Reprinted from
Suid-Afrikaanse Tydskrif vir Wetenskap *Vol. 82* *Oktober 1986*

The roles of sedimentation and plant growth in changing flow patterns in the Okavango Delta, Botswana

T.S. McCarthy, W.N. Ellery*, K.H. Rogers*, B. Cairncross and K. Ellery*

Department of Geology and *Botany, University of the Witwatersrand, Johannesburg 2001, South Africa.

Individual distributaries of the Okavango Delta are subject to progressive blockage and ultimately are abandoned, on a time scale of fifty to one hundred years, and new channel systems form in consequence. This constant migration of channels is apparently the result of sediment accumulation in channels which causes aggradation of channel beds, accompanied by vertical aggradation of the flanking vegetation. The rate of aggradation may exceed five centimetres per year. This aggradation ultimately reduces hydraulic gradients down the channels, resulting in a decline in flow velocity and hence progressive vegetation blockage. Water is re-directed as a result and new channel systems are created.

Die afsonderlike verspreidingstrome van die Okavango-delta raak in toenemende mate binne 'n tydsverloop van 50 tot 100 jaar versper en die strome word dan vervang deur nuwe kanaalstelsels wat gevorm word. Die voortdurende verskuiwing van kanale is vermoedelik die gevolg van sedimentversameling wat tot die opvulling van stroombeddings lei, gepaard met die vertikale aanwassing van plantegroei langs die kante. Die opvultempo kan selfs meer as 5 cm per jaar wees. Die hidrouliese gradiënt word deur opvulling van die kanale verminder, waardeur die water se vloeisnelheid afneem en die versperring deur plantegroei voortdurend toeneem. Die waterloop verander as gevolg hiervan en 'n nuwe kanaalstelsel ontstaan.

The Okavango river rises in the highlands of central Angola and flows southwards across the Caprivi Strip, discharging into the Okavango Delta in northern Botswana, where some ninety-five per cent of the water is lost by evapotranspiration.[1] This delta forms part of a large, internal drainage basin known as the Kalahari Basin. In the upper reaches of the delta, the Okavango river is confined in a relatively narrow, linear depression known as the 'panhandle' (Fig. 1) but at Seronga the river system disperses into a classic 'bird's foot' delta. Preliminary survey work indicates that the delta has a typical conical form, although the gradient is extremely shallow, averaging 1 in 3 300 over the entire delta.[2] Total fall between the top of the panhandle and the outflow at the south-eastern end of the delta, a distance of 240 km, is only 65 metres.

Within the delta the Okavango river flows into two distributary systems, which carry water to the northern and western sides of the central Chiefs Island (Fig. 1). During the last century the main distributary to the west was the Thaoge river but this is now extensively blocked by papyrus. The Jao/Boro river system now carries most of the water on this side of the island. The Nqoga river is the main northern distributary but papyrus blockages in its lower reaches (Fig. 1) since the 1920s are forcing more and more water to flow down the Maunachira river system. These distributaries in turn give rise to other, progressively smaller channel systems. These are insufficient to carry the seasonal flood waters of the Okavango river and accordingly there is considerable overspill, of a permanent nature in the upper portions of the delta

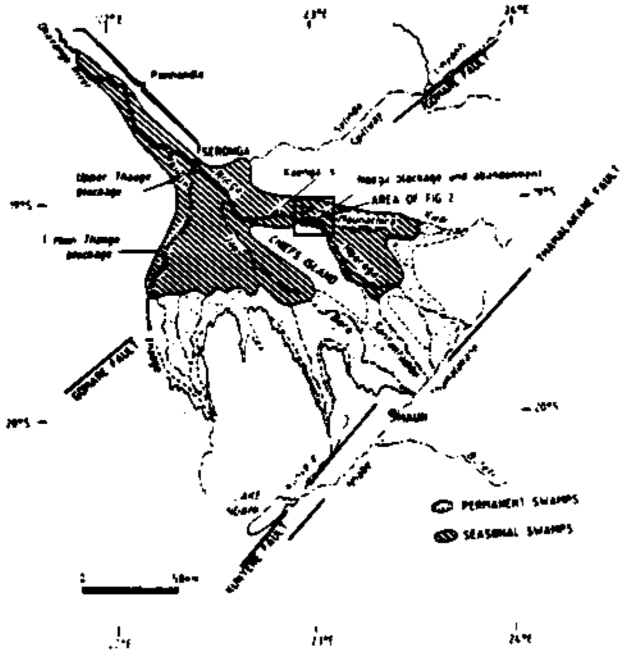

Fig. 1. Map of the Okavango Delta showing the major channels, the distribution of seasonal and permanent swamps and the major fault lines and blockages. The spelling of place names is based on the 1:350 000 map of the Okavango Delta distributed by the Botswana Department of Lands and Surveys, 1985 edition.

and seasonally in the lower portions.

At the southern end of the delta, outflow from the majority of the distributaries unites in the Thamalakane and Kunyere channels, which flow into the Boteti river and Lake Ngami, respectively. In years of exceptional floods, water may also flow eastwards via the Selinda spillway into the Linyanti area.

Channel systems are subject to blockage and abandonment, modifying the distribution of water in the delta. Where channel blockages occur in the upper reaches of the delta, flow patterns may be radically altered, as evidenced by the switch in flow from the Thaoge on the western side to the Ngoga on the eastern side late in the last century.[3–5] Such changes cause hardship to the local inhabitants, affect the distribution of wildlife and have important implications for the planning and use of Botswana' largest water resource.

Several hypotheses have been put forward to explain the large-scale changes in flow, namely seismic activity,[6] maj climatic change,[4] vegetation growth and sedimentation.[3,7,10] W suggest that, although earth movements and climatic change ma be responsible for the position and size of the delta within th Kalahari Basin, vegetation growth and sedimentation are impo tant in blockage and abandonment of individual channels withi the delta (i.e. locally) on a short time scale (decades). In this pap we present a model to explain mechanisms of channel blocka and abandonment incorporating sedimentary processes and pla growth, the former being a particularly neglected area of resear in the Okavango Delta.

Long-term changes in the delta

The considerable debate concerning long-term changes in th drainage of the region in which the delta occurs has been we summarized by Cooke.[4] The present position of the delta pears to be controlled by subsidence in the earth's crust; panhandle may be the result of subsidence along a north-weste trending fault set,[5] whereas the south-eastern margin of the de is defined by two major faults, the Thamalakane and Kunye faults (Fig. 1). These latter have a Holocene downthrow to th north-west which probably exceeds 200 metres.[6] The area of th

Fig. 3. A sand bar in the abandoned Nqoga channel.

de
th
ca
K
nu

de
T
ex
fl
ch
m
th
of
tc
se

Sl

di
ti
re
re
cc
in
di
in
be
tc
bl
N
th

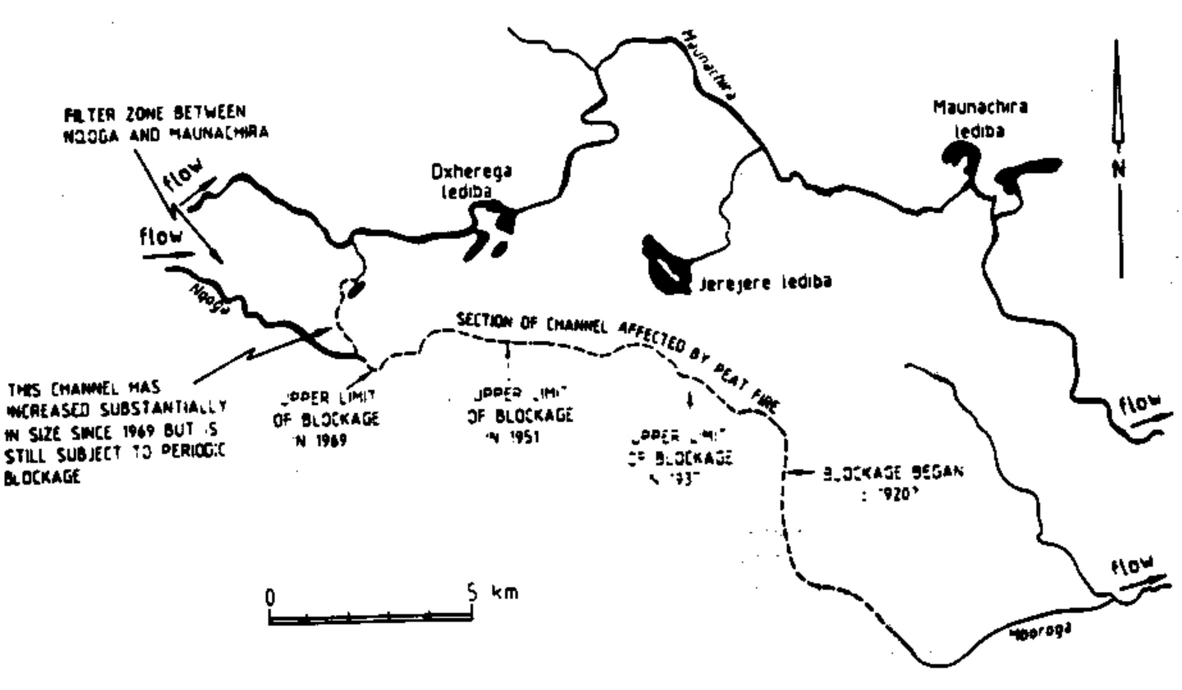

Fig. 2. Map showing the region of blockage on the Nqoga channel. See Fig. 1 for location. (Modified after ref. 3)

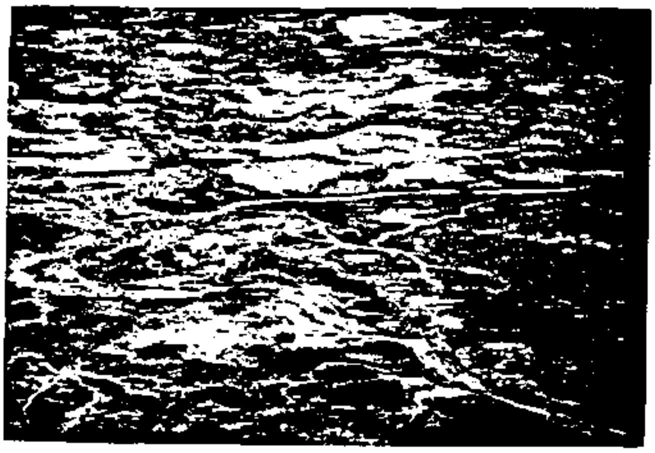

Fig. 4. An aerial view of the sinuous ridges formed by abandoned channels.

Fig. 5. Ground view of a sand ridge representing a former side channel.

delta is seismically active and an earthquake measuring 6,7 on the Richter scale struck Maun in 1952. A microseismic survey carried out by Scholz[6] indicated that the Thamalakane and Kunyere faults zones and their extensions are the loci of continuing seismic activity.

Superimposed on the tectonic controls on the position of the delta are the probable effects of long-term changes in climate. There is abundant evidence that both wetter and drier periods existed in northern Botswana in the past,[4] which have also influenced the size and character of the delta. While both climatic change and seismic activity are clearly important factors in promoting change in the delta on a long time scale, it is unlikely that they are important in the short-term blockage and abandonment of channels. These channel changes occur too rapidly to be due to climatic change, but too slowly and progressively to be seismically induced.

Short-term changes in the delta

Wilson[3] provides an account of the changes in drainage distribution which have taken place within the delta in historic times, with particular reference to attempts which were made to restore flow in various channels. The record of change in more recent years is particularly good, because the delta has been covered by aerial photography at regular intervals since 1937. During much of the last century, the Thaoge (Fig. 1) was the main distributary of the delta. David Livingstone recorded strong flow in the discharge from the river into Lake Ngami. The Thaoge began to block with aquatic vegetation in about 1883 and ceased to run into the lake in 1884. Today the Thaoge is extensively blocked and even in exceptional years flow does not reach Lake Ngami, which now derives its water from tributaries arising in the north-east.

The decline in the Thaoge was accompanied by an increase in flow in the Nqoga-Santantadibe system (Fig. 1), and in the early years of this century this was the major distributary system. The lower reaches of the Nqoga became blocked with vegetation in the 1920s, and over the next sixty years blockages developed progressively further upstream[3] (Fig. 2). Consequently, more water began to flow into the Maunachira river system.

The channel blockages referred to are manifest by the accumulation of aquatic plants, especially papyrus (*Cyperus papyrus* L.), in the channel. Papyrus is constantly being broken off margins of the upper channels and floating rafts of this plant are carried downstream.[3,10] They ultimately become lodged in a channel and, in the cases of the blockages referred to, the rhizomes become entangled, forming a dense mat which eventually completely blocks the channel. Wilson[3] notes that because of the continuous generation of plant debris in the upper channels, vegetation blockages are an inevitable and normal consequence of delta evolution. He does, however, raise an important issue: why does a channel system such as the Thaoge, which for decades remained clear, suddenly start to block with vegetation? He discounts climatic change, but raises the possibility that seismic activity may in some way be responsible. Our own observations, and in particular a visit (in September, 1985) to the abandoned portion of the Nqoga channel (Fig. 2), led us to believe that sedimentation within channels confined by vegetation is the predominant agent initiating channel abandonment.

The abandoned section of the Nqoga channel

Since the formation of a vegetation blockage in the lower portion of the Nqoga river in the 1920s (Figs 1 and 2), the channel and its surrounding area have become progressively drier. Much of the area dried up completely and in the early seventies the thick

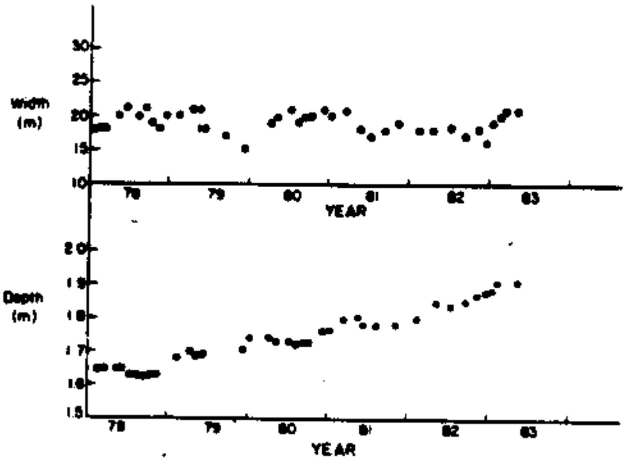

Fig. 6. Change in water level and channel width at Xaenga island between 1978 and 1983.

Fig. 7. A view of a typical papyrus-lined channel. The flanking vegetation is rooted in a submerged bed of peat and there is no dry land flanking the channel.

peat flanking the old channel caught fire and burnt out over a period of several years (P.A. Smith, pers. comm.). Such a subsurface fire is quite different from a normal surface fire, and results in a collapse of the affected area — a consequence of the decrease in volume caused by destruction of organic matter. The channel in the burnt-out section now consists of a sinuous, sandy tract, often draped with a layer of silt, in which the original bar forms are still clearly visible (Fig. 3). The former channel is, on the whole, a positive topographic feature flanked by the collapsed, former peat-covered areas. Minor side channels of the main channel occur as sinuous, sandy ridges rising sometimes more than a metre above the burnt peat (Figs 4 and 5). The collapsed areas flanking the channel form an extensive, flat plain broken only by occasional anthills. The substrate consists of clay which at depth is extremely porous as a result of the destruction of entrapped plant material. The clay is predominantly kaolin, which has been heated to above 300°C in the peat fire.[6] Of particular importance is the fact that the abandoned channel and its surrounding areas are completely dry. An examination of processes taking place in the upstream (active) section of the Nqoga river provides an explanation for this phenomenon.

The active portion of the Nqoga channel

The water level at Xaenga island (Fig. 1) on the active portion of the Nqoga channel is considerably higher than in the surrounding swamps (1,3 m in 1937 when it was last surveyed[10]). This is attributed by these authors to the deposition of bed-load on the river bottom within a channel confined by vegetation; any water loss from the channel by lateral flow is incapable of removing this bed-load sediment from the channel. There has been a steady rise in the water level at Xaenga island as recorded on a depth gauge fixed to the bank of the channel (Fig. 6). Since this has not been accompanied by any significant changes in width (Fig. 6), it may indicate either continuous channel bed aggradation of some 6 cm/year or a steady rise in discharge. There is no evidence for the latter, whereas aggradation can be accounted for by available data on sediment flux and its deposition within the delta as a whole.

Sedimentation as an agent of channel blockages

Very little is known about sedimentation in the delta, although its potential importance has been recognized.[2,10] Some preliminary work on sediment flux was carried out (ref. 2, p. 109) which indicated that 600 000 tonnes, or 400 000 m^3, of bed-load sediment (fine sand) enters the delta each year via the Okavango river. In addition to bed-load sediment, there is an unknown quantity of suspended sediment being brought into the delta. Water clarity suggests that this may be less important than bed-load.

The estimated introduced bed-load component is small in relation to the total area of the delta (about 18 000 km^2). However, as a result of channel morphology and especially the vegetated banks (Fig. 7), bed-load sediment cannot escape from the confined channels. Only the upper and middle channel systems have sandy beds, indicating significant transport of bed-load sediment. Accumulation of the introduced sediment must therefore be confined to these channels. In this context the quantity of introduced sediment is in fact very large. This is best illustrated by an order of magnitude calculation. Assume all of the sediment entering the delta accumulates as a uniform layer on a channel bed 20 m wide and 200 km long, the latter being the approximate distance from the top of the panhandle, where sediment flux was determined, to the Nqoga blockage. This would uniformly raise the bed of the channel by some 10 cm each year. This calculation indicates that rapid aggradation of channel beds may indeed be taking place in the delta and supports the hypothesis that the steady rise in apparent water level at Xaenga (6 cm/yr, Fig. 6) is due to this process. However, since the gross channel morphology has remained unchanged, aggradation of the channel bed must have been matched by aggradation of the channel flanks. Vegetation growth plays an important role in this process.

The effects of sediment transport and deposition are also vividly illustrated by examination of the Dxherega lediba (lake) located on the Maunachira channel. The outlines of this lediba, based on the 1969 and 1983 aerial photography, are shown in Fig. 8. In areas remote from the inlet, the outline has not changed and even intricate details of embayments are intact. However, near the inlet, extensive shrinkage has occurred. The agent responsible for this change is a tongue of sandy sediment, straddled by transverse dunes, which is prograding into the lediba (Fig. 9). Vegetation has encroached across the deeper water towards this sand body, shrinking the lediba.

The role of plants

Comparable rates of plant growth and peat accumulation are not available for the delta, but according to current research findings[9,11] and to the literature,[2,3,7,10] vegetation plays an important role in this promotion of channel abandonment. The major role is in confining the deposition of bed-load sediment within the channels. Furthermore, channel bed accretion is accompanied by aggradation of the vegetation-lined flanks of the channel. Plants fringing the channel receive higher levels of nutrients and suspended clay particles than those further removed from the channel. Peat accumulation is therefore most rapid adjacent to the channel, as is the trapping of suspended clays by plant roots. These processes lead to the formation of levees consisting mainly of the roots and rhizomes of plants.

The giant sedge *C. papyrus* is the dominant species lining chan-

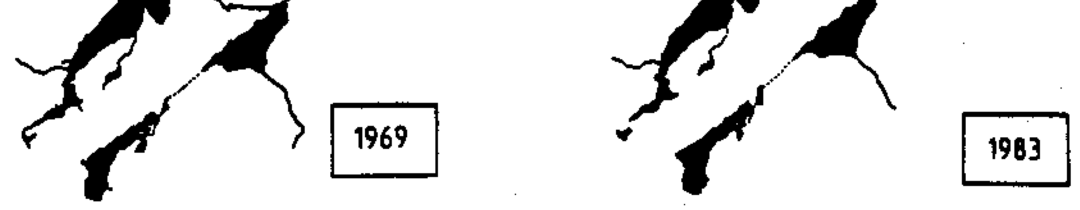

Fig. 8. Change in the outline of Dxherega lediba based on aerial photography of (*a*) 1969 and (*b*) 1983.

nels in the areas where blockages occur. It produces four or more leafless culms per year from a perennial rhizome, and these extend into the channel. Where the current is strong, these rhizomes break off and float downstream as debris. Individual pieces of debris become entangled, forming large debris mats which may become lodged in the channel. Although the vertical thickness of these mats depends upon the amount of debris produced upstream of them, they tend to be shallow, surface phenomena. The water is thus not diverted, but flows underneath them. Where flow rates are sufficiently high these mats are soon broken up,[9] but under reduced flow rates they may become consolidated and permanent — as in the case of the progressive blockage of the lower Nqoga described by Wilson. Accretion of debris rafts is probably also responsible for the rapid shrinkage of the Dxherega lediba near its inlet (Figs 8 and 9).

A model for channel changes in the delta

Flood waters entering the Okavango Delta transport sediment both as suspended-load and as bed-load. The channels are flanked by vegetation and in the upper parts flow conditions and vegetation growth are probably in equilibrium, giving these upper channels long-term stability.[1,9] Water is lost from these channels by overspill and seepage through the vegetation flanks. In the downstream section of the active channel, *C. papyrus* becomes dominant, channel width decreases and an increasing proportion of water is lost from the channel by overbank flooding. This results in a decline in the ability of the channels to carry bed-load sediment, which is accordingly deposited on the channel bed, causing aggradation. Overspill promotes plant growth on the vegetation-dominated banks — due to increased nutrient supply. Channel bed aggradation is therefore accompanied by the accumulation of peat and clay which become trapped within the root zone in areas flanking the channels, forming a kind of levee. As a result of these processes the channel and its flanking vegetation become raised relative to their surroundings (Fig. 10). The dense vegetation inhibits water flow from the channel into the lower lying areas, resulting in a higher water level in the channel relative to the surrounding swamps, as for example at Xaenga.

In time, hydraulic gradients down the channel will become progressively reduced, whereas gradients at right angles to the channel axis will increase. Water shed laterally from a deteriorating channel through the flanking vegetation will seek out new paths which may, for example, be provided by hippo trails. Water entering such a path will be free of sediment and, given a suitable hydraulic gradient, will begin to erode a new channel. More water will thus be diverted away from the main channel, further promoting sedimentation within it. Once the gradient in the main channel has been reduced to a critical value, vegetation 'blocks' the channel. This is achieved by a combination of growth of *C. papyrus* from the banks into the channel, the deposition of plant debris within the channel and the consolidation of this debris by plant growth. The continuous input of debris to the semi-abandoned river course results in the progressive upstream invasion of the channel by plants and the formation of a 'channel blockage' — a process well documented in the case of the abandoned section of the Nqoga[3] (Fig. 2). Once this stage is reached sediment will start to enter the new channel system, initiating a new cycle of aggradation.

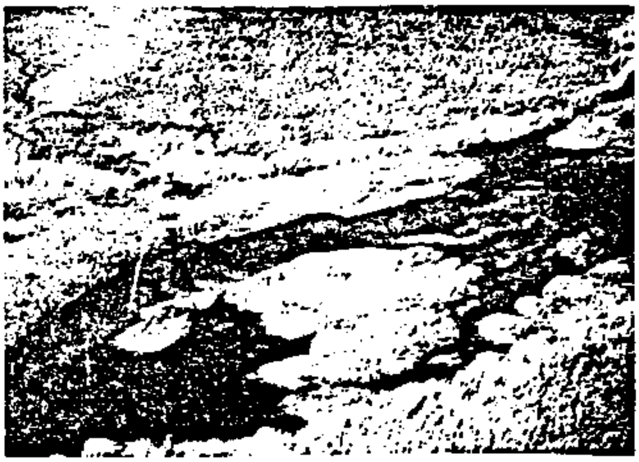

Fig. 9. An aerial view of the sand spit developed at the entrance to Dxherega lediba (September, 1985).

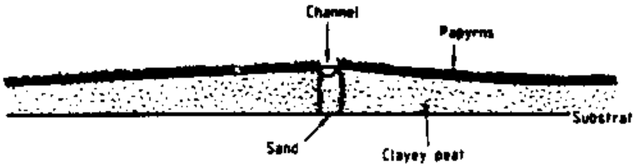

Fig. 10. A cross section of a mature channel showing the distribution of sand and peat.

During aggradation of a channel system, a characteristic accumulation of sediment results; sand accumulates in the channel while peat, containing clay, collects in the areas flanking the channel (Fig. 10). Once the channel system is abandoned the peat-covered areas will become compacted, a process which may be enhanced by peat fires, resulting in topographic inversion of the channel (Figs 4 and 5). Termites invade the area, constructing termitaria. When such an area is reflooded, due to aggradation elsewhere in the system, the former channel beds will stand as a sinuous chain of islands, with the flanking flooded area being dotted with small islands resulting from termitaria. This type of terrain is commonly seen on aerial photographs of the upper swamps. Reflooding such as described here is perhaps one way in which large bodies of open water (madiba) may form. These are common in certain regions of the delta, especially along the Maunachira and upper Nqoga channels.

Comparison of the Okavango Delta with other fluvial models

The distributary channels of the Okavango Delta contain elements of several fluvial models. The various parameters such as sediment type, sediment transport, channel morphology and resultant sequences of deposited sediment bear some resemblance to the anastomosed river model, although some significant differences exist.

Anastomosed river deposits have been described from modern and ancient settings.[13-15] The definition of an anastomosed river is: a system comprising an interconnected network of low-gradient, relatively deep and narrow, straight to sinuous channels composed of stable banks of silt, clay and vegetation. It has been quantitatively demonstrated that vegetated channel margins are highly resistant to bank erosion and significantly stabilize channel margins.[12] Deposits result from vertical aggradation within the channel, rather than from lateral migration of the channel system. Furthermore, the deposits of anastomosed rivers originate in a mosaic of sub-environments including peat swamp, backswamp, crevasse splay and channel settings. Smith and Smith[14] state that the anastomosed system in Banff, Alberta, is characterized by overbank deposits which constitute 80 – 90% of the total accumulations, while channel-fill sequences, consisting of sand and gravel, form only a small proportion of the total sequence.

The Okavango river channels bear several similar features to the anastomosed model. These include: vegetation-stabilized channel margins; channel-fill sequences consisting of shoe-string sand accumulations enclosed within the adjacent and surrounding peat; sedimentation within the channels occurs by vertical accretion due to the confinement of the sand to the in-channel areas.

Several significant differences exist, however, when comparing the Okavango distributaries to the anastomosed model. Sedimentation caused by overbank flooding and crevasse splays is virtually non-existent. Water flow over the channel margin during high flow stage enters the adjacent swamp terrain, carrying no bed-load material and little suspended load. The minor amount of suspended clay (kaolin) becomes trapped in the channel margin vegetation. Therefore, the channel-fill sequences account for a substantial proportion of the clastic (non-organic) material deposited in the delta, with no evidence of clastic splay deposits being found. This is in contrast to Smith and Smith's[15] model, wherein overbank material constitutes a large proportion of the total sediment accumulations.

Sediment distribution in rivers of the Okavango Delta shows that the bulk of clastic material consists of fine- to medium-grained, well-sorted sand with a small amount of silt and clay. As such, bed-load transport is the main mechanism whereby the clastic sediment is transported downstream. Therefore, bed-load processes, characteristic of braided river environments, are occurring in a fluvial system which clearly consists of highly stabilized channel banks. The resultant morphology and characteristics of the Okavango Delta rivers are therefore a composite of braided river channel features (sand-dominated bed-load with little fine-grained suspended load) and anastomosed channel features (stable banks and vertical aggradation of sediment comprising the channel-fill deposits). Bank stability is, however, not due to plant stabilization of overbank deposits but to the rapid vertical accretion of a mat of papyrus rhizomes which form an erosion-resistant peat. Furthermore, the present Okavango fluvial system displays little or no tendency to meander. These findings reiterate those of Jackson[16] and others, who state that a combination of features is often more common in fluvial environments, rather than the presence of a dominant variety such as purely meandering or braided systems. Furthermore, the Okavango Delta distributaries bear little resemblance to the straight distributaries of other river-dominated deltas such as the Mississippi.[17]

Finally, the fluvial style of the Okavango channels and resultant clastic sequences may provide a modern-day analogue for the ancient anastomosed river deposits interpreted within the Witbank Coalfield.[18,19] These ancient sequences appear to be dominated by channel-fill sequences rather than overbank flood material — a feature evident in the Okavango Delta system.

Conclusion

It appears from the observations made over many years that changes within the distributary system of the Okavango Delta occur on two time scales; on a long time scale, controlled by tectonic activity and by climatic change, and on a shorter time scale, in which sedimentation within vegetation-confined channels is the dominant initiating agent.

Sedimentation takes place predominantly in the upper portion of the delta and its effect is most pronounced in the middle channel regions where water loss from the channels is at a maximum, and rapid aggradation is probably taking place. The rate of aggradation in these regions may be substantial, probably of the order of several centimetres per year. Historical records indicate that over the last one hundred years, distribution has switched from the Thaoge to the Nqoga to the Maunachira, suggesting an effective life of a channel system of the order of one hundred years. In this time, net aggradation may be of the order of five metres, assuming a sediment accumulation rate of 5 cm per year.

It is apparent that vegetation blockage is a symptom of advanced deterioration in a channel rather than the ultimate cause, and it is not surprising that efforts to clear channels of obstructing vegetation, graphically described by Wilson,[3] have be totally unsuccessful.

The model for sediment-induced changes in channel syste described here has important practical implications for wa management schemes in the delta. It now becomes possible formulate a monitoring strategy for channels in the delta by whi their well-being can be constantly assessed. Providing the re vant data are known, it is possible in principle to predict the li expectancy of channel systems and the direction of changes flow.

Finally, the Okavango Delta appears to represent, in part, modern-day analogue of depositional systems which gave rise the coal deposits of Southern Africa and detailed study of t delta will provide insight into conditions which prevailed duri their formation.

We gratefully acknowledge the support, advice and long discu sions we had with P.A. Smith of the Department of Water A fairs, Maun. His input has been a major factor in guiding o thoughts. We nevertheless assume responsibility for simplific tions and omissions in this paper. C.M. Breen and B.H. Walk also provided thought-provoking discussion. We als acknowledge the Hydrological Section of the Department Water Affairs, Botswana, for permission to publish the da presented in Fig. 6.

Received 6 June 1986.

1. Dincer T., Hutton L.G. and Kupee B.B.J. (1981). Study, using stable isotop of flow distribution, surface groundwater relations and evapotranspiration the Okavango Swamp, Botswana. *I.A.E.A. Proc.*, Ser. STI/PUB/493, 3 – 2
2. UNDP (1977). *Investigation of the Okavango Delta as a primary water resou for Botwana.* United Nations Development Programme: Food and Agricultu Organization. AG: DP/BOT/71/506.
3. Wilson B.H. (1973). Some natural and man-made changes in the channels the Okavango Delta. *Botswana Notes and Records* 5, 132 – 153.
4. Cooke H.J. (1976). The palaeogeography of the middle Kalahari of northe Botswana and adjacent areas. *Proc. Symposium on the Okavango Delta a its Future Utilization.* Botswana Society, Gaborone, 21 – 28.
5. Hutchins D.G., Hutton S.M. and Jones C.R. (1976). The Geology of t Okavango Delta. In ref. 4, pp. 13 – 20.
6. Scholz C.H. (1975). Seismicity, tectonics and seismic hazard of the Okavan Delta, Botswana. In ref. 2.
7. Smith P.A. (1976). An outline of the vegetation of the Okavango draina system. In ref. 4, pp. 93 – 112.
8. McCarthy T.S., McIver J.R. and Cairncross B. (1986). Carbonate accumu tion on islands in the Okavango Delta. *S. Afr. J. Sci.* 82, 588.
9. Ellery W. (1985). Vegetation dynamics of channel fringe communities in t north-eastern Okavango Delta. In *Vegetation dynamics of the north-easte Okavango Delta.* Progress report to Botswana Department of Water Affai Gaborone.
10. Wilson B.H. and Dincer T. (1976). An introduction to the hydrology a hydrography of the Okavango Delta. In ref. 4, pp. 33 – 48.
11. Ellery K. (1985). Bog succession in the north-eastern perennial swamps of t Okavango Delta. In ref. 9.
12. Smith D.G. (1976). Effect of vegetation on lateral migration of anastomos channels of a glacier meltwater river. *Geol. Soc. Am. Bull.* 87, 857 – 860.
13. Smith D.G. and Putnam P.E. (1980). Anastomosed river deposits: modern a ancient examples in Alberta, Canada. *Can. J. Earth Sci.* 17, 1396 – 1406.
14. Le Blanc Smith G. (1980). *Genetic stratigraphy and palaeoenvironmental co trols on coal distribution in the Witbank Basin Coalfield.* PhD thesis, Unive sity of the Witwatersrand, Johannesburg.
15. Smith D.G. and Smith N.D. (1980). Sedimentation in anastomosed riv systems: examples from alluvial valleys near Banff, Alberta. *J. Sed. Petrol* 50, 157 – 164.
16. Jackson R.G. (1978). Preliminary evaluation of lithofacies models for meande ing alluvial streams. In *Fluvial Sedimentology*, edit. A.D. Miall. Can. So Petrol. Geologist, Mem. 5, 543 – 576.
17. Saxena R.S. (1976). *Modern Mississippi Delta — depositional environme and processes.* Am. Assoc. Petrol. Geol. Soc. Econ. Paleont. Minera Guidebook, New Orleans.
18. Le Blanc Smith G. and Eriksson K.A. (1979). A fluvioglacial a glaciolacustrine deltaic depositional model for the Permo-Carboniferous co of the north eastern Karoo Basin, South Africa. *Palaeogeog. Palaeocli Palaeoecol.* 27, 67 – 84.
19. Cairncross B. (1980). Anastomosing river deposits: palaeoenvironmental co trol on coal quality and distribution, northern Karoo Basin. *Trans. Geol. So S. Afr.* 83, 327 – 332.