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Fluvial Form Variability in Arid Central Australia

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ABSTRACT

Many arid rivers are sensitive to variations in discharge and subject to extreme flows. These non-equilibrium rivers exhibit significant fluvial form variability. In the Todd River in arid central Australia, this variability is manifest in two ways. First, downstream variation in fluvial morphology occurs as a series of step changes rather than gradually. Abrupt morphological change at river confluences is pronounced. Discordant and barred junctions result from asynchronous tributary activity and differences in flow magnitude from contributing systems. Factors such as tributary spacing, tributary length, rainfall and runoff variability, hydrological lag and transmission losses are important in determining fluvial form variability. Additional influences include boundary roughness and resistance to erosion, and sediment supply. The pulsed movement of sediment in ephemeral systems creates a complex assemblage of landforms. Patterns of vegetation growth and stability are important influences on ephemeral sedimentation, storage time and associated landform distribution.

Second, there are three scales of landforms: small, medium and large. Extreme floods have deposited large-scale fluvial forms across the landscape. The resultant morphology and sedimentology of these events modulate the response of lower-magnitude flows by directing floodwaters and providing an abundant supply of sediment to the system. In this way form evolution occurs episodically and preservation is closely linked to flood magnitude.

INTRODUCTION

The geomorphology of arid and semi-arid rivers remains one of the least studied and understood aspects of fluvial systems (Reid and Frostick, 1997). Reviews of desert environments include descriptions of the variation in rainfall, the rapid runoff from contributing slopes, transmission losses, the flashy nature of flood hydrographs, asynchronous tributary activity, the generally high suspended sediment loads and the tendency for suspended sediment concentrations to increase downstream (e.g., Mabbutt, 1977; Graf, 1988a; Scoging, 1989, Reid and Frostick, 1997; Cooke et al., 1993; Thornes,

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1994a,b). What is not equally well documented is the morphological response of arid rivers to these dynamic processes. This paper addresses this issue by describing the geomorphology and aspects of form variability of a central Australian arid river.

Accepted models of river behaviour that have been predominantly developed in temperate and humid areas consider that fluvial systems develop a dynamic equilibrium between river form, discharge and sediment (Chorley and Kennedy, 1971). This concept is difficult to apply to arid systems dominated by variability that do not display an obvious quasi-equilibrium. Pickup and Rieger (1979) noted two types of non-equilibrium rivers: those sensitive to variations in discharge, and those subject to extreme flow. In this sense many arid-zone rivers are non-equilibrium rivers.

The discontinuous nature of flow in arid ephemeral systems limits the channel's ability to adjust. For example, Schumm (1961) found that channels in aggrading ephemeral rivers follow a pattern of alternate deposition and erosion (Schumm and Hadley, 1957). Such behaviour led Graf (1988a) to suggest that arid river systems essentially are not in equilibrium. Additionally, event-based changes in ephemeral rivers are common and channels respond to the variable discharge regime by dramatically adjusting their morphology and pattern. For example, the Salt and Gila compound channels in Arizona oscillate between a low-flow meandering channel and a larger braided flood channel (Graf, 1988b). Similar adjustments to variations in discharge were described along Cooper Creek in semi-arid Australia (Rust and Nanson, 1986) where braiding and anastomosing networks coexist.

The behaviour of arid-zone rivers is dominated by extreme events and the morphological response is typically step-like. Research in the Nahal Yael watershed (Schick, 1974) and in Central Australia (Bourke, 1994) indicates that intermittent discharges produce a channel unable to accommodate the occasional very large flood. The occurrence of low frequency "superfloods" completely alters the process–morphology relationship. Hence, ephemeral streams are best described as catastrophic whereby very large discharges drastically alter channel morphology. The Todd River is an example of a non-equilibrium river that is sensitive to variations in discharge and subject to extreme flows.

We describe the geomorphology of the Todd River in four zones: the headwaters, the piedmont zone, the alluvial plains and finally the longitudinal dunefield of the northern Simpson Desert. We discuss the impact of three factors on the patterns of fluvial form: the influence of tributaries, sediment transport dynamics and the variable discharge regime. In this ephemeral system, landform variability is expressed in two ways. First, fluvial morphology changes downstream as a series of steps rather than gradually. Factors such as asynchronous tributary activity and distances between points of tributary entry, variable boundary roughness and resistance have a dominant morphological and sedimentological signature. Second, landforms occur at three scales (small, medium and large).

CHARACTERISTICS OF THE TODD RIVER

The Todd River drains from the MacDonnell Ranges in central Australia (23°40′ S, 133°50′ E) passing through the town of Alice Springs (Figure 10.1). It is one of several internally draining ephemeral streams in the Lake Eyre Basin (>1 300 000 km^2), which

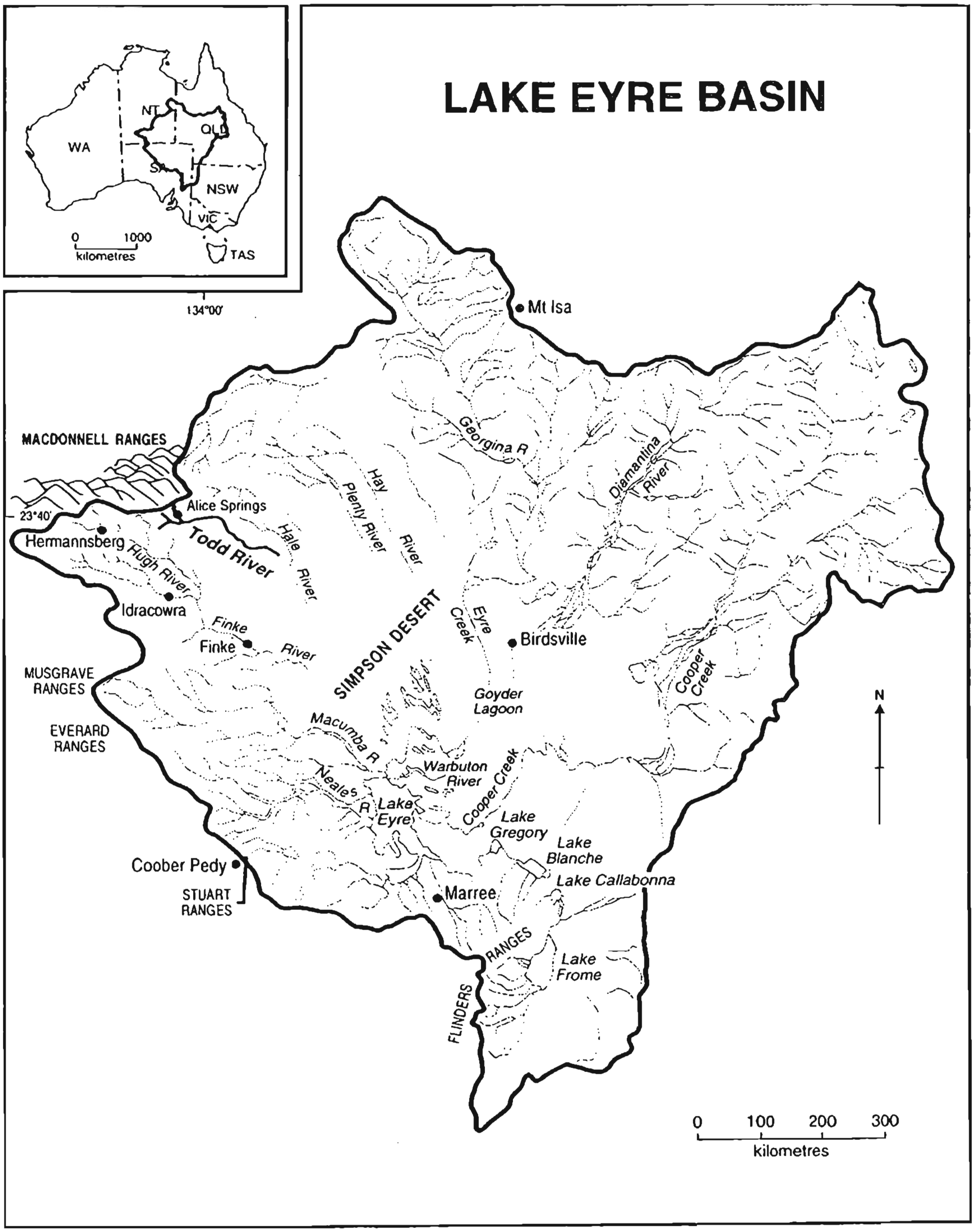

FIGURE 10.1 The Lake Eyre Basin, showing the location of the Todd and Finke Rivers

contains a wide range of river types and catchment sizes. These include the large braiding and anastomosing systems such as Cooper Creek (306 000 km^2) and the Diamantina River (365 000 km^2; Kotwicki, 1986) that rise in the tropical region of north Queensland (for detailed description see Rust and Nanson (1986) and Knighton and Nanson (1993)). Smaller systems include the Neales River (*c.* 35 000 km^2) rising in the more arid western basin (Croke et al., 1996). The Lake Eyre playa is the terminus for many of these

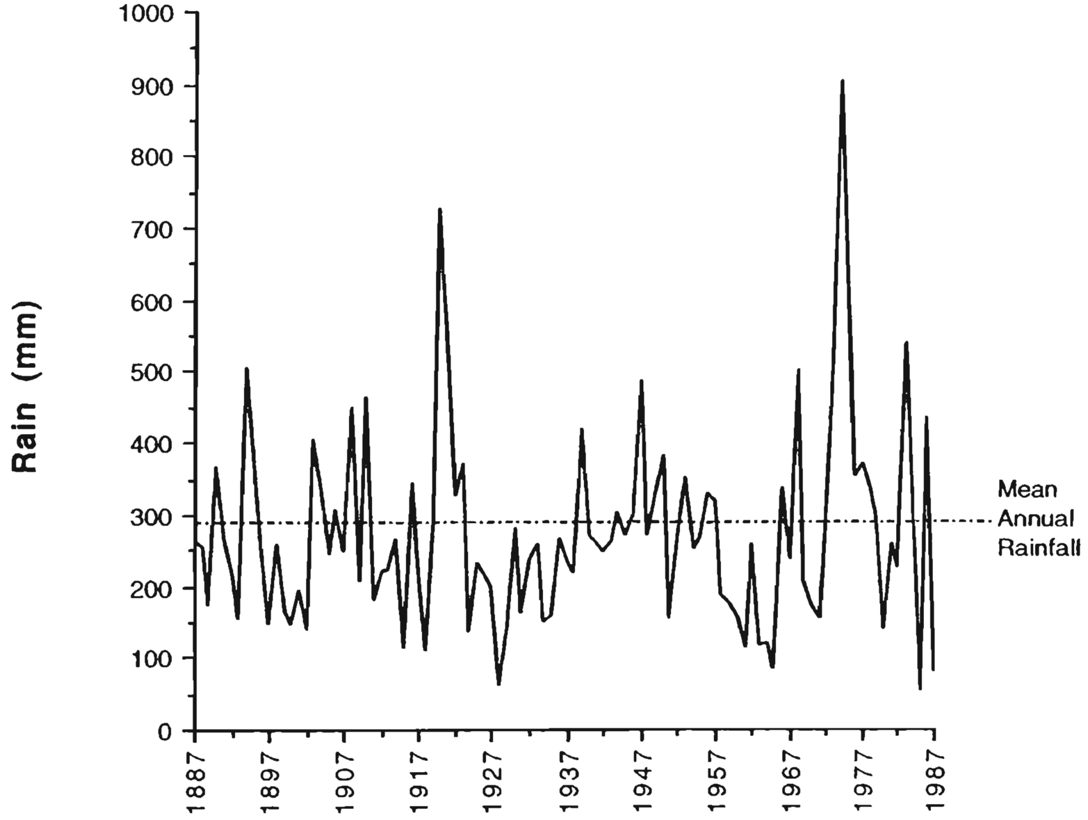

FIGURE 10.2 Total annual rainfall recorded at Alice Springs Post Office between 1887 and 1987. For location see Figure 10.3. Note the interannual variability in rainfall

internally drained river systems (Magee et al., 1995) but not the Todd which dissipates amongst longitudinal dunes in the northern Simpson Desert.

Rainfall in the Todd catchment is infrequent and most events occur between November and March during the Australian summer. Mean annual rainfall about the MacDonnell Ranges is 274.4 mm (median 238 mm) and displays high interannual variability (Figure 10.2). The spatial and temporal variation of rainfall is an important influence on fluvial landforms because it affects the magnitude and timing of drainage network activation. The asynchronous activity of channels results in a spatially variable distribution, and a temporally variable development of fluvial landforms. Rain typically reaches central Australia as discrete storms that move across the catchment. For example, a six-day rain event in March 1972 precipitated rainfall totals close to the annual average across the eastern Todd catchment but rainfall maxima occurred on different days at different gauges. Giles Creek (Ringwood gauge; Figure 10.3) recorded peak rainfall on the day prior to the peak at Ross River (Figure 10.4). Rainfall over the middle and upper Todd catchment during this period was much less than in the Ross and Giles that join the lower Todd.

The Todd River has few gauges downstream of the town of Alice Springs (Figure 10.3). The hydrological regime is best described as "flashy" as the river bed is dry 98% of the time and flow events rise and recede rapidly. The largest discharge event on record was measured in Alice Springs in 1988 and had a peak discharge of 1190 $m^3 s^{-1}$ for a catchment area of 450 km^2 (Barlow, 1988). This is regarded as a one-in-50 year event, on the basis of gauging since 1953.

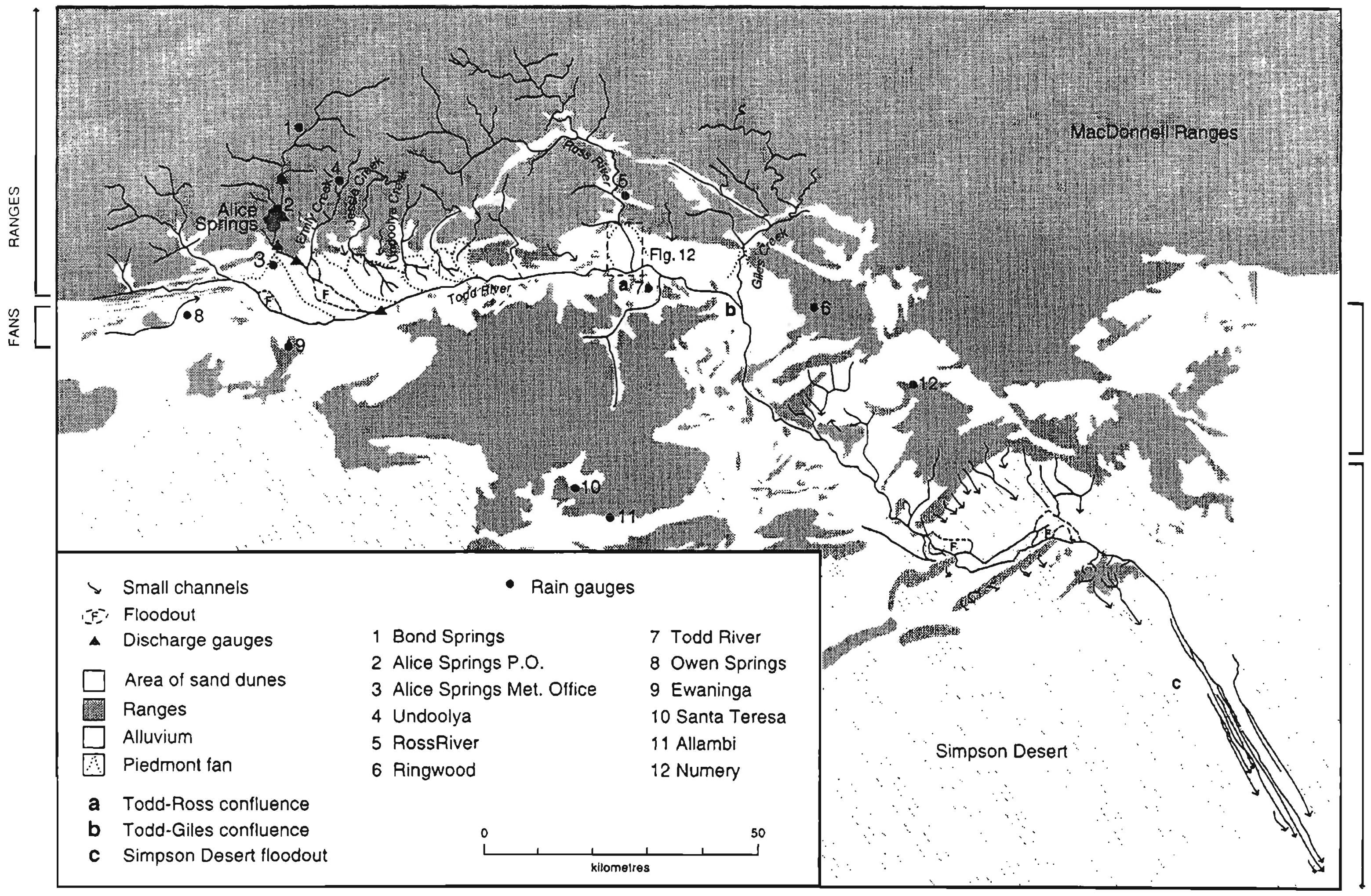

FIGURE 10.3 Todd River catchment, indicating the location of Alice Springs, rain and flow gauges, the main tributaries and the topographic domains: ranges, piedmont fans, alluvial plain and desert. The location of Figure 10.12 is also shown

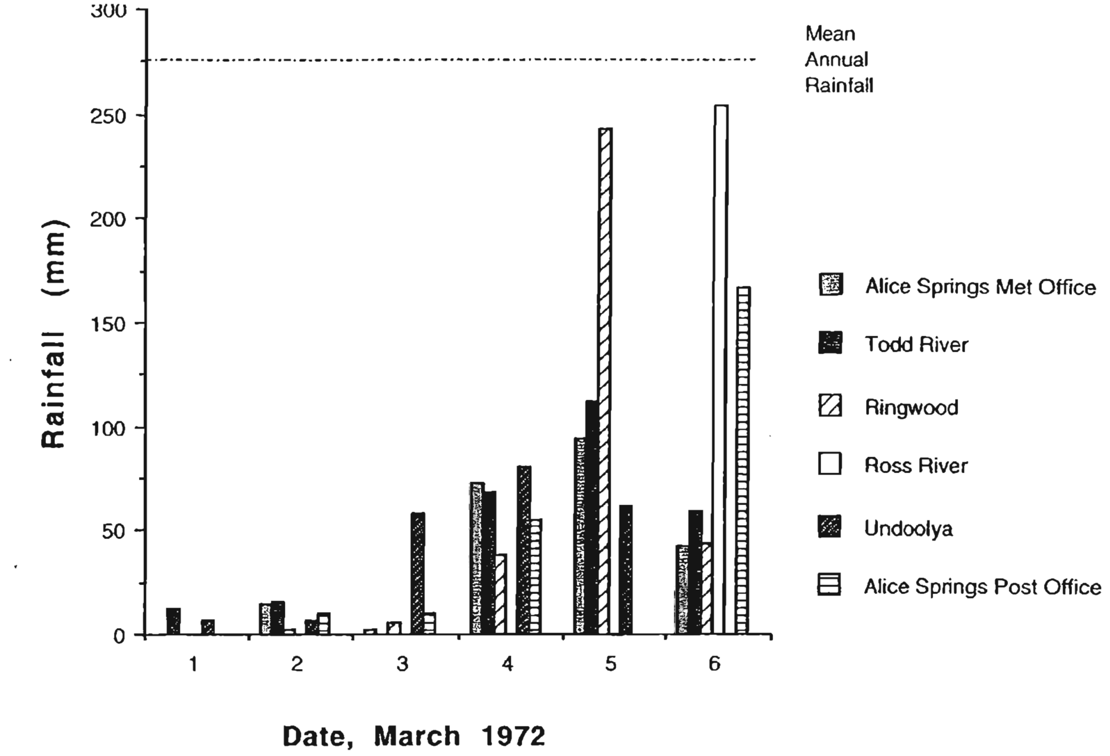

FIGURE 10.4 Temporal and spatial variation of rainfall, March 1972, Todd River catchment. For location of gauges see Figure 10.3

The catchment upstream of the Simpson Desert has an area of approximately 9300 km^2, with several large tributaries draining from the north (Figure 10.3). The headwaters of the Todd and its tributaries rise in Proterozoic crystalline and metamorphic rocks of the MacDonnell Ranges (Shaw and Wells, 1983). Soil in the ranges is predominantly shallow sandy lithosols with flanking outwash plains capped by red clays. South of the ranges, the soils are dominantly siliceous sands (Northcote and Wright, 1983). Since European settlement of the region over 100 years ago, land use within the catchment has become predominantly pastoral. Prior to this, nomadic hunting and gathering was practised by Aboriginal people (Spencer, 1896).

The Todd River essentially has a single, straight or gently winding channel, changing to a distributary pattern in floodouts (Figure 10.5b). Channel gradients, measured from 1:50 000 topographic maps, vary from approximately 0.00266 m m^{-1} in the ranges to

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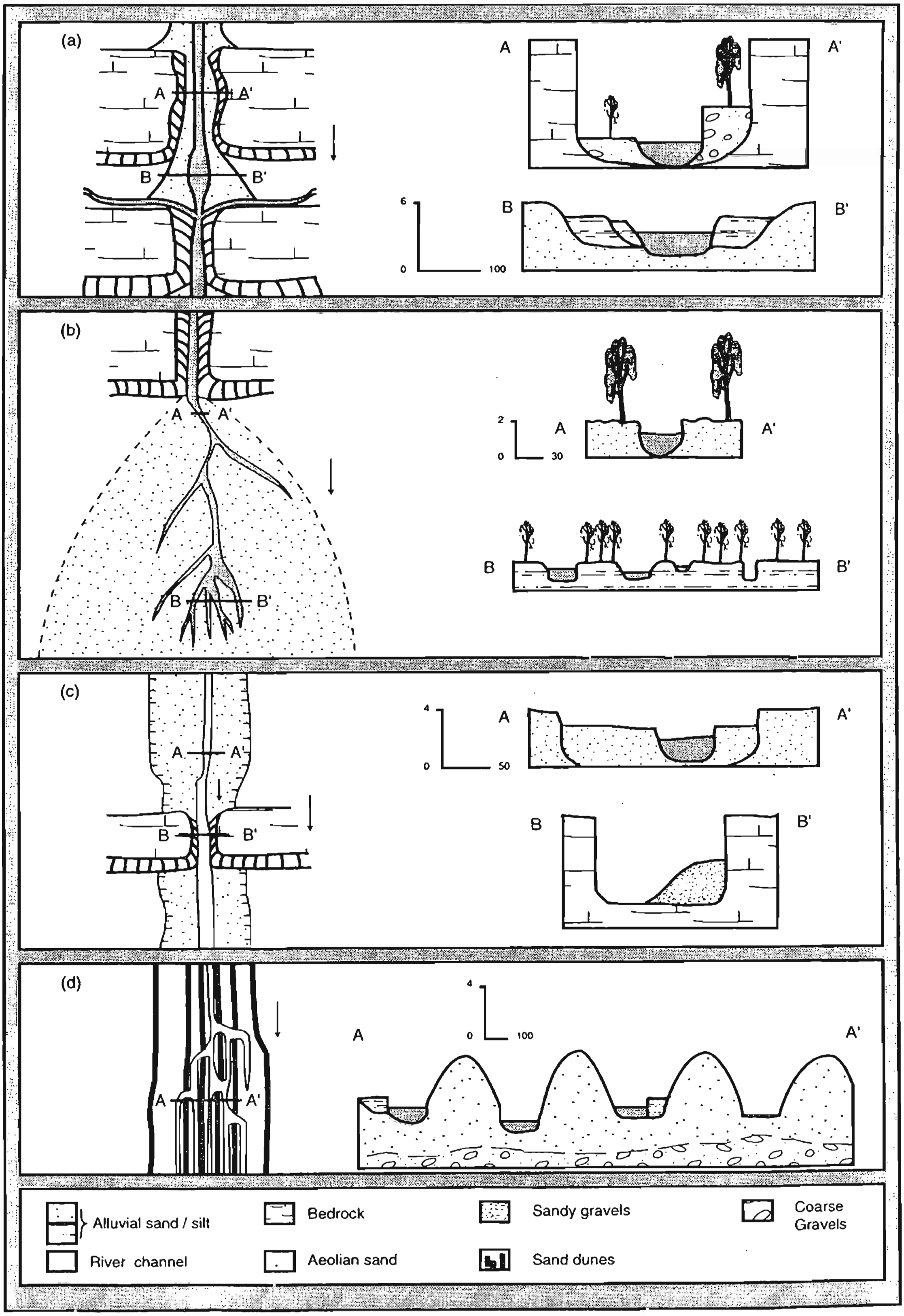
FIGURE 10.5 *(opposite)* Schematic diagrams of Todd River planform and cross-sections in each topographic domain (see Figure 10.3). Arrows indicate flow direction. (a) Gorge/strike valley. A–A′, cross-section through the gorge reach: a confined channel with coarse lateral deposits. B–B′, cross-section through the strike valley reach: a relatively unconfined channel inset in alluvium with well-defined channel and floodplain development. (b) Piedmont reach. A–A′, single-thread channel inset in piedmont fan alluvium. B–B′, multiple channel network with reduced channel capacity and dense vegetation. Note distributary channel pattern of floodout. (c) Alluvial plains with outcropping ridges. A–A′, single-thread channel inset into alluvium. B–B′, confined channel with asymmetrical channel cross-section indicating a deep bedrock pool and lateral sandy deposit. (d) Desert reach. A–A′, cross-section through terminal floodout as channel flows along aeolian dune swales. Note trellis-style channel pattern


(a)
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A'
B
B'
4
0
50
(d)
A
A'
4
0
100
Alluvial sand / silt
Bedrock
Sandy gravels
Coarse Gravels
River channel
Aeolian sand
Sand dunes

0.00150 $\mathrm{m\,m^{-1}}$ further downstream. The channel cross-sections are wide and shallow (average width–depth ratio is 90). The channel is usually well defined and is incised into Pleistocene alluvium, palaeoflood deposits and modern alluvium. Banks are composed of erodible sandy material, but at some locations older cemented Pleistocene alluvium and aeolian deposits form resistant channel boundaries. The channel carries a coarse sandy load, deposited as large-scale ripples and tabular bars. These may be interspersed with fine-grained silt and clay deposits that settle out in localized channel lows.

Floodplains are well developed but infrequently inundated and, where the channel is confined, are laterally restricted. In these confined reaches floodplain morphology and sedimentology reflect a system subject to high-energy flows, characterized by "chaotic" sequences of inset fills (Figure 10.6) composed of vertically accreted layers of gravelly sands, sands and mud (Bourke, 1994). The youngest floodplain elements in these confined reaches are composed of sediments 1–2 m thick, deposited since 1950 (Bourke, 1998a). This recent phase of floodplain building is believed to relate to the period of above-average rainfall (1972–1979) following a severe drought (1958–1965) (Pickup, 1991; Bourke, 1998a).

The landscape through which the Todd River and its tributaries flow includes the strike ridge-dominated MacDonnell Ranges, Pleistocene piedmont fans, wide alluvial plains, and a terminal floodout in longitudinal dunes of the northern Simpson Desert. Below is a summary of the broad topographic domains (Figure 10.3) and a brief description of the landform assemblage in each domain (Figure 10.5a–d).

In the headwaters, the Todd River and its tributaries flow through narrow and sometimes meandering gorges, which pass south through low, sharp-crested, east–west trending ranges, formed through large-scale etching of folded Precambrian quartzite, sandstone and accessory carbonate rocks. These ridges are separated by narrow, strike valley plains, and the structurally controlled drainage pattern is trellised. Channel morphology in the steep-gradient gorges, through the strike ridges (Figure 10.5a), is similar to that of the upper Finke River described by Pickup et al. (1988) and includes an assemblage of coarse gravel bar deposits. Slackwater deposits sometimes occur in the narrower valleys and small gorges that follow structural lineaments.

The Todd River and its tributaries exit from the MacDonnell Ranges through a series of low-angle fans (approximate average gradient is 0.0036 $\mathrm{m\,m^{-1}}$). Channels of the larger tributaries are continuous, but those of smaller tributaries often terminate in distributaries (Figure 10.5b).

Downstream from the fans, the Todd River traverses a broad, strike-trending lowland, occupied by a wide alluvial plain bordering a broad sand plain interspersed with minor rounded hills and discontinuous strike valleys. These dissected plains and tablelands also contain small aeolian dunefields that are outliers of the Simpson Desert (Figure 10.3). In places, the Todd River has incised into carbonate-rich red earth, developed on the Pleistocene alluvial surface (Figure 10.6).

In its lower reaches, the Todd River channel occupies 300–500 m wide, interdune corridors between longitudinal northwest trending dunes of the northern Simpson Desert (Figure 10.5d). It maintains a well defined channel for 10 km, then the channel crosses a longitudinal dune and bifurcates. In this reach, incipient floodplains form discontinuous, bench-like insets composed of fine sandy material, unconformably overlying the aeolian sands. Approximately 20 km further downstream, the channel splits again and occupies

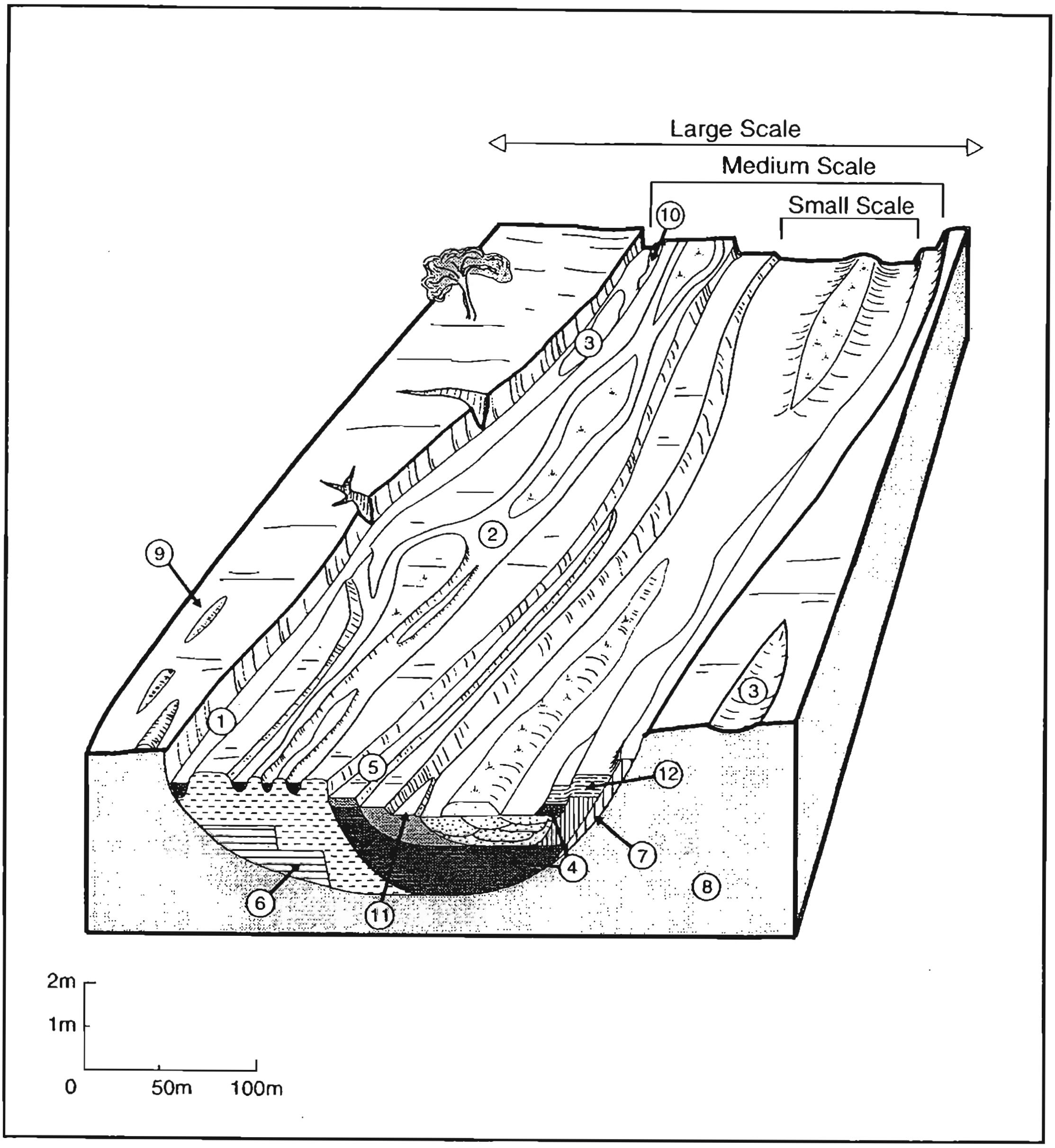


FIGURE 10.6 Schematic block diagram of the Todd River channel and floodplain. Note the variable surface morphology and complex subsurface fill units. 1, Back channel; 2, flood channel; 3, swirl pit; 4, channel inset; 5, floodplain inset; 6, buried floodplain remnant; 7, surface floodplain remnant; 8, Pleistocene red earth alluvium terrace; 9, overbank bars; 10, back channel inset; 11, stripped surface; 12, floodplain veneer deposit. For full description see Bourke (1994). The hierarchical scheme of flood forms is indicated as small, medium and large scale. Reproduced from Bourke (1994) by permission of IAHS Press

several parallel swales. Channels support dense stands of coolibah trees (*Eucalyptus microtheca*) and channel morphology is subdued. Where the channel passes through dunes, mud is deposited as backflood sediments in the dune swale. This pattern continues for a further 40 km until flow dissipates in a terminal floodout (Figure 10.3). The pattern of the longitudinal dunes controls the prevailing trellised, distributary channel pattern in this reach (Figure 10.5d).

PHYSIOGRAPHIC FACTORS INFLUENCING LANDFORM VARIABILITY

Downstream changes in channel morphology, planform and sediments are step-like in the Todd River. The channel bed in some places is cut into relatively indurated Pleistocene alluvium or bedrock, while further downstream it may be locally aggrading and contain thick sequences of sandy tabular bars. Many factors, such as the nature of sediment transport, sediment supply, channel boundary irregularities and knickpoint development, contribute to this pattern of variability. This section will focus on the step-change in channel morphology at tributary confluences.

In ephemeral streams, the pronounced variability of flow from confluent channels results in an exaggerated and often rapid change in channel morphology (Mabbutt, 1977; Reid et al., 1989), and channels often aggrade at or below junctions (Schumm, 1961; Everitt, 1993; Thornes, 1994b). It is the variability in the timing and magnitude of flow discharges between the contributing systems at confluences that influence the change in channel bed morphology and sediments above and below confluences in the Todd catchment. Two factors dominate the magnitude and direction of change: tributary spacing and tributary length.

Tributary spacing and tributary length

The channel distance between significant tributary inputs is an important influence on the behaviour of the floodwave downstream. In arid and semi-arid channels, transmission losses through drainage diffusion, infiltration and evaporation/evapotranspiration are significant (e.g., Schumm and Hadley, 1957; Schumm, 1961; Knighton and Nanson, 1994). While no transmission data exist for the Todd River, reports from the manager of the Todd River Station indicate that many large flows recorded at Alice Springs do not reach the Ross River confluence 78 km downstream (Figure 10.3) (I. Lovegrove, pers. comm.). Transmission losses into the channel bed result in a rapid downstream attenuation of flood magnitude. Flow is only augmented by a few large tributaries, the most significant of these being the Ross River and Giles Creek (Figure 10.3).

The proximity of the tributaries to sediment sources in the mountain ranges is an important factor affecting channel morphostratigraphy at confluences. The layout of the

TABLE 10.1 Channel distance from piedmont apex to confluence

Tributary	Channel distance to confluence from range outlet (km)	
	Tributary	Trunk stream
Emily	8	5
Jessie	10	28
Undoolya	13	35
Ross	10	78
Giles	13	100

Todd catchment is such that, south of Alice Springs, the trunk stream drains eastwards along a wide strike valley (Figure 10.3). As a consequence, tributaries travel relatively short distances from the ranges to confluence points (Table 10.1, Figure 10.3). Accordingly, the sediment loads, textures, channel gradients and flow magnitudes in the larger tributaries are often greater than those in the trunk stream, despite the observation that transmission losses probably increase between the mountain and alluvial fan reaches. As a consequence, several of the small tributaries have unchannelled junctions with the trunk stream.

RESPONSES OF A MAJOR CONFLUENCE TO RAINFALL EVENTS

The confluence dynamics of the Todd and Ross Rivers were monitored between 1993 and 1995 and are used here to illustrate the impact of tributary spacing and length upon confluence morphology and sediments (schematically represented in Figure 10.7). During this period, the geomorphic effects of a series of low flows down the trunk stream of the Todd River in conjunction with a series of moderate to high flows from the Ross River tributary were observed. The distinctive morphostratigraphy that developed in the Todd channel bed upstream of the confluence is illustrated (Figure 10.7a, Table 10.2). Upstream of the confluence, the Todd channel bed material fined downstream, from coarse and medium sands arranged in large tabular bars to horizontally laminated, thinly interbedded layers of fine sand and silty clay. This rapid downstream fining of bed material was accompanied by a decrease in channel gradient with a gradient reversal ($-0.0007\,\mathrm{m\,m^{-1}}$) near the confluence. Channel width decreased from 120 m to 40 m and the channel had a trench-like morphology with vertical channel banks. Floodplain sediments along this reach are vertically accreted, thickly bedded flood couplets and sand sheets.

At that time, bed elevation stepped upwards at the entrance point of the Ross River (Figure 10.7a), forming a barred confluence. Channel width increased from 40 m to 180 m (Figure 10.8), and channel bed material coarsened to gravelly sands. The channel bed gradient increased to $0.0032\,\mathrm{m\,m^{-1}}$ (Table 10.2). Channel bed morphology is typical of the wide braided reaches of central Australian streams described by Zwolinski (1985) with large bar forms and multiple channels. In addition there are a series of alluvial benches inset against the steep channel banks (Bourke, 1994).

Material deposited by the Ross River during the final phase of moderate to high flows, locally aggrades the bed, partially migrates up the Todd channel and effectively dams the lower-magnitude flows travelling down the Todd (Figure 10.7a), which deposit suspended load augmented by backflooding of fine sediment and plant detritus from the Ross.

However, this is a highly dynamic confluence, owing to uneven patterns of rainfall distribution described earlier. Hence, relative magnitude and timing of flows from Alice Springs and the Ross River vary through time and so too does the confluence morphostratigraphy. A recent flow (a one-in-five year event at Alice Springs) transformed the barred confluence to a discordant confluence, where both systems contain gravelly sands (Figure 10.7b).

During this event, total rainfall receipts at the Ross gauge measured 204.2 mm (peak rainfall 12–13 March) and 188.5 mm at the Bond Springs gauge (peak rainfall 16 March) north of Alice Springs (for locations see Figure 10.3). The Ross River flow peaked at the confluence before flow that travelled down the Todd and the Ross River aggraded its bed

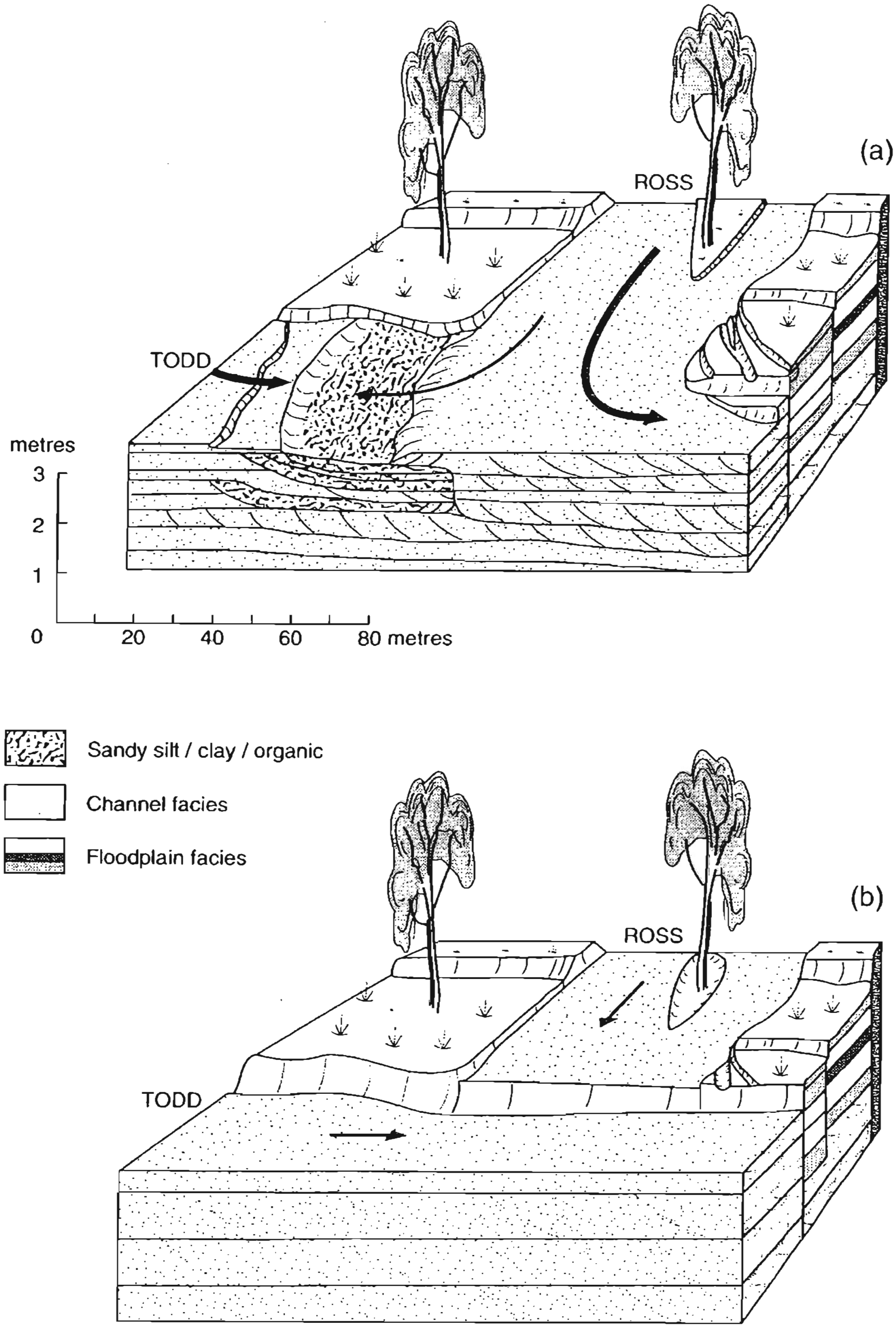


FIGURE 10.7 Todd/Ross confluence dynamics. Channel and floodplain morphostratigraphy following: (a) a sequence of low flows down the Todd channel and high flows down the Ross channel, resulting in an interfingering of coarse and fine units and a reversed local channel gradient. Sediment size coarsens significantly along the main channel through the confluence; (b) a high-energy flow down the Todd channel. The river has incised its bed and transformed the channel bed morphostratigraphy, forming a discordant junction in addition to eroding its floodplains

TABLE 10.2 Characteristics of the Todd channel upstream and downstream of the Ross River confluence in 1993

Variable	Upstream of confluence	Downstream of confluence
Gradient ($m\,m^{-1}$)	−0.0007	0.0032
Width (m)	40	180
Bed material	Horizontally bedded clay-rich silt and fine sand, plant material	Cross-bedded gravelly sand
Channel pattern	Straight	Locally braiding

in a manner similar to that illustrated in Figure 10.7a. Arriving later, the Todd flood peak incised and truncated the alluvial dam from the Ross River, leaving the channel bed of the Ross hanging 2.6 m above the thalweg of the Todd River (Figure 10.7b). The discordant junction morphology persisted for several months until a lower-magnitude flow event on the Ross incised a small inset channel to local base level at the confluence.

These adjustments of confluence morphology illustrate three aspects of landform variability in ephemeral systems. First, during high-magnitude flows in ephemeral streams, it is the process that controls form, and forms created by such flows partly control processes during subsequent smaller events. In this way the persistent erosion and

FIGURE 10.8 An oblique aerial photograph of the confluence of the Todd and Ross River, taken in 1993. The Ross River enters the photograph on the lower right and the Todd on the upper right. Flow is towards the left of the photograph. Note the relatively narrow channel dimensions and fine sediment, as indicated by the darker colour, in the Todd channel bed upstream of the confluence. The Ross River tributary is clearly the dominant system at this time

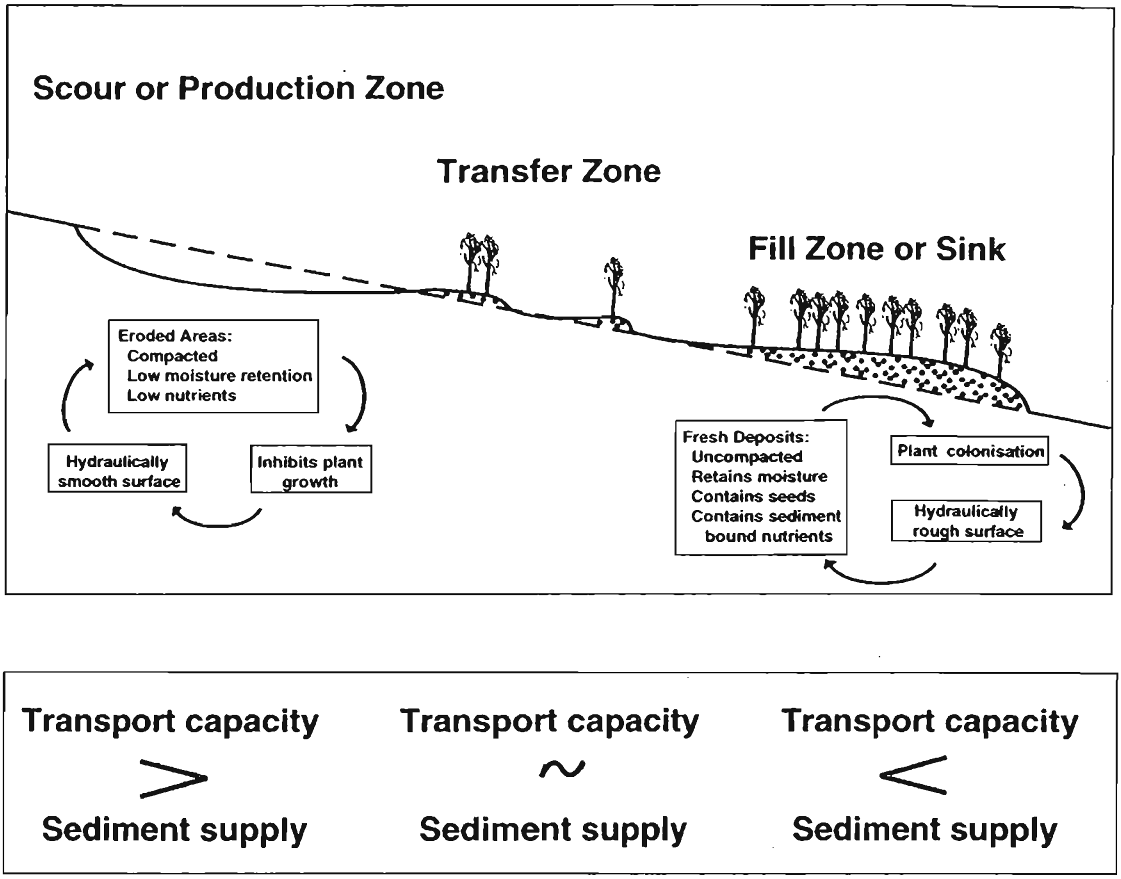
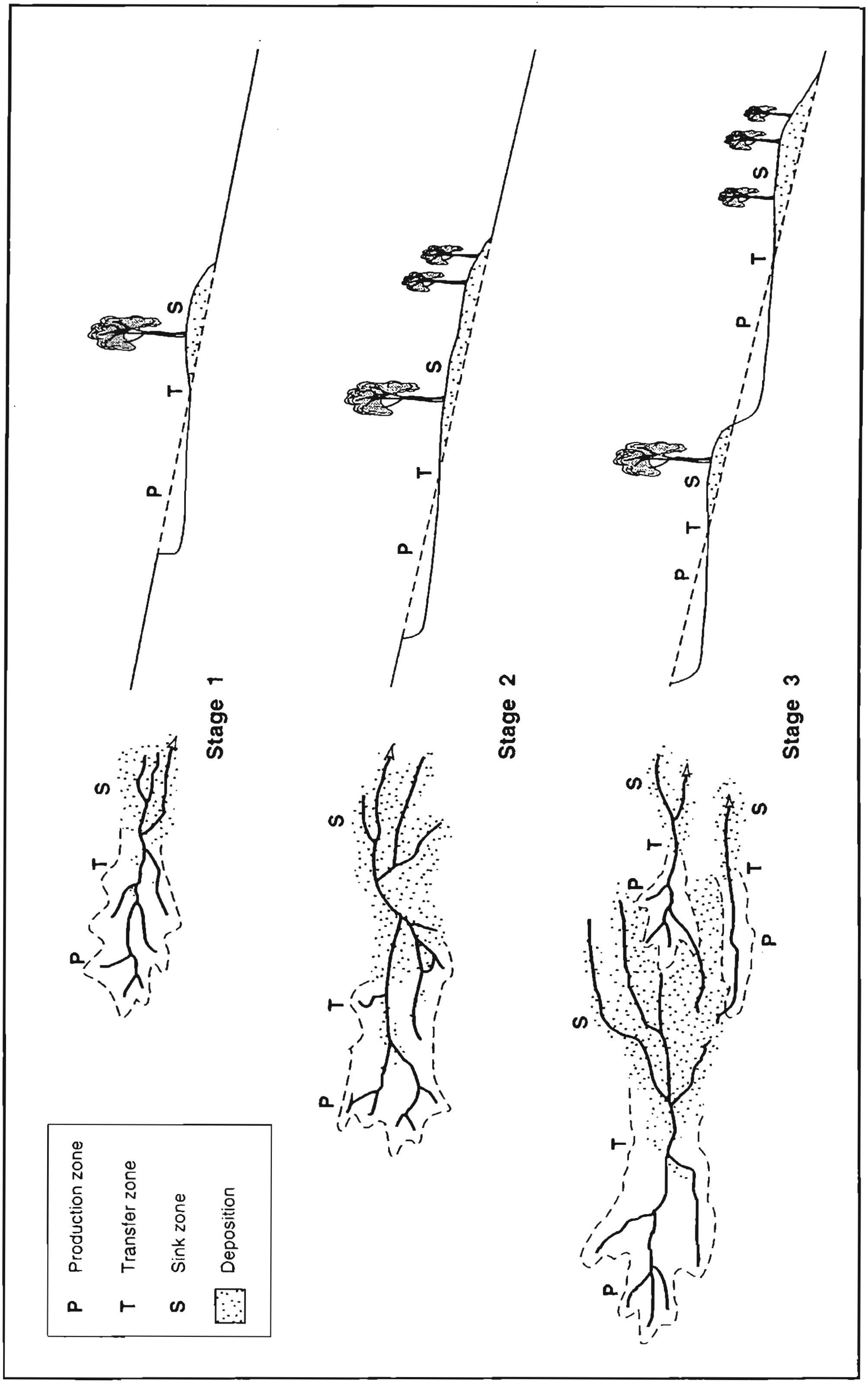


FIGURE 10.9 Schematic model of an erosion cell. The scour zone is an area of erosion and actively sheds both water and sediment. The transport zone occurs downslope and is occupied by discontinuous patches of sediment in transit or in temporary storage. In arid and semi-arid regions, storage may be for a considerable time as transport events are intermittent and short-lived. The fill zone lies downslope and is an area of sediment deposition. Accumulation rates are variable and are dependent on rates of sediment delivery and the propensity for the channel to change location. Reproduced from Pickup (1988a) by permission of Academic Press Ltd

depositional patterns generated by floods modulate the landscape response to subsequent and smaller events. Second, they highlight the importance of the order and magnitude of preceding events on the geomorphic response to flow events (cf. Pickup and Rieger, 1979). Third, it supports the view of Cooke et al. (1993) that forms and processes are rarely in equilibrium in ephemeral streams.

Similar effects from asynchronous flow peaks at confluences include the alternating damming and breaching of tributary confluences along the Wadi Watir in the

FIGURE 10.10 *(opposite)* The temporally variable landform assemblage of an erosion cell mosaic in a flat area such as an alluvial fan or floodplain. The shifting pattern is determined by the evolution of the erosion cell over time and the complex interaction of large- and small-scale erosion cells. Stage 1: erosion cell established as small production, transfer and sink zones. All three zones begin to extend upslope. Stage 2: upslope extension continues. The sink zone is elongated and no longer aggrades at the downstream end, but receives sediment-deficient flow. Gully initiation in distal reaches. Stage 3: development of new erosion cell. Primary sink may become inactive as new erosion cells capture diverted runoff. Reproduced from Pickup (1985) by permission of the Australian Rangeland Society


P Production zone
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southeastern Sinai (Schick and Lekach, 1987) and the distinct sedimentological signature of asynchronous tributary activity in channel bed sediments downstream of the confluence of the Il Warata and Il Naitiwa in Kenya (Reid et al., 1989).

PATTERNS OF EPHEMERAL SEDIMENTATION

Sediment supply in arid fluvial systems is episodic in time and variable in space and is strongly linked to patterns of vegetation cover. Pickup (1985, 1988a,b) has shown that patterns of shifting erosion and sedimentation, at different scales, in central Australia are modulated by colonization of newly deposited sediment by plants. The landscape can be considered in three zones: a sediment scour or production zone, a sediment transfer zone, and a sediment sink or fill zone (Figure 10.9). Newly deposited sediment in the fill zone (Figure 10.9) is uncompacted and potentially can hold more moisture than older compacted sediment, and may also contain seeds and a higher proportion of sediment-bound nutrients. Thus it tends to be readily colonized by plants, which stabilize the surface and promote further deposition. At the smallest scale these three elements can be identified within channels as scours, planar beds and shoals formed during smaller floods; at a larger scale, downcut channel reaches represent the sediment source zone, sandy channel reaches with transient bar features the transport zone, and aggrading channel reaches represent the fill zone. At the largest scale are extreme flood deposits, described later. These three elements shift around the landscape and scours become sediment traps while transfer channels and fill zones become new source zones (Figure 10.10).

At a relatively large scale the scour–transport–fill (STF) model is illustrated by floodouts located in the piedmont zone of the MacDonnell Ranges (Figures 10.3 and 10.5b). The bare, steep rock slopes in the steep-gradient headwaters of the Todd River constitute the source zone from which sand and angular weathered clasts pass through a series of small-scale fans into a network of gullies which feed into the channel of the Todd River. This detritus is then transported together with locally reworked alluvium to the broad piedmont where it is deposited, contributing to extended aprons of alluvial fill. These features are schematically represented in Figure 10.5b and are typically vegetated by coolibah trees (*Eucalyptus microtheca*).

The scales of STF sequences are not exclusive and may have complex spatial relationships; for example, the distal zone of one floodout may be the production zone for another STF sequence, or smaller cells may be embedded within larger ones. Erosion cells may not be fully developed or represent latent features in the landscape (Pickup, 1988b). The transition between linked cells tends to be morphologically abrupt. This patterning of arid-zone sediment transport and deposition produces a shifting mosaic of ground surface sediments known as an erosion cell mosaic (Pickup, 1985; Figure 10.10).

VARIABLE DISCHARGE REGIMES: A MULTISCALE APPROACH TO FLUVIAL LANDFORMS

Fluvial landforms that develop under variable flow regimes are best described using a multiscale approach (Gupta, 1988, 1995; Pickup, 1991). In these environments, landform assemblages are associated with discrete flow magnitudes. Examples include the nested channel systems described by Graf (1988b) and the nested fluvial forms of the Auranga River, India (Gupta, 1995). Under the present climatic regime, the Todd River is subject to flow at extremes of the magnitude/frequency spectrum, i.e. there are long periods with no flow in the channel interspersed by flood events including occasional superfloods (Bourke, 1998a). Hence, fluvial landforms evolve episodically rather than continuously and fall into discrete size classes.

Fluvial landforms of the Todd River fall into three categories based primarily on landform scale and associated flow magnitude: landforms generated by within-channel flows (small scale); those formed by flows which extend across floodplains (medium scale); and superflood landforms (large scale) (Figure 10.6). Dimensions across these three classes vary by an order of magnitude; for example, longitudinal bars in the three categories measure 10 m, 100 m and up to 2000 m, respectively. Approximate return periods for flows at each respective scale are less than one-in-10 year flood, one-in-100 year flood, and an estimated one-in-1000 year flood. Geomorphologically, these different scales of flow produce complex nested assemblages of fluvial landforms in the Todd River system. A description of the geomorphic effects of small- and medium-scale events is given, highlighting the importance of local factors on landform variability, followed by a description of large-scale flood features.

Small-scale fluvial landforms, formed by flows within the active channel banks, have a significant impact on channel side and channel bed. The main geomorphic effects include localized but sometimes substantial channel widening; erosion of within-channel benches in some reaches and aggradation in others; bank accretion; channel bed aggradation and incision (Figure 10.6).

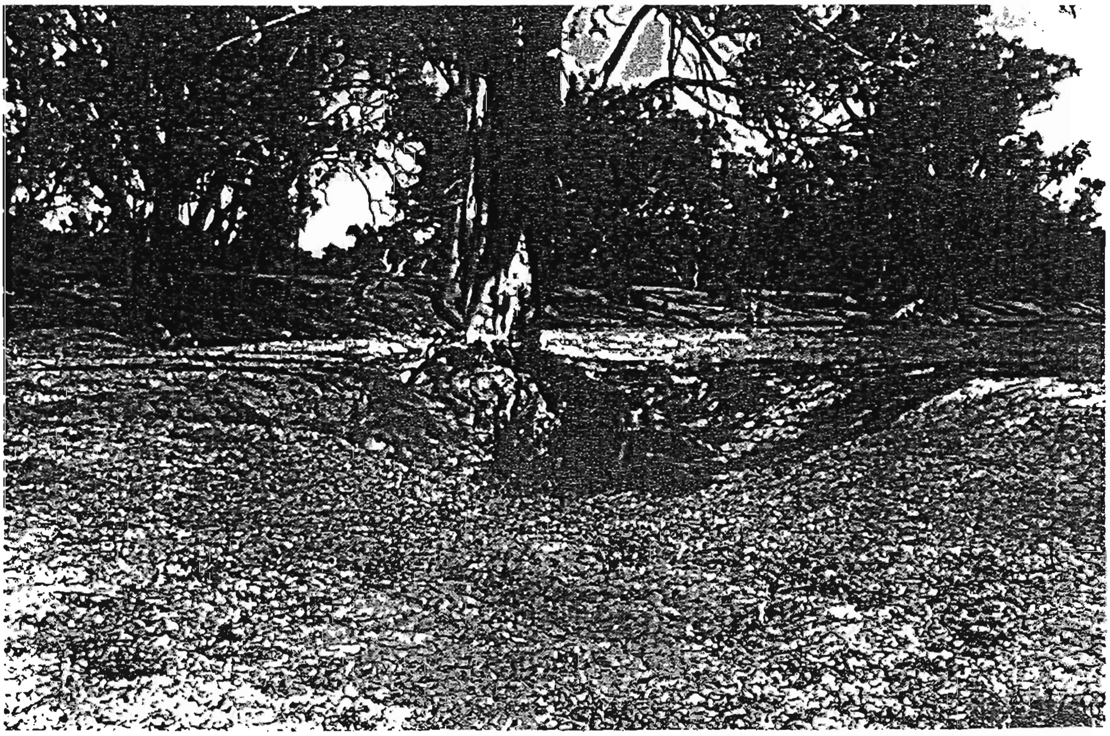

FIGURE 10.11 Elliptical scour around river red gum (*Eucalyptus cameldulensis*) formed during medium-scale flow in Todd River channel. Person in right foreground of the scour gives scale. Flow is towards the camera. Note the partial re-excavation of buried trees along the right bank

Medium-scale fluvial landforms are formed by flows which spread across floodplains (Figure 10.6). The lateral extent of these floods is limited by event magnitude and by topographic barriers such as older, higher alluvial and aeolian surfaces. The geomorphic effects are more pronounced in areas where the active channel is entrenched into older, more resistant alluvium. Where floodplains are laterally extensive, flood effects decrease with distance from the channel. The largest gauged event on the Todd River occurred in 1988, with an estimated return interval of one-in-50 years. The geomorphic effects of this event include channel widening by 300%, the lateral and downstream extension of braided reaches, especially downstream of confluences (Pickup, 1991), and the deposition of ripples, longitudinal, transverse and linguoid bars in the channel bed throughout the catchment. Also observed was the removal of within-channel benches, lateral and vertical erosion of floodplains, erosion around large trees, and discontinuous deposition of sand sheets, splays and bars on floodplain surfaces.

Local factors strongly influence channel response to small- and medium-scale events. We have already mentioned the effects of asynchronous flooding at confluences and the importance of pre-existing channel configuration upon local changes at the Todd–Ross confluence (Figure 10.7). Other influential factors include channel roughness and variable boundary resistance. A spectacular example is the effect of vegetation on the development of asymmetric, elliptical scours which are formed by eddies around river red gums (*Eucalyptus cameldulensis*), both in the channel bed and on floodplain surfaces (Dunkerley, 1992; Bourke, 1994) (Figures 10.7b and 10.11). Large trees on elongated in-channel bars act as sediment traps at some flows and initiate substantial leeward scour at others. Variations in channel width are related to local bank resistance: extensive channel widening commonly occurs where channel banks are composed of unconsolidated sand, often associated with aggradation of the channel bed. In areas with more resistant boundary materials, for example where the river flows through indurated Pleistocene alluvium, large scour holes dominate the channel bed (similar to that shown in Figure 10.5c).

In central Australia, as in other arid and semi-arid regions, extreme events are geomorphologically the most important (Schick, 1974, 1995; Thornes, 1976; Wolman and Gerson, 1978; Patton and Baker, 1977; Harvey, 1984; Pickup, 1991; Patton et al., 1993). The largest-scale fluvial landforms in the Todd River (Figures 10.12 and 10.13) are formed by extreme flows, which occur rarely and inundate vast tracts of the landscape including the swale systems of aeolian dunefields. The occurrence of very large floods in the palaeohydrological record of central Australia was demonstrated by Baker et al. (1983) and Pickup et al. (1988), who reported late Holocene slackwater sequences in the Finke gorge. Pickup (1991) and Patton et al. (1993) described the geomorphic effects of very high-magnitude events on piedmont fans of the Todd and Ross, and Bourke (1998a) has detected the geomorphic effects of extreme flood events downstream to the terminal floodouts in the northern Simpson Desert.

Large-scale flood landforms include sand sheets, ripple fields, overflow channels (Pickup, 1991), large-scale palaeobraid channels, levee deposits and broad, low-relief bars (Patton et al., 1993) (Figures 10.12 and 10.13). In addition, large-scale channel avulsions have eroded longitudinal dunes of the northern Simpson Desert. The beds of these scoured channels are punctuated by large-scale swirl pits up to 2.5 m deep and 15 m

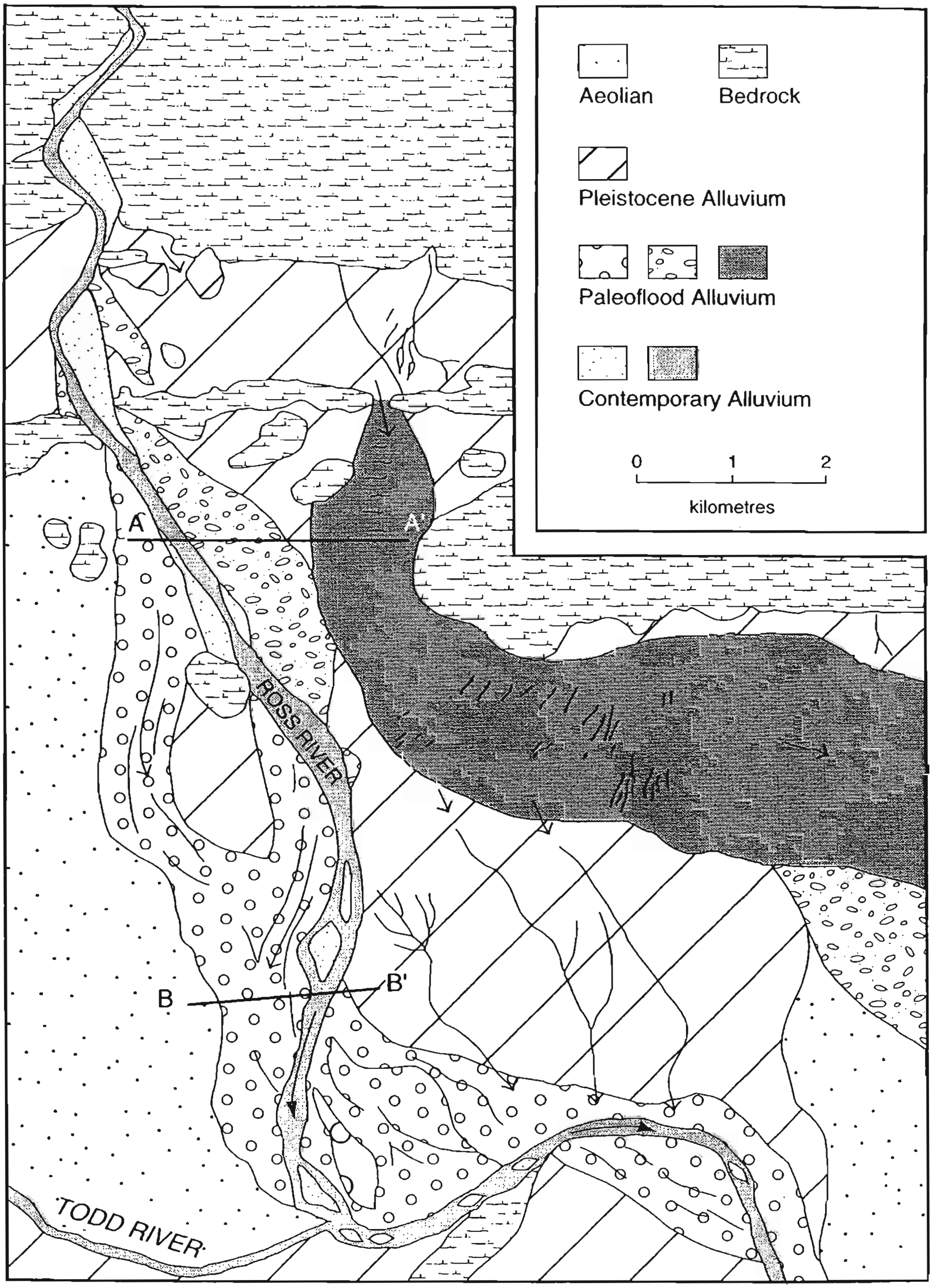

FIGURE 10.12 The Ross River palaeoflood channels. For detailed description see Patton et al. (1993). These channels cross the piedmont reach south of the MacDonnell Range. Note the higher Pleistocene surfaces around which the high-magnitude flows are deflected. Reproduced from Patton et al. (1993) by permission of Academic Press, Inc.

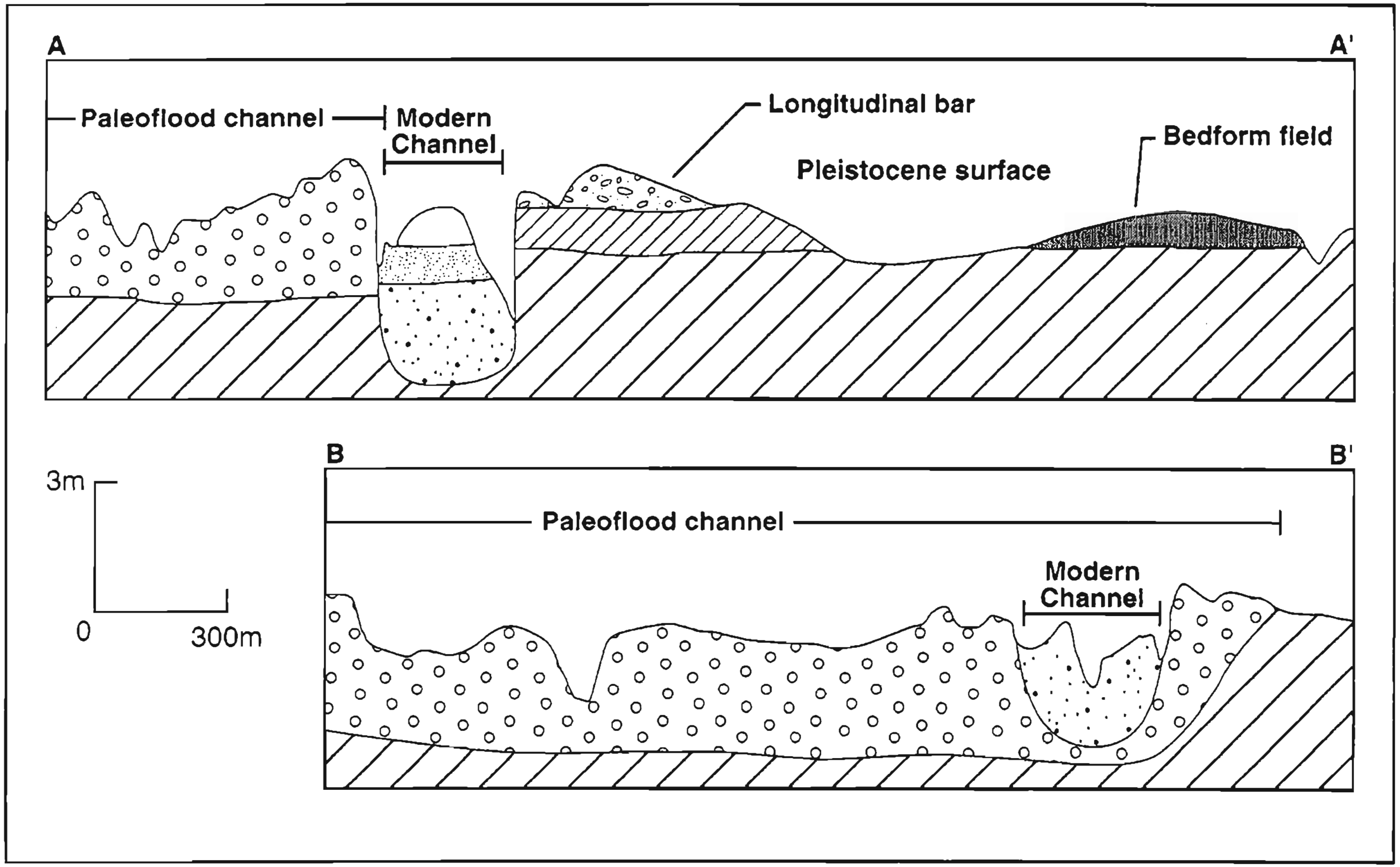

FIGURE 10.13 Schematic cross-sections of the superflood morphology of the Ross River palaeoflood channel. For location see Figure 10.12. The assemblage of large-scale palaeoflood channel forms extends long distances from the contemporary channel and displays a variety of morphologies. For full description see Patton et al (1993). Reproduced from Patton et al. (1993) by permission of Academic Press, Inc.

long. Selected cross-sections (Figure 10.13) illustrate three aspects of the superflood landscape: fluvial landforms extend several kilometres from the modern channel; the scale of fluvial landforms is more than 30 times that of the modern channel; and palaeofloods generate a variety of morphologies including palaeochannels, high-level bars and ripple fields. These large-scale landforms evolve episodically and remain inactive for long periods of time (Pickup, 1991), and may appear to be in disequilibrium with the contemporary channel.

In addition to the geomorphological imprint of a highly variable discharge regime, three other effects are noted. First, the scale of flows affects the frequency of reworking of alluvial deposits and the balance changes downstream, so that the headwaters and piedmont reaches of the system are more frequently reworked by small- and medium-scale flows than the downstream reaches, owing to transmission losses downstream. Second, the preservation of flood features is scale-dependent: forms created during large-scale flows potentially are preserved for longer than those generated during medium- and small-scale flows. Third, as channel recovery from extreme floods is ongoing, the landforms produced by smaller-scale flows cannot be adequately explained without reference to the more regional-scale events (Pickup, 1991; Bourke, 1998b).

CONCLUSION

To summarize, in this variable discharge regime, landforms develop episodically, and downstream transitions tend to be abrupt. At tributary confluences disequilibrium is expressed as discordant and barred junctions. Asynchronous tributary activity is influenced by the spatial and temporal patterns of rainfall and runoff, the tributary spacing and length, hydrological lags and transmission losses. Discharge events range from the extreme superflood to small flows which dissipate rapidly downstream. This variability produces an assemblage of fluvial forms that varies across a hierarchy of scales. Form preservation is related to distance downstream and distance from the active channel with the larger-scale forms preserved for longer periods. The older forms and sediments deposited during high-magnitude events modulate the geomorphic response to lower-magnitude flows. This assemblage of fluvial forms is the product of a system where form and process are rarely in equilibrium.

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