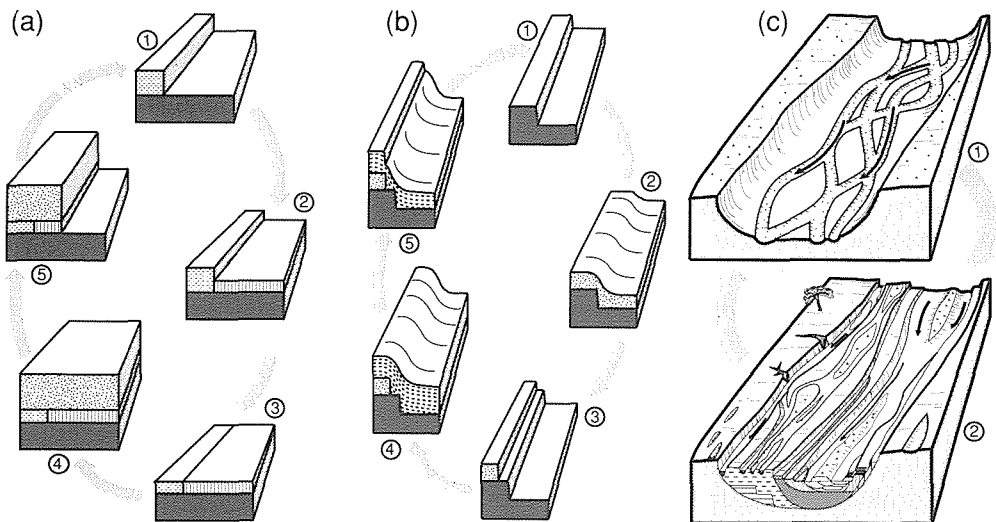


significant process of flood plain construction. A maximum thickness of 2 m has been measured for these aggradational units

**Channel and swirl pit fill** Although channels on the flood plain surface are actively incising the flood plain, many are reworking their own fill. Eroded channels are also backfilled by overbank deposition by, for example, large bars which can partially block flood-channel threads. This overbank migration of large bar features also fill the large depressions formed by macroturbulent scour. Significant aggradation of these scours is also achieved by the deposition of suspended load material from the pools of water contained in the swirl pits after a flood.

## MODELS OF FLOOD PLAIN MORPHODYNAMICS

Detailed morphologic and stratigraphic investigation of the flood plains in the study area have revealed the highly complex nature of these flood plains. Based on these observations, three morphodynamic models have been drawn up which conceptualize the processes of flood plain destruction and construction described above. These models are based on specific type-sites in the study area. The evidence suggests that processes of flood plain construction and destruction have occurred repeatedly in punctuated cycles. The processes of construction and destruction of flood plains enter the model at



**Fig. 5** Models of flood plain morphodynamics.

(a) *Micro scale*: <20 cm, sedimentary layer. 1 – Partial stripping of sedimentary layer. Note the erosional scarp. 2 – Inset deposition. 3 – Stripping of surface. 4 – Vertical accretion. 5 – Stripping.

(b) *Meso scale*: <3 m, flood plain. 1 – Stripping of flood plain. 2 – Terrace veneer deposition and burial of flood plain remnant. 3 – Stripping of flood plain. 4 – Terrace veneer deposition. 5 – Stripping of flood plain. Note: Micro scale processes operate within this scale.

(c) *Mega scale*: Valley bottom alluvial sequences. 1 – Complete removal of valley bottom alluvial sequences to resistant Pleistocene boundary. 2 – Rebuilding predominantly by (a) and (b).

three scales. The *micro* scale concerns the removal and deposition of individual sedimentary layers, or part thereof (Fig. 5(a)). The *meso* scale describes processes involved in the erosion and accretion of several meters of alluvium, that is, the alteration of large sections of a flood plain (Fig. 5(b)). The *mega* scale conceptualizes the hypothesis that floods have removed entire valley bottom aggradational sequences in this reach of the Todd River (Fig. 5(c)). Evidence for this is based on the chronological hiatus between two alluvial units. Until the absolute chronology is established, a relative chronology is determined from contrasting alluvial characteristics (see Table 1) The youngest alluvium unit ( $A_0$ ) is inset unconformably in the Pleistocene alluvium ( $A_2$ ). The lack of induration, and excellent preservation of sedimentary structures in the younger unit along with other contrasting characteristics outlined in Table 1 indicate a chronological hiatus between the two alluvial units. This hiatus is interpreted here as evidence for an erosional event or series of events in the Holocene which completely removed most of the previous alluvium. The timing and extent of this event(s) is the subject of further inquiry.

## DISCUSSION AND CONCLUSIONS

Cyclical components of disequilibrium flood plain formation have been outlined in other studies (Nanson, 1986; Schick, 1974). This study is the first to provide stratigraphic and morphologic data to support the hypothesis. The morphostratigraphy of flood plain remnants, both surface and buried, indicate that the destruction of flood plains, principally by processes of stripping and channel widening, have occurred repeatedly in the past. Facies analysis of the flood plains indicate that the episodic aggradational sequence of flood plains is disrupted by several erosional episodes. Although flood plain aggradation is predominantly achieved by vertical accretion, the geometry of the aggradational units is complex revealing an assemblage of flood plain and channel insets, terrace veneer sedimentation, channel fill sequences and macroturbulent scour fills. In a companion paper the flood plain morphodynamic model is applied to flood plains along the Todd River in order to demonstrate that high magnitude floods in the semiarid zone of Australia dominate floodplain formation (Bourke, in prep.).

Previous studies in this drainage basin have viewed the response to floods in the piedmont zone of the MacDonnell ranges as dominantly aggradational (Pickup, 1991; Patton *et al.*, 1993). This study indicates that downstream of the piedmont zone the geomorphic response to floods is both erosional and depositional in nature, resulting in a highly complex alluvial geomorphology. This complex response to high magnitude floods within the Todd drainage basin reflects contrasting styles of flood flows between the two reaches. Where the Todd River and its tributaries exit from the confined gorges of the MacDonnell Ranges, large, low angled, alluvial piedmont fans have been built. During higher magnitude flows, flood waters spread out and form wide unconfined shallow flood sheets (Patton *et al.*, 1993). Downstream from this reach, in the study area, floods are partly confined within the incised Pleistocene alluvium. The dissipation of flood energy across the piedmont zone results in net vertical aggradation. Whereas the more confined flow conditions in the study reach increases the potential for flood erosion. Future work will extend this analysis further downstream where factors such as distance from the ranges, infiltration and evaporation of floodwaters and the diversion

of floods from the main channel via major flood distributaries influence flood plain morphodynamics.

The complexity of these flood plains indicates that paleoenvironmental reconstructive techniques using, for example, paleochannel dimensions or rates of flood plain aggradation (Nanson *et al.*, in press) should not be attempted for this drainage basin without extensive stratigraphic interpretation. Larger channel dimensions or high rates of flood plain aggradation may simply be the geomorphic response of semiarid flood plains to high magnitude flood events.

**Acknowledgements** The author is currently completing a PhD at the Australian National University, funded by the National Greenhouse Advisory Committee and the Sydney Water Board. The author wishes to thank Phil Ward for considerable assistance in the field. Ian Heyward for cartographic assistance and John Chappell, Jacky Croke and Eugene Wallensky for helpful comments on this paper.

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