

# Palaeofluvial geomorphology in southern Africa: a review

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**Abstract:** This article presents an overview of palaeofluvial geomorphology research in southern Africa. For the purposes of this article this includes South Africa, Zimbabwe, Namibia, Lesotho, Swaziland and Botswana. Although interest in fluvial systems has a long history in southern Africa, the scientific study of rivers was initiated by the discovery of the first alluvial diamond along the banks of the Orange River in 1867. Since then, significant progress has been made in unravelling the fluvial history of southern Africa from the early Archaean Ventersdorp Contact Reef River to modern channel process studies. The development of an understanding of palaeofluvial systems has occurred along two main lines. The first was alluvial diamond exploration work undertaken by the large mining houses. The second line was of a more 'academic' interest and included determining the impact of superimposition, tectonics, base level and climate changes. The review suggests that southern Africa fluvial systems have shown large-scale changes in drainage pattern, discharge and sediment yield and that these can be related to a complex set of causative factors including the geological template, the Jurassic rifting of Gondwana, tectonic episodes and climate change.

**Key words:** palaeofluvial geomorphology; drainage; tectonics; climate change; Orange; Vaal; arid rivers; Molopo; Zambezi.

## I Introduction

Research into southern African fluvial geomorphology has a long history (Dollar, 1997). Like Australia (see Tooth and Nanson, 1995) the environment, landscape and fluvial systems have played a central role in people's lives in southern Africa for thousands of years. It is, however, only within the last hundred years that scientific study of the environment, landscape and fluvial systems has developed. This article will focus specifically on fluvial work in southern Africa. For the purposes of this review this will include South Africa, Lesotho, Swaziland, Botswana, Namibia and Zimbabwe. Figure 1 shows the fluvial systems of southern Africa.

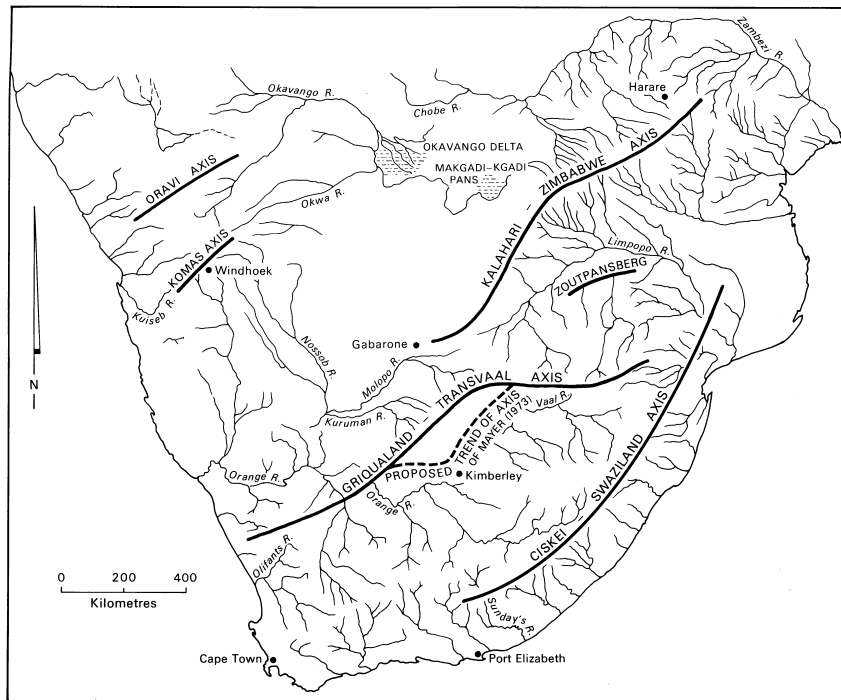


Figure 1 Fluvial systems of southern Africa

## II Ancient fluvial systems

Modern southern African fluvial systems owe their development to the geological template, Jurassic rifting of Gondwana and subsequent creation of new base levels for erosion. There is an extensive literature dealing with pre-Gondwana fluvial systems. Details regarding ancient fluvial systems have been uncovered through the deep mining operations in the highveld of South Africa. A good example of this is the early Archaean (2885 Ma BP) Ventersdorp Contact Reef (VCR) which is a sedimentary layer that occurs at the base of the Ventersdorp lavas which rest on the Witwatersrand supergroup (de Kock, 1941). This fossil river has been mined for gold since 1888 (de Kock, 1941; Chunnert, 1994). This ancient fluvial system shows evidence of successive terraces, cuesta ridges, theatre-headed valleys, trellis drainage, strath terraces, wash terraces and concave bedrock ridges (see, among others, Krapez, 1985; Hall, 1994; Henning *et al.*, 1994; MacWha, 1994; Viljoen and Reimold, 1994). The sedimentary rocks of the Karoo supergroup have also been extensively studied. These are best exposed in the Karoo Basin. The basin fill consists of up to 9 000 m of clastic sediments and lavas. The ages of these sediments range from around 300 Ma BP to *c.* 190 Ma BP. The depositional environments are well documented (see, for example, LeBlanc-Smith and Eriksson, 1979; Eriksson, 1986; Visser, 1989; Smith, 1995; Smith *et al.*, 1997).

An in-depth review of the post-rifting landscape and the associated fluvial landforms has been admirably achieved by other workers (cf. King, 1963; Fair, 1978; Partridge and Maud, 1987; Dardis *et al.*, 1988; De Wit, 1993; Hattingh, 1996a; Maud, 1996). Here, a short

review will suffice. In southern Africa, long periods of tectonic stability (African, post-African I, post-African II erosion surfaces) have been interspersed with periods of tectonic uplift (Miocene and Pliocene) along clearly defined axes that have influenced the macrolevel functioning of southern African rivers (Figure 1). The main denudational period was initiated shortly after the rifting of Gondwana and extended to the late Cretaceous. Major sedimentation peaks in the Eocene, Miocene and Pliocene relate to these periods of maximum relief. Imprinted on these tectonic phases have been the impact of climatic change with associated periods of wetness and dryness and concomitant changes in vegetation cover, runoff, erosion, weathering rates and environmental change. After an extensive period of planation the African erosion surface developed with flat meandering rivers dominating the southern African landscape (Partridge and Maud, 1987). Two periods of renewed axial uplift in the Miocene and Pliocene rejuvenated many southern African rivers – hence the incised nature of many coastal rivers. The fluvial geomorphology of southern Africa must be seen within the context of these (polycyclic) macroprocesses.

### III Early work

Although the first written records of landscapes in southern Africa appear with the advent of European colonists, human interest in the landscape long predates this (Lewis-Williams, 1981). Early travellers and missionaries wrote about southern African fluvial systems from the sixteenth century (see, for example, Kolb, 1727; Allamand and Klockner, 1778; LeValliant, 1790; Barrow, 1801; Campbell, 1815; Burchell, 1822; Napier, 1849). The work by explorers, missionaries and travellers was generally descriptive in nature (Livingstone, 1858; Selous, 1896; Forbes, 1957).

Much of the early scientific work on South African fluvial systems was driven by mineral exploration, although some early workers took a wider ‘academic’ view of geomorphology (Rogers, 1903; Schwarz, 1907; Shand, 1913). It was the discovery of the alluvial diamond fields of Griqualand West in 1867 (De Wit, 1996) that activated fluvial geomorphology as a science in southern Africa. These deposits are concentrated along the right banks of the Vaal, Riet and middle Orange Rivers. Shaw (1872) first wrote about these ‘Vaal diamond gravels’ in the *Quarterly Journal of the Geological Society of London*, noting that the gravels were probably ‘not locally derived’. Penning (1901) suggested that the terraces indicated the Vaal at different levels. The discovery of a tooth of a *Mastodon* in a ‘60–80 ft terrace’ (Beck, 1906) and the fossil remains of ‘*spp.*’ *Hippopotamus* and *Equus* (Fraas, 1907) sparked considerable worldwide interest in the Vaal gravels. A further small deposit was discovered along the Limpopo River – the Seta deposit (Trevor *et al.*, 1908). In 1912 the discovery of diamonds around Schweizer Reneke led to the development of the Lichtenburg fields. By 1926 these fields had become the most significant source of alluvial diamonds in South Africa (De Wit, 1996).

The economic reasons for the interest in the origins of these diamondiferous gravels are obvious (Williams, 1905; Du Toit, 1906; Johnson and Young, 1906; Merensky, 1908; Harger, 1909; Lotz, 1909; Wagner, 1914; Cornell, 1920; Williams, 1930; 1932). Du Toit (1910) provided the first reasoned explanation for the diamondiferous gravels. He recognized the significance of palaeodrainage lines in explaining the origins of the gravels. Du Toit (1922) regarded the Vaal River terraces as palaeoindicators, but was reticent to correlate the terraces according to age. He suggested that climate change,

tectonic uplift and warping and the breaching of rock barriers were possible reasons for the existence of the terraces, but that the causes were complex.

The 1920s started an era where general, regional descriptive work became commonplace (cf. Wood, 1922; Ranke, 1931). Wellington (1929; 1933; 1938; 1941; 1945) was instrumental in dividing southern Africa into various regional 'areas' and describing regional drainage patterns and morphologies. During this time, interest in climate change and river metamorphosis became apparent. Rogers (1922) speculated on the changes in climate since the late Cretaceous. Maufe (1930), writing on the Umgusa River in Southern Rhodesia (now Zimbabwe), argued that alternating periods of aggradation and degradation in fluvial systems could only be ascribed to climatic change as there was no evidence for any epeirogenic movement. Aggradation was ascribed to a heavier, more widespread rainfall than the present – a pluvial period – while degradation was affected by semi-arid drier conditions. Maufe (1930) cautioned against extrapolating local evidence of climate change to other areas. He pointed out that while semi-arid conditions were being experienced in southwestern Southern Rhodesia, large rivers were traversing Griqualand West (Rogers, 1922), indicating a much wetter climate (Goodwin, 1926). Maufe (1930) therefore correctly pointed out that climatic changes are geographically varied, and that wetter climates in one part of the subcontinent may be complemented by a contemporaneous drying climate in other parts of the subcontinent.

During the 1940s descriptions of river superimposition, antecedent drainage and reconstructions of palaeodrainage lines became fashionable (Fair, 1944; King, 1944; Taljaard, 1944; Wellington, 1945; Dixey, 1945a; 1955). Wellington (1941) pointed out that South African river systems were strongly controlled by superimposition, and that rivers in the southern Transvaal were superimposed rivers derived from incision through the covering Karoo sediments on to the pre-Karoo surface. There was also renewed interest in the impact of tectonic uplift and warping on drainage morphometry (Wellington, 1955, provides a comprehensive discussion of superimposition in his book on South African geography). Dixey (1943) suggested that the Congo–Zambezi watershed had been initiated by warping of the Miocene peneplain (cf. Du Toit, 1933). Consequently, this uplift reversed and rejuvenated many of the rivers on the fringes of the watershed. Dixey (1945b) suggested that the upper Zambezi River had been captured by the Congo. Superimposition became a common explanation for the macroform functioning of southern Africa rivers with research focusing on the Vaal and its tributaries (Du Toit, 1951; Cooks, 1968; Le Roux, 1968; Beckedahl and Moon, 1980; Twidale and Van Zyl, 1980; De Villiers, 1988) and the Zambezi and its tributaries (Boocock and van Straten, 1962). Stream capture became an acceptable explanation for the trellis drainage pattern of the Cape Fold Mountains (cf. Haughton *et al.*, 1937; Beekhuis *et al.*, 1944; Mabbutt, 1952; Lenz, 1957; Maske, 1957; Söhnge and Greeff, 1985; Rust and Illenberger, 1989; Söhnge, 1991; Hattingh, 1996b; 1996c) while Baillie (1969; 1970), Cooks (1972), De Swardt and Bennett (1974), De Villiers (1975) and Russel (1976) all stressed the significance of structural control in the evolution of fluvial systems.

#### **IV The major river systems**

##### **1 The Vaal**

Much effort has been exerted on unravelling the complex history of the Vaal/Orange system. The primary reason for this was to identify economically exploitable diamond-

iferous terraces and gravel deposits. Du Toit (1933) argued that the diamondiferous gravels of the Vaal were deposited by a 'much larger river' than the present Vaal, and that this river (with a much larger discharge) could only have been the extension of the present Molopo. Axial uplift along the Griqualand–Transvaal axis during the late Tertiary (Figure 1) reversed the drainage pattern, with the Molopo now flowing into the Limpopo. The Okavango River (it was argued) formerly joined the Limpopo, but the axial arching resulted in a break in the drainage, resulting in the formation of the Makgadikgadi pans. Uplift of up to 350 m resulted in stream rejuvenation and consequently increased drainage (and stream power) of the west draining rivers through the Kalahari sediments. Du Toit (1933) thus argued that the principal cause for drainage evolution and change was tectonic activity, but conceded that climatic change may have played a role. In fact Du Toit argued that uplift (and therefore altitudinal elevation) in itself results in climate change and possibly increased rainfall.

Söhnge *et al.* (1937) divided the diamondiferous gravels of the Vaal into 'younger' and 'older' gravels. It was recognized that the higher, older gravels were nonimplementiferous and therefore difficult to date while the lower, younger gravels were implementiferous. Söhnge *et al.* (1937) suggested that increased rainfall represented a cycle of erosion while decreased rainfall represented periods of aggradation. Cooke (1946) argued that the origin of the diamondiferous gravels could be explained by the capture of a former tributary of the Vaal by the Harts River. Cooke (1949) in a later memoir provided a list of fossil mammals that had been excavated by various diggers and archaeologists in an attempt to fix a date on the various terrace levels.

Van Riet Lowe (1952: 148) suggested that the lowering of the Vaal bed could only have been achieved by increased runoff, ultimately resulting in terrace formation and thus concluded: 'it is clear that we cannot escape the conclusion that long-term oscillating wet and dry climates had almost as profound an effect ... in South Africa as the oscillating glacial and interglacial conditions had in Europe.' Van Riet Lowe (1952) provided a table showing the climatic conditions associated with the Vaal River deposits (Table 1). Visser and Van Riet Lowe (1955) argue that the evolution of the Caledon River could be

**Table 1** Vaal River chronology

Vaal River deposit	Climatic conditions
Surface sand	Semi-arid
Gritbands, calcrete and ferricretes	Oscillating wet and dry
Wind-blown (Kalahari?) sand	Dry
Younger gravels III	Wet
Calicification of silts and sands	Dry
Aggradation of silt and sand	Less Wet
Younger gravels IIB	
Younger gravels IIA	Wet
Younger gravels I	
Redistribution of red (Kalahari?) sands	Dry
Degradation of valley and aggradation of older gravels	Wet
Red (Kalahari?) sand	Dry
Basal older gravels	Wet

Source: After Van Riet Lowe, 1952.

similarly explained. Research at this stage on southern African palaeofluvial geomorphology was clearly influenced by the glacial/interglacial cycles that had recently emerged from the European and North American literature (Du Toit, 1939; Mabbutt, 1952; Flint, 1959; Bond, 1963; Cooke, 1941; 1957; 1967). Flint (1959) argued that although it was *probable* that African climatic change was contemporaneous with the glacial/interglacial cycles of Europe, the evidence was as yet unsupported because the data were so few.

Wells (1964) reinterpreted the faunal assemblage of the 'younger gravels' of the Vaal, while Mason (1967) attempted to link the gravels to an archaeological chronology. Earlier workers had questioned the terrace sequence and climatic change interpretation (see Flint, 1959; Bond, 1967) including the archaeological evidence (see Mason, 1967) but it was Partridge and Brink (1967) who provided the first comprehensive 'anti-climatic change' argument. They argued that there was no evidence to suggest that climate change was responsible for the sequence of terraces in the Vaal, but rather, the terraces were the result of a single cycle of channel development involving entrenchment over a long period of time. They argue that the development of the Vaal was primarily a function of axial warping during the Pliocene, followed by the headward advance of knickpoints across rock barriers. The Vaal closely follows the contact between the Karoo and Ventersdorp systems, while the dip of the Ventersdorp system to the south caused the shifting of the Vaal southwards resulting in the predominance of the terraces on the north bank of the river. The use of Landsat images revealed that there had been little deviation from present-day drainage and that although the Vaal had migrated south-east with time, it had kept the same basic shape as the modern channel (Partridge and Brink, 1967).

Partridge and Brink (1967: 37) argued that the assertion that an oscillating wet and dry climate was responsible for the development of the Vaal River terraces was '... no longer tenable ... and must be discarded once and for all'. They suggested that the upper 200 ft terraces are of Neogene age and the lower implementiferous terraces are middle Pleistocene. Bond (1967), who identified terraces along the banks of the Zambezi, was equally cautious of evoking climate change as a causative factor in river metamorphosis. He argued that in order for a landform (river) to change from one form to another, it must be a function, not of rainfall, but also vegetation cover, chemical weathering, mass movement and sediment delivery ratios. Bond (1967: 303) stated that 'until river behaviour is better understood through critical studies of the present, little progress will be made in interpreting their past records'.

Partridge (1968; 1969) continued to make a strong plea for caution in using fluvial deposits to reconstruct Quaternary climates. He pointed out that there is little clarity on the functioning of modern fluvial systems in terms of aggradation and degradation, and that these processes can occur contemporaneously within a single stretch of a river system. Assigning fluvial aggradation to periods of aggradation and degradation is at best hazardous. He points out that abandoned shorelines in central Africa were once thought to represent pluvial and interpluvial periods (Cooke, 1957; Flint, 1959), but that later work showed that tectonic displacement of shorelines and warping were more likely factors.

Van Rooyen and Burger (1972) argued that the terraces and pans of the Vaal were simply remnants of a succession of land surfaces left behind during the river's incision into bedrock. Mayer (1973) extended the debate around the Vaal River to include the Harts and Molopo Rivers. He argued strongly that the present stream patterns of the Vaal, Harts and Molopo Rivers and associated terraces are a function of tectonic

movement along the Griqualand–Transvaal axis in the late Tertiary. He modified the Griqualand–Transvaal axis (Figure 1), suggesting that the central thrust of the axis extended further south than that suggested by Du Toit (1933), running roughly parallel to the Vaal between Klerksdorp and Barkly West. The uplift terminated the palaeo-Harts drainage system which he suggested was a much larger river than the present Harts and which drained well into the present Botswana. The eastern tributaries of the palaeo-Harts probably drained into the present watershed between the Crocodile and Vaal Rivers, while the western tributaries (relicts of which are abandoned channels and pans) extended to Schweizer Reneke. River capture associated with the tectonic warping led to the capture of the palaeo-Harts by the palaeo-dry Harts. The Vaal River was also diverted at this stage. The Vaal followed a course from Pniel towards Schmidtsdrift along a river course which Mayer (1973) suggested is represented by the Droogeveld gravels. Uplift and tilting reduced the flow in the Vaal considerably. Mayer (1973) argued like King (1963) that Pleistocene climate change was not as extensive as had been suggested by earlier workers (cf. Van Riet Lowe, 1952; Cooke, 1957; Le Roux, 1968; Butzer, 1971; 1972) and that the past climates of South Africa have not varied greatly from today.

The debate surrounding the Vaal gravels refused to die down. Butzer *et al.* (1973) undertook a ‘reappraisal and reinvestigation’ of the Vaal terraces. Butzer *et al.* (1973) rejected the notion by Partridge and Brink (1967) that the gravels represented a single-cycle channel entrenchment representing intermittent headward advances following the breaching of rock barriers. They argue that the calcified sands that lie above the younger gravels are stratigraphically distinct from, geochemically different from and lie disconformably above the younger gravels and therefore could not possibly be a one-phase subcontemporary feature.

Partridge and Brink (1974: 665) continued to reject Butzer *et al.*’s hypothesis, stating: ‘It is therefore considered that the interpretative stratigraphic framework for the Vaal terraces provided by Butzer *et al.* must be regarded as highly speculative unless they can provide convincing correlation with deposits in other drainage basins.’ Partridge and Brink (1974) made the point that if climatic change takes place, it should be regional in extent, and therefore widespread evidence on a regional scale should be apparent. Helgren and Butzer (1974: 666) rejected Partridge and Brink’s catastrophist notion and suggested ‘... it is difficult to prove the existence of a 100 year old or greater flood; these remain statistical speculations, not demonstratable in the geological record’.

Helgren (1979a) was at pains to point out that Du Toit (1933: 9) regarded the axial warping not so much ‘... as an axis of upheaval, but as primarily to the sinking of the ground on its northern side ... the southern side ... remained almost untilted’. Helgren (1979a: 179) pointed out that ‘... despite Du Toit’s emphasis on the lack of tilting on the south side of this “axis” the arguments have recently gone full circle with Mayer (1973) concluding that the Older Gravels in the lower basin demonstrate the tectonic deformation of the upper’. Helgren (1979a) stressed that the origin of the older gravels still remains conjectural, and that (p. 180, emphasis in original) ‘*cyclic denudation during the Cenozoic is not explicitly demonstrated.*’ He does however suggest that the older gravels should best be viewed as an erratic, depositional residue of a long period of continuing erosion. He suggested (p. 182) that ‘Better interpretations of the Older Gravels will only be possible when other ancient surficial deposits of the South African interior are studied in detail’.

Although he conceded that stream capture did occur, Helgren (1979b) regarded it as being insignificant, suggesting that tectonic deformation in the Vaal Basin was

unimpressive and that the Vaal Basin has been essentially stable and cohesive within the recent geological past (Helgren, 1977a; 1977b). If tectonic warping (Du Toit, 1933; Mayer, 1973) did occur to produce large-scale cut-and-fill cycles then the whole drainage basin would require tilting. Helgren inferred that the evidence for warping was flimsy and could easily be explained by differential erosion of variably resistant lithologies.

Helgren (1979a) argues that the 'younger gravels' represent at least eight depositional cycles and that the Riverton Formation provides evidence of alluviation during a period of fluctuating regional climate. Regional climatic change provides the only reasonable explanation for the Rietputs Formation. He concluded (Helgren, 1979a: 312) that '... the climatic alternative provides the only viable interpretive hypothesis. It is clear that due to the complexity of palaeofluvial reconstruction, simplistic causal relationships should be avoided, and that the present state of geomorphic knowledge does not allow for detailed reconstructions to have any merit'.

Helgren (1979a) rejected King's (1963) theory of landscape development (for a full description see King's, 1963, *South African Scenery*) and chastised South African workers for allowing King's model to be (Helgren, 1979a: 292) '... uncritically embraced ... in South Africa and are now virtual dogma'. Helgren argued that King's model is of little use for explaining the origins of the Vaal Basin. King's model rests on three suppositions: 1) episodic uplift; 2) slopes retreat inland for long distances; and 3) river knickpoints can also retreat inland for long distances. These cannot, according to Helgren, be supported as there is no theoretical nor empirical evidence (see Helgren, 1979b: 294–99, for a full explanation). Helgren argued that an alluvial fill represents a record of a net, but *not* necessarily a continuous or homogeneous aggradation of the valley. However, what is significant is that for a net alluviation to occur, sediment delivery to the channel must exceed sediment transport in the channel, and therefore a change in net alluviation can be the result of increased sediment delivery, or reduced effectiveness of sediment transport, or both. For degradation of the channel bed (incision) the system should be transport limited, with stream power directed towards erosion of the bed (and banks). This provides complex relationships between form, geometry and process, such that fluvial histories of aggradation and degradational processes are dependent on the magnitude and frequency of processes as well as spatial and temporal variations. It has been shown that floodplain alluviation can occur in a variety of climates (humid to semi-arid), and therefore alluviation is not diagnostic of a specific climate. What appears to be significant in fluvial systems (Wolman and Miller, 1960; Baker, 1977) are the magnitude and frequency of processes (especially channel-forming discharge) forming and acting on the channel perimeter and floodplain. Helgren (1979a: 318) argued that researchers should thus focus their efforts on the '... geomorphic environments that condition or predicate stream behaviour rather than on climatic regime'. Helgren (1979a: 317) finally concluded: 'Having eliminated possible random and structural-tectonic explanations for the Rietputs formation, the alternative of climatic change remains, if only by default.'

## 2 The Orange

The first diamond discovered in South Africa was along the banks of the Orange River in 1867 (De Wit, 1996). The most significant alluvial diamondiferous deposits occur along the middle course of Orange River. Diamondiferous site deposits often occupy potholes along the banks of the river. The oldest terraces along the Orange River are found at Arrisdrif and are referred to as the Arrisdrif Formation (De Wit, 1996). These terraces



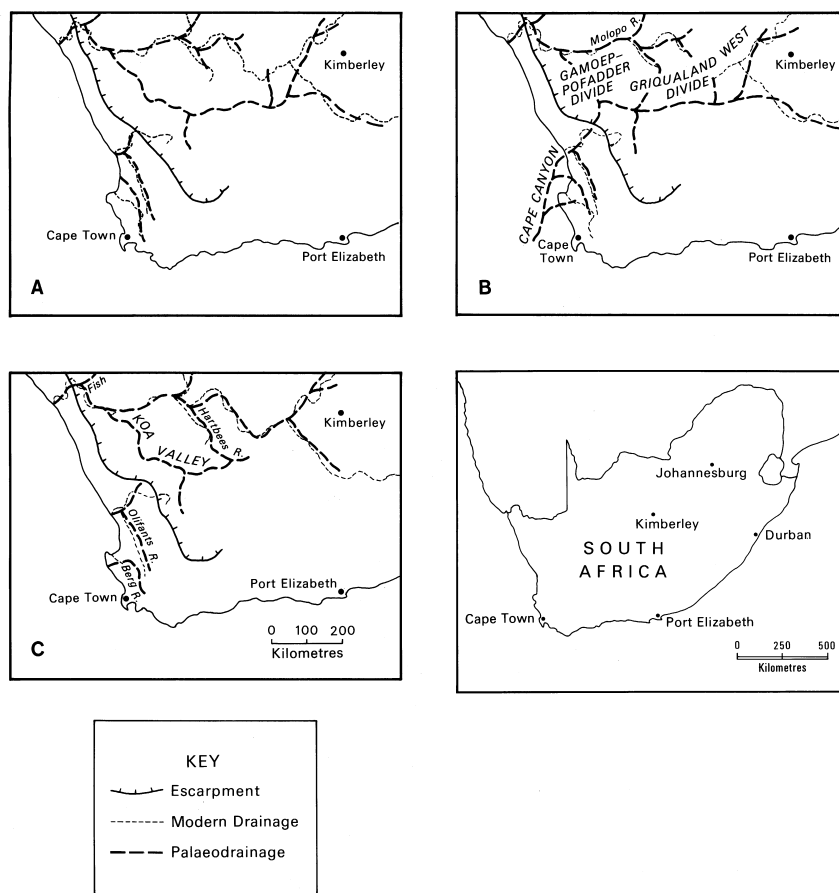
(+70 m) have been ascribed a mid- to late-early Miocene age and are referred to as the 'proto-Orange' River terraces. Similar terraces have been described along the Sak River (Bamford and De Wit, 1994; De Wit, 1996). De Wit (1993; 1996) argues that these terraces represent a Miocene pluvial phase. Progressive desiccation during the plio-Pleistocene resulted in the formation of the lower terraces along the Orange (mesoterraces).

The presence of banded ironstone in the gravels below the confluence of the Vaal and Orange led McCarthy (1983) to believe that they had been fluvially introduced from outside the present basin via the dry valley between the Ghaap Plateau and the Asbestberge to the west. Terrace stratigraphy and grain size suggested a river entered the Orange from the north carrying four times the volume of sediment as the present Orange River. McCarthy (1983) suggested a palaeocatchment area extending into south-central Africa – for this reason he proposed the name of the trans-Tswana River, suggesting that the basins of the Kalahari may once have formed part of this extensive drainage network.

Dingle and Hendey (1984), pointing to the offshore sedimentary record, provided evidence to show that the Orange River which presently discharges at Oranjemund (28° S) is an episodic mouth. The Orange on previous occasions discharged some 500 km further south (31° S) via the present Krom/Olifants system through the now submerged Cape Canyon during low sea stands. These shifts (at least two) were brought about by large-scale drainage reorientation at the beginning of the late Cretaceous. Large-scale changes in drainage basin orientation and area are implied (Figure 2). McCarthy *et al.* (1985) argue that, during the Oligocene regression, the Orange was part of a much smaller system, but that during the late Oligocene/early Miocene, the Orange was captured by the Koa and diverted through the Koa Valley into the present lower Orange's course. Flow stopped in the Koa Valley and further capture of the upper Orange by the lower Orange resulted in the modern course of the channel. Thus two major drainage systems are implied: 1) the upper Orange/Vaal linked to the Olifants; and 2) the lower Orange, draining southern Namibia and Botswana linked to the palaeo-Molopo River. This was termed the 'Kalahari River' (Partridge and Maud, 1987). Malherbe *et al.* (1986) argued that the capture of the Tertiary Koa River by the present Koa Valley and its subsequent capture of the Krom provides valuable biogeographic information and explains the similarity of fish species in these two rivers.

De Wit (1993) produced an extensive PhD on the reconstruction of the drainage systems of the northwestern Cape. He argues that the periods during which the fluvial systems were most active were late Cretaceous, middle Miocene and plio-Pleistocene. Drainage during the late Mesozoic consisted of two major rivers (discussed earlier): 1) the upper Orange/Vaal/Olifants system (termed the Southern or Karoo River); and 2) the northerly 'Kalahari River' which drained Namibia and Botswana. These were inferred to be high-discharge rivers associated with tropical climatic conditions. The early Cainozoic was characterized by a desiccating climate. The Karoo River was captured by the Kalahari in the early Tertiary. The drying climate reduced flow competence and sediment transport was limited. All major river changes had been completed by the early Tertiary. The Miocene terraces record the first wet phase after the Tertiary arid period. Although De Wit (1993) concedes that tectonic adjustment did play a role in the drainage evolution of the northwest Cape, he argues that (p. 339)

Whilst Partridge and Maud (1987) argue major periods of uplift occurred during the Miocene and Pliocene, this study, however, concludes that climate was more likely to be a controlling factor in the deposition of the Miocene and Pliocene gravels, and the evolution of the drainage systems in the Tertiary. Minor tectonic readjustments are likely to have taken place on an almost continuous basis.

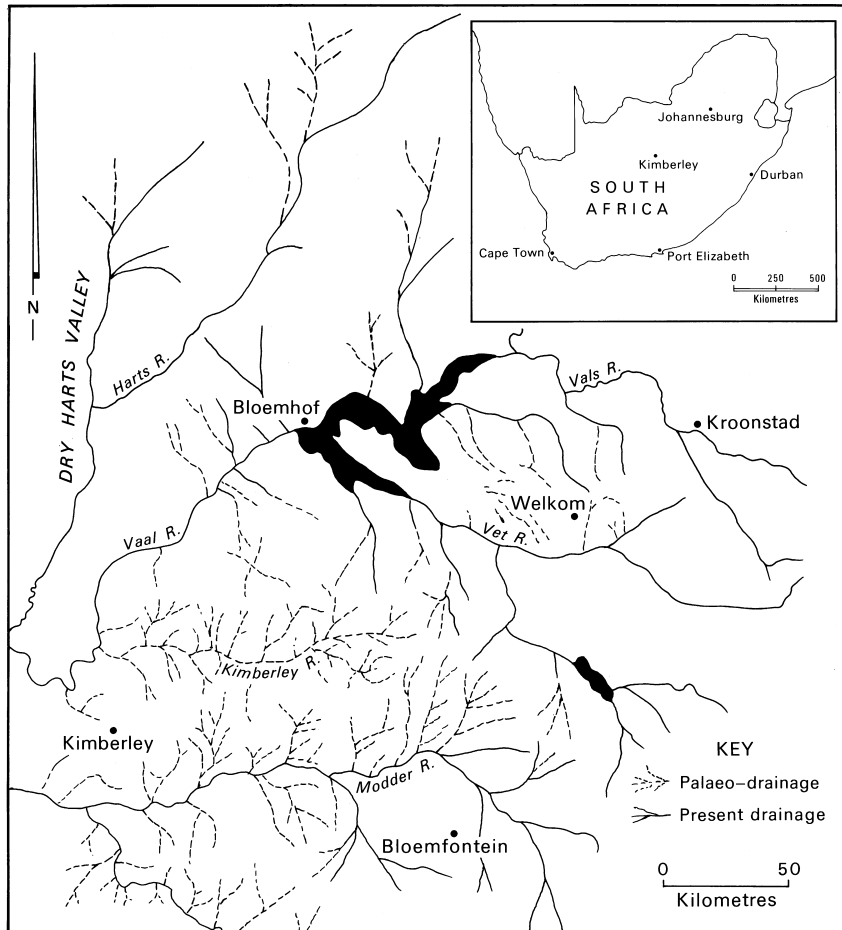


**Figure 2** Evolution of the Orange River system: a) late Cretaceous; b) Palaeogene; c) Neogene  
*Source:* After Dingle and Hendey (1984)

Downcutting by the Orange and its tributaries left extensive high-lying 'proto-Orange' terraces and more recent lower-lying 'meso-Orange' deposits (De Wit, 1988; Spaggiari, 1993). The higher-lying terraces indicate higher concentrations of alluvial diamonds (De Wit, 1996; De Wit *et al.*, 1997).

### 3 The Molopo

The Molopo River and its tributaries received considerable attention in the literature due to the diamondiferous deposits associated with the system. These deposits are intimately associated with the karst topography of the underlying dolomitic basement and palaeodrainage lines of the Molopo system (De Wit, 1981; Brinn, 1991; Marshall and Baxter-Brown, 1995). Work by Marshall (1986a; 1988a; 1988b; 1989; 1990a; 1990b; 1991) and Bootsman (1997) renewed earlier interest (Du Toit, 1907; 1933; 1951; Retief, 1960; Stratten, 1979; De Wit, 1981) in the alluvial gravels around the Molopo (Lichtenburg area). These deposits were thought to be the remnants of an extension of the Molopo River by early workers (*cf.* Du Toit, 1907; 1933; 1951).



**Figure 3** Morphotectonic reconstruction of the Vaal River system  
*Source: After Marshall (1996)*

Marshall (1986b) argued that earlier work (cf. Stratten, 1979) which indicated that the gravels were derived from ancient drainage lines from the north should be discounted. She suggested that these gravels could be accounted for by recent fluvial reworking of older gravels. Marshall (1986b) also discounts Mayer's (1973) account of river capture following intermittent uplift of the Griqualand–Transvaal axis. She argued that the majority of the gravels have a local source, while small amounts were transported from eastern Botswana (via palaeo-Harts drainage line), the Northern Province (via the Dwyka Glaciers) and Lesotho. The gravels were emplaced by a combination of tectonic upheaval and climatic change. The palaeo-Harts operated during the planing of the Tertiary land surface, washing materials into the 'London-run'. Mid-Tertiary uplift cut off the palaeo-Harts from the Vaal through river piracy by the Dry Harts and led to the unconformity between the older and younger gravels. The period of aggradation was interrupted in the late Pliocene/early Pleistocene by climatic change, when the Rietput gravels were reworked. Morphotectonic studies indicated that the Vaal had a left bank tributary extending southwards from Christiana (Figure 3). This was cut off in the

mid-Tertiary by headward erosion of the Kimberley River (another left-bank palaeotributary). Prior to being cut-off, this palaeotributary transported diamondiferous gravel to the main Vaal around Christiana.

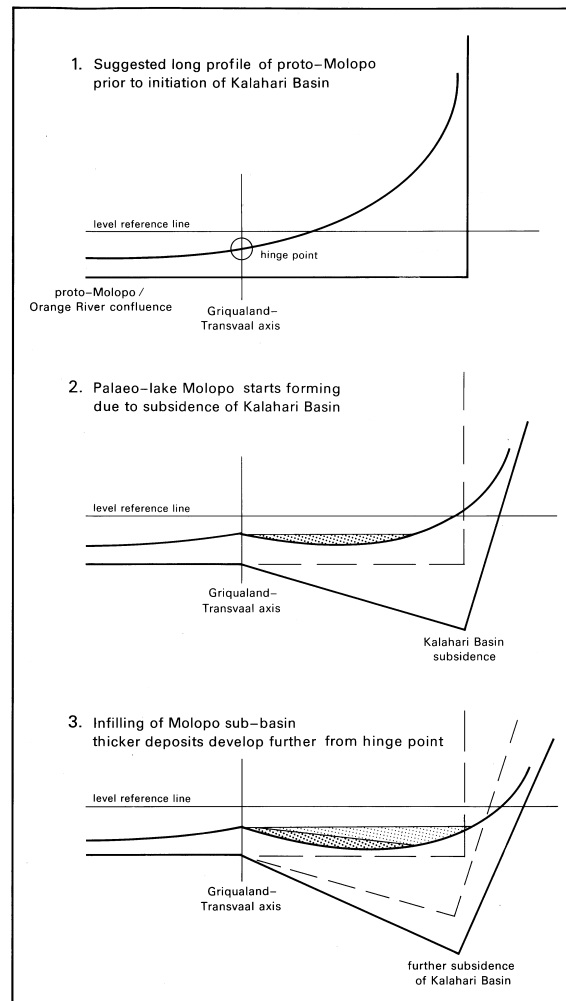
The headwaters of the Kimberley River were later captured by the Modder River. Therefore, in contrast to earlier work on the sources of the diamondiferous gravels as being extrabasinal, Marshall (1986a) argues for a local source for the bulk of the alluvial diamonds and gravels. Marshall (1988b) considered the origins of the diamondiferous gravels of the Bamboesspruit of the southwestern Transvaal and divides them into the Rooikoppie (derived) gravels and the terraced gravels. The terraced gravels' origin are ascribed to earlier Tertiary warping of the interior and later climatic change. Bootsman (1997) argued that the history of the Molopo system can only be understood through recognizing the combined impact of the intracontinental tectonic axes of the uplift of the Griqualand–Transvaal axis, the Kalahari–Zimbabwe axis, the mid-Tertiary subsidence of the Bushveld Basin as well as climate change (Figure 4).

It is interesting to note (see De Wit, 1996) that most of the alluvial diamond deposits in southern Africa are found outside the Karoo bedrock (Figure 5). There are, however, a few exceptions around Aliwal North, in Swaziland and in the Northern Province. These deposits are associated with trapsites created by dolerite sills and dykes. The bulk of the diamondiferous deposits are found along the northern boundary of the Karoo Basin. The horizontal sedimentary Karoo rocks are simply not capable of trapping diamonds. Where the rivers emerge from the Karoo sediments on to the pre-Karoo (especially the Ventersdorp Supergroup) surface significant placer development occurs. Reasons for this are two-fold (De Wit, 1996): 1) the topography of the pre-Karoo surface is sufficient to trap the coarse debris; and 2) the weathering of the Dwyka tillite at the base of the Karoo system and exfoliation of the Ventersdorp lava provide the pebbles, cobbles and boulders that comprise the coarse debris.

#### 4 The Sundays

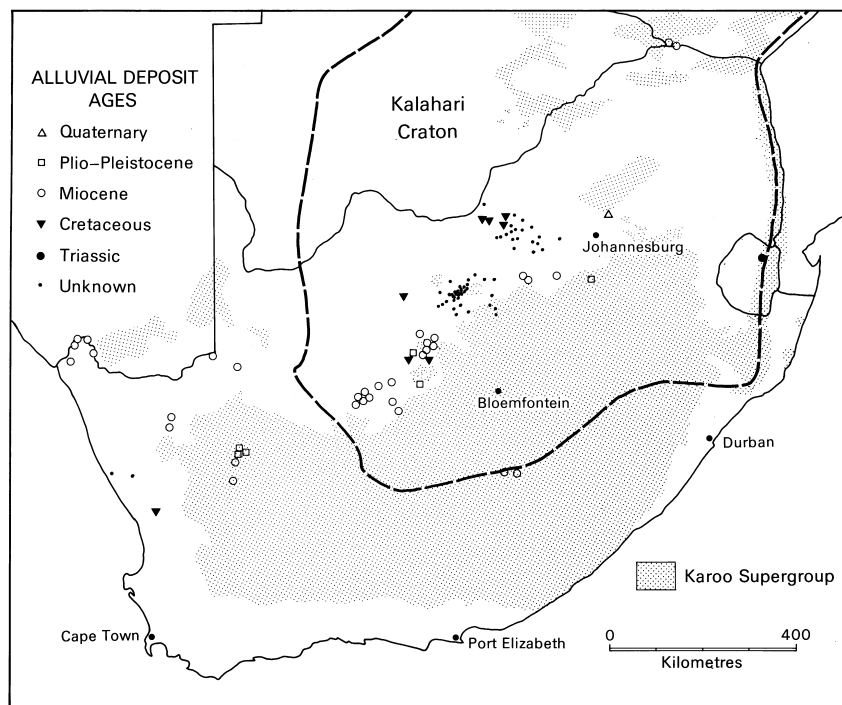
The predominance of the Vaal River gravels in the literature was mitigated to some extent by work done on the Eerste River terraces around Stellenbosch (Krige, 1927) and the emergence of further evidence for fluvial change in the Sundays River in the Eastern Cape. Ruddock (1945) reported on a series of terraces in the Sundays River valley, dividing them into 'higher' (at and above 170 ft) and 'lower' terraces (below 100 ft). Ruddock concluded that the terraces were a result of sea-level changes linked to what he termed 'major' and 'minor' emergences. Further work by Ruddock (1957) on the Coega terraces showed that the terraces of many coastal rivers can be related to marine transgressions during the late Quaternary. Ruddock (1968) has shown that coastal rivers like the Sundays were impacted by marine transgressions and regressions. He concluded that there were probably three major transgressions and regressions during the Cainozoic, one in the late Tertiary (probably Miocene), one in the Pliocene and one in the plio-Pliocene. He suggested that base-level rises associated with the transgressive events resulted in channel gradient reductions and concomitant aggradation. Regressive episodes resulted in increased gradients, stream power and subsequent incision. In this manner, a series of terraces were abandoned, testimony to sea-level changes.

A reinvestigation of the palaeo-Sundays River was undertaken by Hattingh (Hattingh, 1994; 1996a; 1996b; 1996c; Hattingh and Goedhart, in press; Hattingh and Rust, in press a; in press b). Hattingh was able to show that the formation of a sequence of 13 terrace



**Figure 4** Back-tilting of the proto-Molopo drainage system  
 Source: After Bootsman (1997)

levels in the Sundays River was a complex response to climate and base-level changes. The depositional record in Algoa Bay (cf. Bremner *et al.*, 1991) indicates several cycles of fluvial activity since the breakup of Gondwana. The main processes determining the formation of the terraces are thought to be base-level changes. The fluvial deposits in the Sundays suggest that the uplift leading to the post-African I surface was late Miocene (6 Ma) and not early Miocene as proposed by Partridge and Maud (1987). The late Pliocene termination of the post-African I cycle correlates well with the depositional characteristics of the terraces, but Hattingh (1996b) argues that there is little evidence for the magnitude of the post-African II erosion cycle as proposed by Partridge and Maud (1987). Quaternary deposits tend to reflect the glacial/interglacial stages through sea-level changes and to be finer grained, indicating a less active fluvial environment. Hattingh (1996c) was able to show that sea-level changes, climatic change and a



**Figure 5** Alluvial diamond deposits in South Africa  
*Source: After de Wit (1996)*

tectonically active landscape combined to produce the Sundays River terraces. Late Miocene to late Pliocene tropical climatic conditions and a steep channel gradient resulted in high discharges and sediment load. Quaternary sea-level changes led to intermittent periods of aggradation and degradation resulting in the formation of the younger terraces.

## 5 The Zambezi

The post-rifting development of the Zambezi River has received significant attention. As early as the 1920s (Du Toit, 1922; 1933) it had been proposed that the upper and middle sections of the Zambezi had only recently been joined. Later authors supported this hypothesis (cf. Dixey, 1955; Wellington, 1958; Bond, 1963; Grove, 1969; Lister, 1979; Thomas, 1986). The upper and middle Zambezi are thought to have evolved as separate systems, with the upper Zambezi previously joined to the Limpopo system, the middle Zambezi forming part of the Shire system. Tectonic enhancement of the stream power of the palaeo-middle Zambezi and down-warping led to the capturing of the upper Zambezi (Shaw and Thomas, 1988; 1992). Nugent (1990; 1992) agreed that the capture of the middle Zambezi's upper catchment has been clearly demonstrated, but disagreed on the timing and causative mechanisms of the capture. Nugent argued that the joining of the upper and middle Zambezi probably took place by the headwards retreat of an earlier knickpoint or, alternatively, by the overtopping of palaeo-Lake Makgadikgadi.

**Table 2** Morphotectonic stages of the middle Kuiseb River

Geomorphic environment	Main geomorphic or sediment criteria
Humid activity	40 m terrace, hanging valleys
Arid stability	
Arid activity	Dunes on southern side of the canyon
Arid stability	Canyon
Humid activity	Gramadulla valleys
Arid stability	
Arid activity	Ossewater sediments
Arid stability	
Humid activity	Upper glacia of Homeb
Arid stability	
Humid activity	Lower glacia of Homeb
Arid stability	Actual river bed

Source: After Rust and Wieneke, 1974.

## V Arid zone rivers

Focus in Namibia was on the Namib Desert and its terrestrial deposits (Stengel, 1964; 1966; Heine, 1983; 1985; Van Zyl and Scheepers, 1991). Again, palaeofluvial work rested strongly on the interpretation of alluvial terraces (Goudie, 1972; Grey and Cooke, 1977; Watson and Price Williams, 1985). Rust and Wieneke (1974) wrote on the fluvial terraces of the Kuiseb River, arguing that the 40 m terrace along the Kuiseb River represented the first stage of river incision, followed by a further 12 morphoclimatic stages representing incision and stillstands associated with oscillating arid and humid climates (Table 2). Seely and Sandelowski (1974) were able to show that desiccation in the Tsondab River was such that by 60 000 BP it stopped flowing at Narebeb 47 km from the Atlantic coast. This was attributed to a desiccating climate with concomitant dune-sand blockage. At an earlier stage, both the Tsondab and Tsonchab Rivers exited into the Atlantic (Figure 6). Marker (1977a; 1977b) pointed out that many of the Namibian rivers have a convex profile, and that this convexity is common in arid zones, as there is often increasing aridity seawards and subsequent loss of energy. She argued that the Kuiseb River shows evidence of episodic rejuvenation and that this can be attributed to the cyclical nature of Cenozoic events, superimposed on base-level impermanence (eustatic and tectonic). Lancaster (1978a; 1978b; 1986) in Botswana argued that pan development in the southern Kalahari of Botswana provided further evidence for the impact of fluctuating climates on fluvial landform development.

Ward (1982) continued the discussion surrounding the Kuiseb River terraces arguing that these (terraces) were remnants of the initial incision of the Kuiseb Canyon. Further work on the Kuiseb River by Vogel (1982) provided a chronological sequence for the terraces. Vogel (1982) argued that changing rainfall conditions produced the sequence of terrace deposits. Ward (1984) argued that there is evidence to suggest progressive aridification in the Namib as evidenced by the alluvial stratigraphy. Most workers concur that the arid regions in southern Africa have experienced periods of increased aridity, but that these have been limited spatially and temporally.

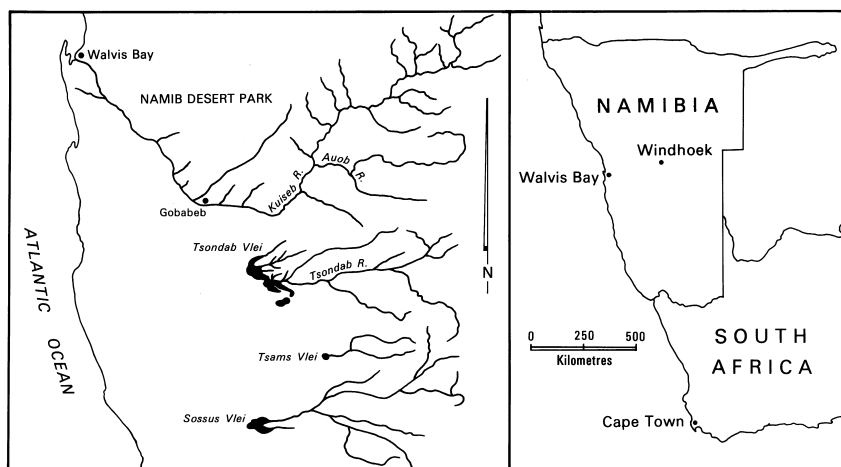


Figure 6 Fluvial systems of Namibia

Lancaster (1984a) pointed out that although there have been periods of aridity in the dry areas of southern Africa that have been more intense than present, the overall trend is one of increased desiccation since the late Cenozoic. Pleistocene evidence from the rivers of the Namib from the Tsondab northwards showed that intermittent alluvial aggradation and incision (cf. Mabbutt, 1952; Korn and Martin, 1957; Selby *et al.*, 1979; Lancaster, 1984b; Wilkinson, 1990; Van Zyl and Scheepers, 1992a; 1992b) have occurred, but that there was not sufficient evidence to determine whether these alluvial deposits could be ascribed to climatic change (cf. Seely and Sandelowski, 1974; Marker and Muller, 1978; Rust and Wienke, 1980; Rust, 1984; Vogel and Rust, 1987; Rust and Vogel, 1988) or eustatic changes (Ward, 1988). What is clear is that researchers on the Namib agree that evidence from fluvial deposits indicates there has been a general progressive desiccation of the Namib during the Quaternary (Seely and Ward, 1988), interspersed with periods of increased (but limited) 'wetter' periods (Ward, 1988).

Vogel (1989) provided a chronology of climate change for the Namib Desert, suggesting that different grain sizes within the fluvial deposits represent different depositional environments and therefore evidence for greater/lesser stream competence and hence wetter/drier climates. Vogel (1989) argued that channel infilling represents decreased flow and consequently drier conditions, while incision represents a return to wetter conditions. Vogel (1989) suggested that the present incision of the Namibian rivers may represent a return to wetter conditions within the last two centuries. A word of caution was suggested by Wilkinson (1990), quoting Miall (1987: 4), who pointed out the limitations of fluvial sedimentology reconstructions as 'fluvial sedimentologists have simply not studied enough rivers to be aware of depositional styles in the full range of tectonic and climatic conditions'.

Palaeofluvial research from Botswana proliferated in the 1980s (Hutchins *et al.*, 1976; Ebert and Hitchcock, 1978; Cooke, 1976; 1979; Heine, 1978; 1982; Cooke and Verstappen, 1984; Helgren, 1984; Goudie and Thomas, 1985; Shaw, 1983; 1985a; 1986; 1988a; Thomas and Shaw, 1992a, 1992b). Shaw (1989) divided the fluvial systems of the Kalahari into three distinct groups, the Okavango Delta and its palaeolake basins dominating the north, the aggressive seasonal streams of the Limpopo to the east of the Kalahari-



Zambezi divide, and the pans and fossil valleys of the Molopo and Okwa-Mmone systems west of the Kalahari–Zimbabwe divide.

Shaw (1985a; 1985b; 1988b) has argued that the present Okavango Delta is a recent feature, as the middle Kalahari shows evidence for three major palaeolake basins, linking the Okavango to the Chobe and Zambezi Rivers (Shaw and Thomas, 1988). Two stages of lake development are identified, the first being tectonic in origin and lasting to approximately 35 000 BP (Lake palaeo-Makgadikgadi covering 60 000 km<sup>2</sup>), the second, and episodic lake, Lake Thamalakane (covering the present Okavango Delta) forming and drying in response to oscillating moisture conditions, but reaching prominence between 17 000 BP and 12 000 BP. Progressive desiccation during the last 2000 years saw the disappearance of these lakes. Shaw (1985b), like Cooke (1976), argues that Lake palaeo-Makgadikgadi at its maximum elevation (945 m level) would only be sustained by a large inflow, probably the Zambezi. Shaw (1985a) thus supports Wellington's (1958) notion of a link between the Okavango system and the Zambezi. Shaw and Thomas (1988; 1992) report on a large late Quaternary palaeolake, Lake Caprivi, to the west of the Okavango depression. They argue that this palaeolake covered an area of 20 000 km<sup>2</sup> and was linked to the Zambezi via the Chobe River. Lake Caprivi was coeval with and an integral part of the 936 m Lake Thamalakane stage which existed during the Last Glacial and again in the late Holocene. Clearly, significant changes in the drainage system of northern Botswana have taken place during the Quaternary (Shaw and Cooke, 1986). Changes appear to be linked to tectonic processes as well as climate change. On the basis of Quaternary landform evidence, Shaw *et al.* (1988) provide a tentative Pleistocene reconstruction for the Kalahari, indicating fairly major shifts in moisture conditions: 45 000–20 000 BP dry conditions; humid Late Glacial conditions 16 000–13 000 BP; drying at around 11 000 BP, with a semi-arid Holocene with precipitation peaks at 6000–5000 BP and at 2000 BP.

The rivers to the east of the Kalahari are strongly seasonal in character (Shaw, 1989), and were strongly impacted on by Tertiary uplift along the Kalahari–Zimbabwe rise as evidenced by extensive terrace sequences along these rivers (e.g., Notwane and Limpopo). Two prominent dry river valleys (Mokgacha) in the southern Kalahari occur, the Molopo and its tributaries (Auob, Nossop and Kuruman) and the Okwa-Mmone draining from the west. The interfluvium between these systems has been termed the 'Bakalahari Schwelle'. Genesis of these Mokgacha have been attributed to much larger discharges in the past (Shaw, 1989). Shaw and De Vries (1988) have suggested that subsurface drainage may have played a role in tectonically stable arid regions. Shaw (1989) and Shaw *et al.* (1992) conclude that all fluvial systems of Botswana have been strongly influenced by changing climatic conditions since the Tertiary and are now adjusting to a new equilibrium condition.

## VI Discussion and conclusion

From the review provided, it is clear that southern African fluvial systems have undergone extensive modification in the last 3 billion years (Dingle *et al.*, 1983). It is impossible to suggest a single cause for fluvial pattern disruption. The evidence presented indicates that, in all cases, fluvial changes are associated with a variety of factors operating over varying temporal and spatial scales. Clearly, geological structure, superimposition and tectonic earth movements provide the template for fluvial change.

Superimposed on these 'macroscale' controls are the impacts of climatic change and marine transgressive/regressive cycles.

A general trend that emerges is to ascribe older (usually early to mid-Pleistocene) fluvial changes to tectonic activity and more recent (usually late Pleistocene to Holocene) fluvial changes to climatic oscillations. Partridge (1988) has pointed out the difficulty in isolating tectonic events from climatic changes. Worldwide advances in the study of the Quaternary glacial/interglacials left little doubt however, that climatic change has played a significant part in the evolution of fluvial systems worldwide and in southern Africa (Maud and Partridge, 1988). A review of late Pleistocene climate change in southern Africa by Partridge *et al.* (1990) and Tyson and Lindesay (1992) showed clear evidence for climatic change. The impacts of climatic change on landforms have been discussed at length (Maud and Partridge, 1988; Partridge, 1988; 1990). The impact of these changes in climate has not been fully appreciated by the fluvial geomorphology community in southern Africa, especially those considering modern fluvial processes and landforms.

The science of palaeofluvial geomorphology has to a large extent been driven in southern Africa by mineral exploration. 'Academic' geomorphology has played a limited role in the unravelling of southern Africa's fluvial systems. However, as De Wit (1996) has pointed out that, based on present knowledge of erosion levels, the total inventory of alluvial diamond deposits above the escarpment is less than 1% of all the diamonds estimated to have been released from known primary sources. Clearly, there is much work to be done.

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