Geomorphology, 1 (1988) 267-278
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands

INCREMENTAL AGGRADATION ON THE OKAVANGO DELTA-FAN, BOTSWANA

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(Received May 11, 1987; revised and accepted November 20, 1987)

Abstract

McCarthy, T.S., Stanistreet, I.G., Cairncross, B., Ellery, W.N., Ellery, K., Oelofse, R. and Grobicki, T.S.A., 1988. Incremental aggradation on the Okavango Delta-fan, Botswana. Geomorphology, 1: 267-278.

Distributary channel switching is a relatively frequent event in the upper reaches of the Okavango Delta-fan, Botswana. This phenomenon was investigated by means of detailed topographic surveys and excavations along an abandoned channel and depth probing along an active channel system. This work has confirmed that channel switching is the result of aggradation within the channel systems. Initially, new channel systems are erosive but later in their evolution both channel bed and adjacent swamp (peat) areas begin to aggrade. This phase leads to a change in channel gradient and causes the channel to become moribund. Abandonment follows with consequent desiccation of the peat. Burning of the peat completes the cycle of the channel evolution, the entire process taking about one hundred years under present flow conditions. The initial aggradation phase results in the accumulation of about 4 m of peat, but net aggradation after collapse of the peat following a peat fire is 30-40 cm. Channel beds probably also experience about 4 m of aggradation, as measured from the eroded, channel floor. After a peat fire, the channel bed sands remain elevated by about 1 m relative to the surrounding, burnt out peat. As a result of the collapse of the peat, the abandoned area becomes available for reflooding.

Introduction

The Okavango Delta is situated in northern Botswana and represents the termination of an internal drainage system which arises in the highlands of central Angola. The delta covers an area of 18,000 km^2 in extent and is a depositional component of the Cretaceous to Recent intracratonic Kalahari Basin.

The term "delta" is long entrenched through common usage, and arose as a result of the classic birds-foot configuration of the distributary channels (Figs. 1 and 2). However, the Okavango Delta is not a delta in the normal sense in that it does not enter a standing water body. It is in fact a large, conical alluvial fan (UNDP, 1977), but one characterized by very low gradients. The average gradient from proximal to distal ends is about 1:3600 (Wilson and Dincer, 1976). Because of long established usage, we shall continue to refer to the Okavango "Delta"

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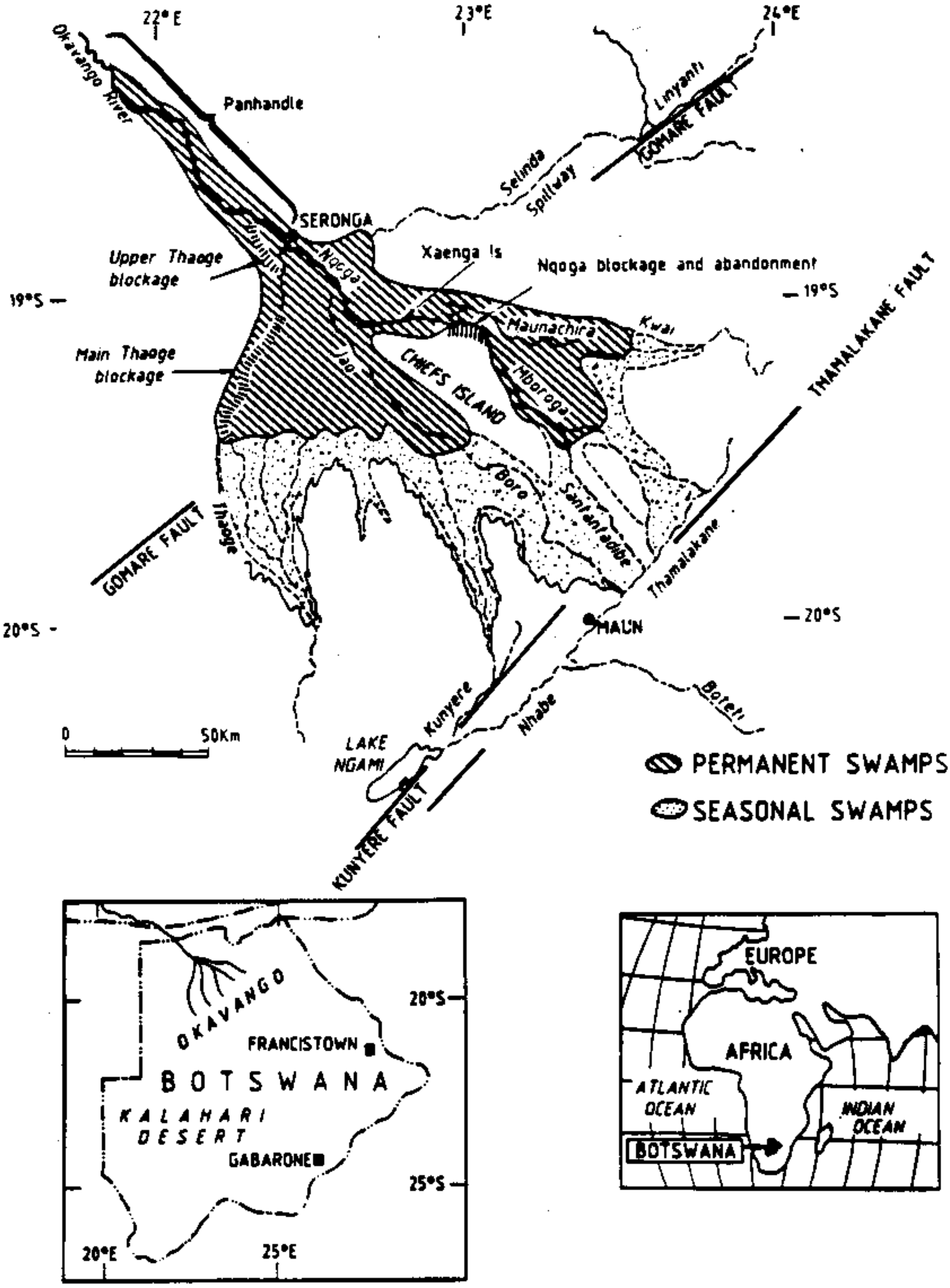


Fig. 1. The Okavango Delta-fan.

or "Delta-fan" although we realize that the use of the term delta in the present context is strictly incorrect.

The delta is confined in a graben-like structure by northeast striking normal faults (Figs. 1 and 2; Hutchins et al., 1976). Maximum sediment thickness in the graben is belie[ved] of the order of 300 m (Hutchins et al[.] Figure 1 shows that inflow at the ap[ex of the] delta occurs via the Okavango River[,] also confined by a northwesterly stri[king gra]ben, forming the so-called "panhandl[e"]

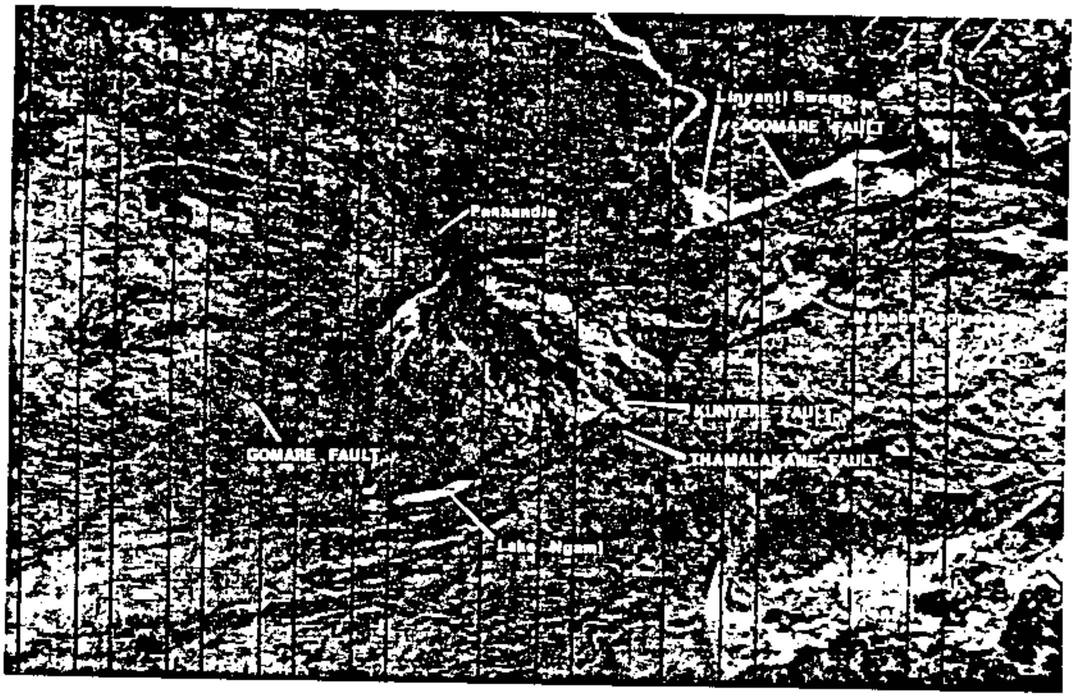


Fig. 2. A NOAA a satellite image of the Okavango Delta and environs. This infrared image was taken after sunset (7.30 p.m. local time) on June 20, 1985.

lies at right angles to the Gomare–Thamalakane fault system (Hutchins et al., 1976).

Broadly, the delta can be divided into three regions (Fig. 1; Wilson, 1973): (1) the panhandle, where flow is confined by faults and vegetation; (2) the central, perennial swamps in which flow is confined by vegetation; and (3) the seasonal swamps where water is relatively unconfined. Scattered throughout the delta are islands which support large copses of palm and other trees, while the remainder of the delta is vegetated with grasses and sedges.

Water dispersion in the delta is locally concentrated within the bifurcated distributary system at any one time. However, the channel systems are insufficient to contain the seasonal flood waters (May–August) and as a result, overspill and sheet flow outside the channel areas is responsible for the bulk of water dispersal in the delta. The overspill has resulted in the formation of extensive perennial swamps in the upper reaches of the delta and in seasonal swamps in the lower reaches. The upper portion of the perennial swamps is subject to frequent channel switching (Wilson, 1973; Shaw, 1984), probably induced by localized aggradation associated with the vegetatively confined channels. The probable mechanisms involved have been discussed by McCarthy et al. (1986). Over time, channels avulse, causing major or minor changes in water distribution within the delta.

Channel avulsion is associated with increments of aggradation on the delta-fan surface. Field work in an area in which avulsion recently took place has allowed us to identify the processes associated with an avulsion and to quantitatively measure the magnitude of the aggradational increment.

Morphology of an active channel system

A typical channel system within the perennial swamps is confined by extensive areas of peat accumulation which underlie actively growing *Cyperus papyrus* L. sedge (Fig. 3). The peat and the papyrus confine channels which typically are 15–20 m wide and 4–5 m deep with flow rates between 0.5 and 0.9 m s^{-1}. The vegetation causes perching of the water level in the

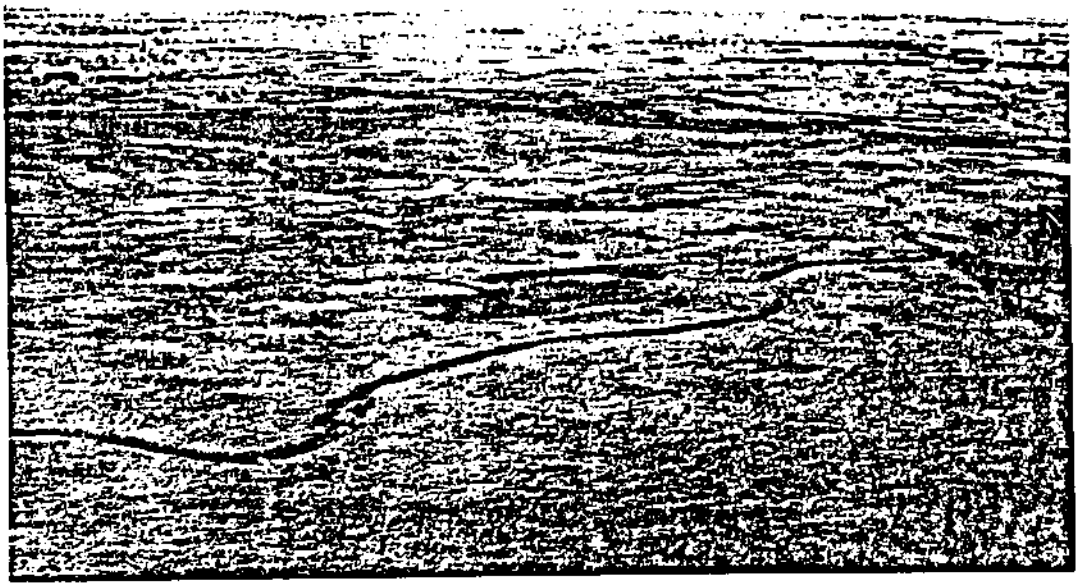


Fig. 3. Aerial view of a typical channel in the upper reaches of the perennial swamp.

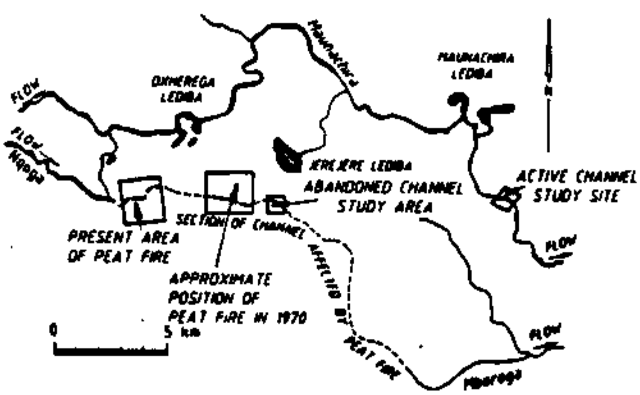


Fig. 4. The Maunachira and Nqoga channels, showing study sites referred to in the text. See Fig. 1 for location of this area.

channels, inducing a gradient in water level away from the channels, which promotes water loss from the channels at slow flow rates through the vegetation and underlying peat.

An insight into the quantity of peat generated in association with a typical active channel system was obtained by depth profiling across the Maunachira Channel and the adjacent pa-

pyrus swamp (Figs. 4 and 5). The ch
some 20 m wide and is flanked by beds
about 3 m thick. Peat and living vegetati
the edges to the channel (McCarthy
1987b). The papyrus roots in the peat
low the water level while the emergent
of the plants rise up to 2 m above wa
and maintain a water level gradient
1:300 away from the channel. This gr
an order of magnitude greater than the
down the channel axis.

The peat itself consists of a black m
vegetation in various states of degradati
surface it is composed of a loose entan
of living rhizomes and dead stalks in
carbonaceous sludge. Deeper down,
tends to become more compact (Fig. 5
content is high throughout. Detritall
duced very fine quartz sand and silt,
with clay (kaolinite) form important i
components throughout the profile. It
that the profiles measured in the Ma
Channel (Fig. 5) are representative
large channels in the delta.

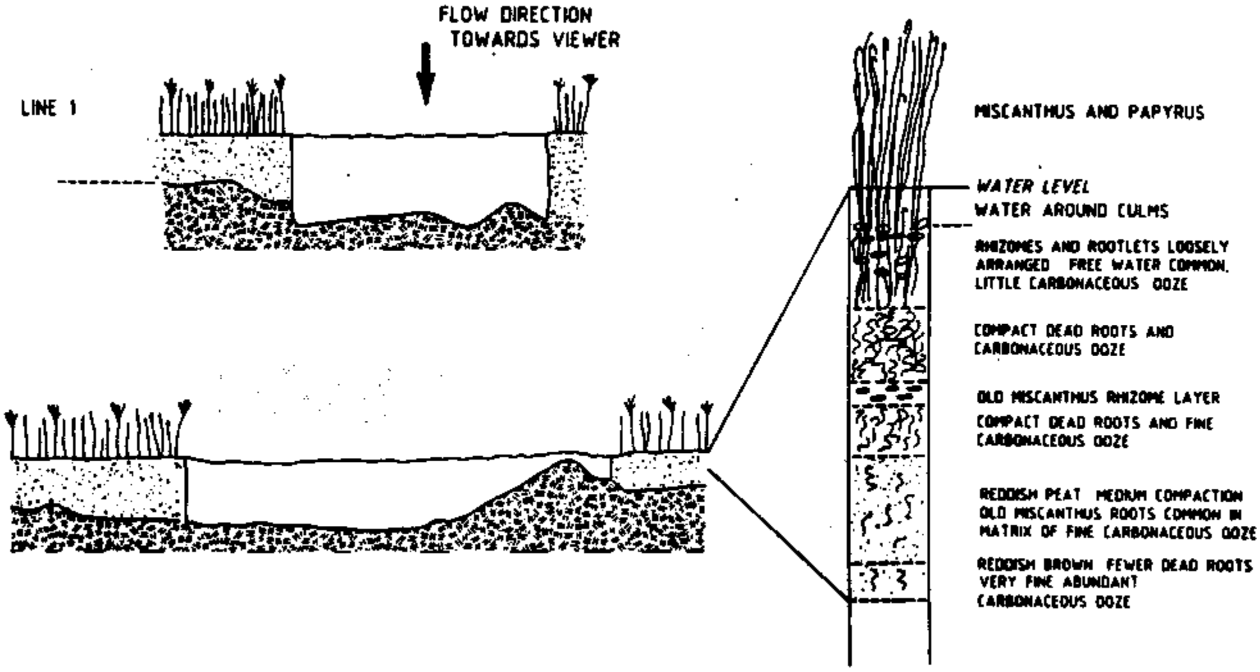


Fig. 5. Two typical profiles across the active Maunachira Channel and a typical profile through the peat.

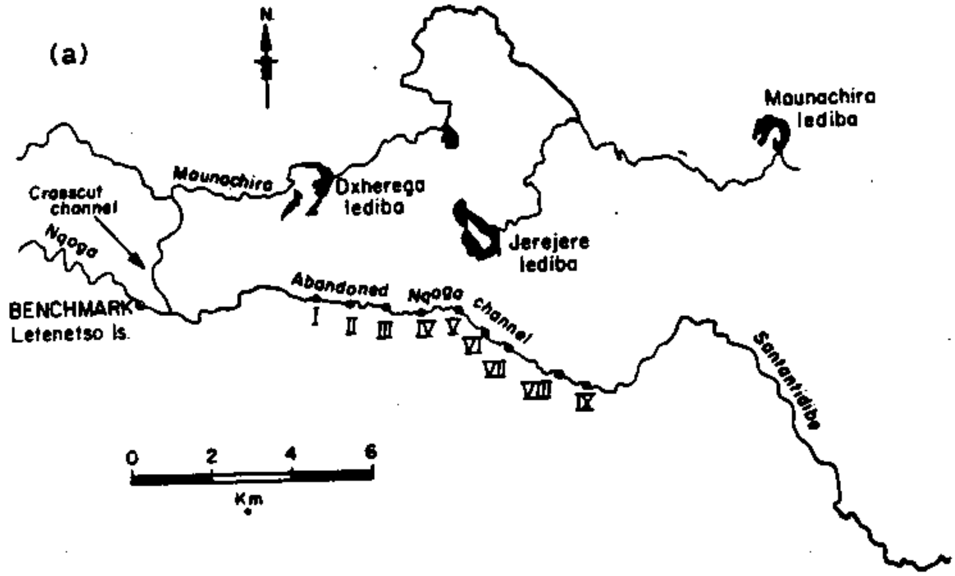
The Nqoga area

The history of an avulsive event, resulting in the complete abandonment of a former major channel system, has been recorded by Wilson (1973) in the Nqoga Channel at the northern end of Chiefs Island (Fig. 4).

In the early part of this century, the Nqoga was a major distributary of the delta and probably resembled the Maunachira today. In the region where the peat fire is currently burning (Fig. 4), Stigand (1923) recorded a channel depth of 5 m and a flow velocity of 0.76 m s^{-1}. In about the 1920s, the lower Nqoga began to block with plant material consisting mainly of papyrus debris. Blockages proceeded progressively upstream over a distance of about 15 km (Fig. 4). In the late 1950s the channel avulsed and flow shifted to the more northerly Maunachira Channel via the newly created Crosscut Channel (Fig. 6a; Wilson, 1973). As a result, the flanking papyrus overgrew the abandoned lower Nqoga Channel.

As a result of reduced inflow, the water table in the area of the abandoned channel began to subside. Some indication of this process was obtained from a detailed, accurate topographic survey carried out by one of the authors (R.O.) along the largely abandoned channel during 1970, and is shown in Fig. 6. Where possible, both channel bed and water level were surveyed. This survey showed that the gradient on the water table (1:1250) was steeper than that of the old channel bed (1:2250, straight line distances used). It is likely that a decline in the water table was progressive along the abandoned channel section. As a result, the peat became subaerially exposed and began to desiccate. Following desiccation, the peat caught fire. It is not clear when this fire commenced, but it was noted during the 1970 survey and it is still burning at present (Fig. 7; Ellery et al., 1987). It is probable that this peat fire has been burning intermittently or perhaps even continuously for several decades, gradually following the declining water table.

The peat fire was examined during July 1986 (Ellery et al., 1987) some 2 km southeast of the avulsion point of the Nqoga Channel (Fig. 4). At the time of the visit, vegetation blockages, which cover much of the Crosscut Channel, had recently been cleared and all surface vegetation



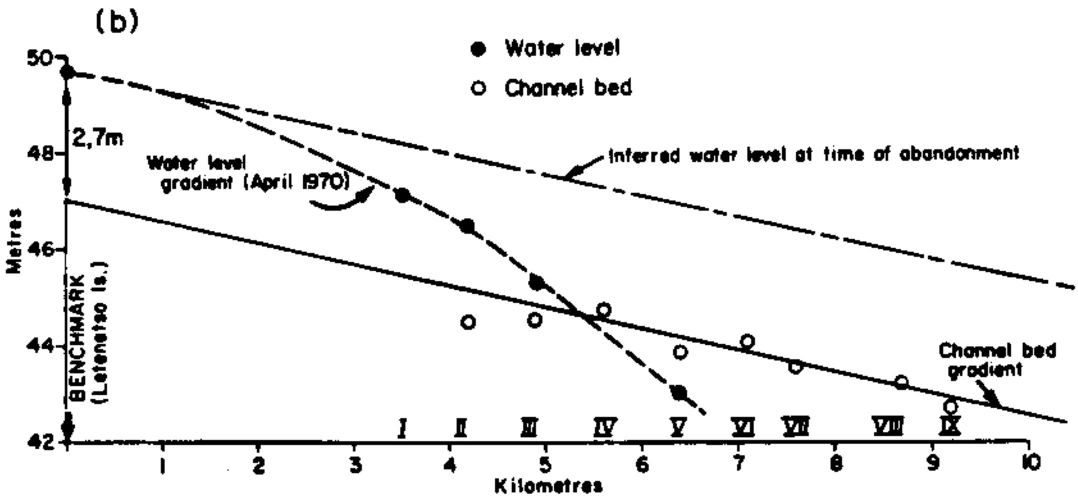


Fig. 6. (a) Location of surveyed points along the abandoned Nqoga Channel; (b) elevation profile along the abandoned Nqoga Channel.

in the area had been destroyed by the common surface fires which pass across the swamps, allowing access to this remote region.

The peat fire was burning over an area of some 1 km^2. The fire was observed to burn down in depth increments, determined by moisture content and oxygen availability. The upper layer of peat, some 10–15 cm thick, burns on a fairly wide front. In addition, deeper fires occ deep cracks which develop as the pe cates. Burning induces collapse of t leaving a residue of extremely fine, pow The surface topography in the burning comes extremely rugged due to differe lapse as the various burning fronts The rate of progress of the fires is ap

Fig. 7. Aerial view of the area affected by the peat fire.

extremely slow, probably of the order of a few centimetres per day. The rate may slow or halt during rainy (summer) months.

Small whirlwinds ("dust-devils") active in the dry winter months disperse some of the ash. However, during the summer rains the ash would tend to become consolidated and furthermore, animals would trample the ash, further compacting it, so that in time the ash would consolidate into a hard layer.

An area to the south of Jerejere lediba (lake) (Fig. 4), where the peat flanking the old Nqoga Channel had burnt out several decades ago, was examined in detail. Figure 8 shows the nature of the topography around the channel and the resultant stratigraphy of the burnt peat. The substratum on which the Nqoga Channel system had developed consists of a dense, grey, silty sand. The stratigraphy of the former vegetated and peat-covered area which overlay the substratum now consists of a basal layer of unburnt peat between 5 and 30 cm thick, occasionally underlain by a thin layer of white sand close to the channel, and overlain by burnt peat products. These consist of yellow ash or carbonaceous silt, the latter representing partially burnt peat, overlain by a grey top soil, which is probably a mixed, bioturbated layer. The former channel is underlain by white sand and is generally raised relative to the surrounding, former peat covered area (Figs. 8 and 9). The topography of the channel bed is extremely irregular (McCarthy et al., 1986, 1987a; Ellery et al., 1987) but is on average about 0.8 m higher than the surrounding areas, as determined by means of several elevation transects across the abandoned channel.

Aggradational increments

At the time the channel was active, peat would have accumulated to local water level (e.g. Fig. 5). Thickness of peat which accumulated along the old Nqoga Channel can be estimated with the aid of Fig. 6b. If the average channel bed gradient is extrapolated to the bench mark and compared to prevailing water depth at the time of the survey, a water depth of 2.7 m is indicated, which compares favourably with a measured water depth of 2.53 m at the bench mark. At the time the Nqoga Channel was active, the gradient on the water surface would have been similar to that of the channel bed (Fig. 6b). Since the bed of the channel is raised by about 1 m relative to the surrounding areas and since peat accumulates to local water level, a pre-

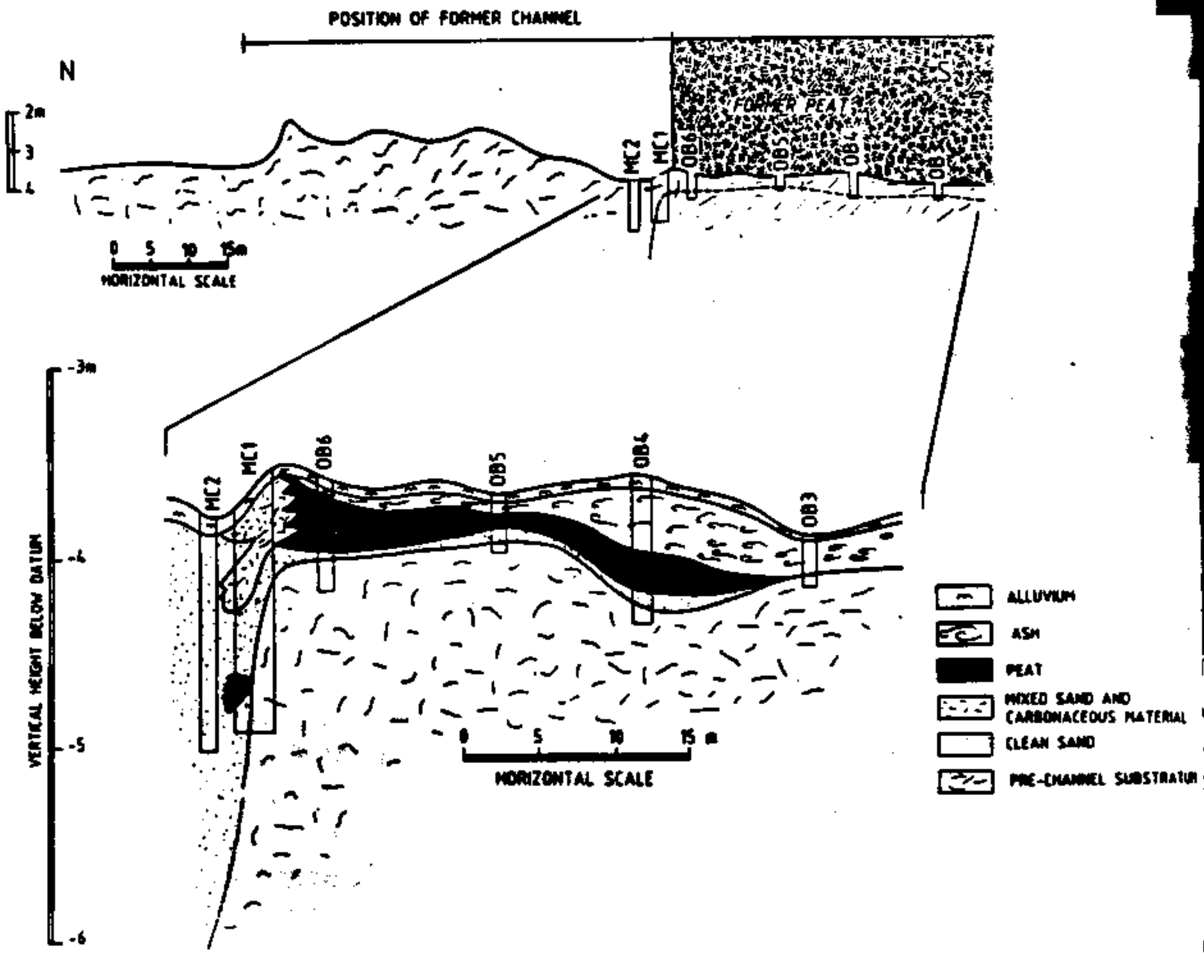


Fig. 8. A surface elevation profile across the abandoned Nqoga Channel. The insert shows the distribution of materi surface.

vious peat thickness close to 4 m adjacent to the former channel can be estimated. This represents the amount of aggradation induced by the Nqoga Channel while active.

This accumulated peat was reduced to a layer no more than 30–40 cm in thickness following complete burning and compaction, which represents the net aggradational increment in areas adjacent to the former Nqoga Channel. As the elevation of the bed of the old channel is about 0.8 m above the surrounding, former peat-covered area, net aggradation associated with the channel itself is of the order of 1.0–1.2 m.

This has important implications as far as local water levels are concerned. The water depth was recorded at the bench mark (Fig. 6b) at the time of the survey to be 2.53 m. In July the water level recorded on this same mark was 2.33 m. It follows therefore th present land surface over much of th which was compacted following the pe lies several metres below water level as isted at the time this section of the Nqo active. In effect, although the land surf been raised by only a very small amou abandoned area has not been reflooded can be ascribed to a combination of e groundwater drainage and the dammin of the peat and vegetation flanking the filled but moribund portion of the Nqoga nel close to where it diverges from the active Maunachira Channel (Fig. 4).

Fig. 9. Sandy ridge representing a former channel.

Earth movements and channel avulsion

Active faulting has been proposed as a possible cause of channel avulsion, and indeed, the final abandonment of the lower Nqoga Channel has been associated with an earthquake which affected the delta in 1952 (Wilson, 1973). In principle, downfaulting of the upper portion of a channel could induce channel avulsion, particularly in view of the shallow gradients which characterize the delta.

In the particular case of the lower Nqoga abandonment, the Gomare fault which has a downthrow to the northwest passes across the upper reach of the abandoned section and could have been responsible for the avulsion. The topographic survey reported in this work has some bearing on this hypothesis as the survey line passes across the region likely to have been affected by faulting (Figs. 1, 2 and 6a). However, the survey failed to reveal any pronounced change in grade which could be attributed to active faulting (Fig. 6b). It is therefore evident that in this case at least, earth movements were not the primary cause of abandonment.

Discussion

Stigand (1923) recorded an oral tradition amongst the local Batswana which holds that the lower Nqoga Channel came into existence during the reign of chief Letsholathebe I (ca. 1840–1874). Prior to this, it was a malapo or shallow swamp, and the Thaoge Channel was the main distributary: "Hippopotami in great numbers breaking through and trampling a big 'hippo-path' created the initial Nqoga Channel and the inflowing water did the rest" (p. 407).

The channel began to block in the 1920s and had effectively ceased to flow by the late 1950s. The cycle of channel evolution was thus completed in about one hundred years, in agreement with the estimate of McCarthy et al. (1986). During this time, a layer of peat some 4 m thick accumulated over a very large area. Although this is a substantial aggradational increment, the effect of compaction and mainly the peat fire which passed over the area was to reduce this thickness to some 40 cm, which represents the net aggradational increment on the land surface. Aggradation in former channels is somewhat greater (about 1–1.2 m) but these are very localized and of relatively small lateral extent. Although the final, net contribution to the delta surface after deflation is less than 40 cm, it must be remembered that the actual amount of aggradation which leads to abandonment is that reflected by the peat prior to burning, i.e. about 4 m. Some of this aggradation undoubtedly occurred prior to the development of the Nqoga Channel per se, when the area was malapo swampland (Stigand, 1923), but it is probable that the bulk of the channel aggradation occurred as a direct result of vegetative aggradation adjacent to the Nqoga Channel itself.

McCarthy et al. (1986) have speculated that a new channel system is initially erosive and scours down into the sediment substratum. This is supported by excavations carried out on the abandoned section of the Nqoga (Fig. 8). However, once a connection through to the main, upstream channel system, which carries the Okavango River's sediment, is created, sediment enters the system and aggradation commences. McCarthy et al. (1986) estimated an aggradation rate of about 5 cm per year for the channel, which is matched by aggradation in the flanking peat. At this rate, it would take only eighty years to aggrade the 4 m estimated for the Nqoga Channel. Since some of this aggradation probably predates the development of the Nqoga Channel, this period of eighty years represents the maximum duration of the aggradational phase of the Nqoga Channel. Although this aggradation is important in terms of its effects on channel evolution in the Delta, the peat fires seem to perform a very important role in the longer term evolution of the delta in that they serve to reduce the accumulated peat and create the potential for reflooding.

The topographic survey has revealed that both former channel and its flanking areas presently lie between 3 and 4 m below the estimated potential water level, yet the area has not reflooded. It is thus evident that the vegetation flanking the presently active channel system forms a virtually impenetrable barrier to water, preventing reflooding. The little water which does pass through this barrier is probably [illegible] idly removed by ground water flow. In a se[illegible] such as this, the importance of large mam[illegible] in creating new channelways, especially [illegible] popotami, cannot be underestimated. [illegible] ways created by these animals in moving [illegible] water bodies to grazing areas would quickl[illegible] come channelways and could result in ref[illegible] ing of formerly abandoned areas. This [illegible] vividly illustrated during the present study[illegible] authors obtained access to the old Nqoga C[illegible] nel from Jerejere lediba (Fig. 4) and to d[illegible] it was necessary to create a path throug[illegible] vegetation (mainly *Miscanthus jun*[illegible] Stapf.) which flanks this water body. O[illegible] fourth day of use, active flow was occu[illegible] along this path away from the lediba. If s[illegible] breach can be produced by a small bodym[illegible] can be seen that repeated use of a similar [illegible] by grazing hippopotami would have a prof[illegible] effect. Reflooding in this instance would [illegible] ably create a low-lying, shallow-water s[illegible] area (malapo) such as that which existed [illegible] prior to the development of the Nqoga Ch[illegible] (Stigand, 1923). The formation of s[illegible] swamp area is possibly an essential pre[illegible] to the development of a new channel sy[illegible] because before a channel can develop it i[illegible] essary that the general level of water ta[illegible] raised to support it.

The net increment of sediment on the [illegible] surface caused by a single cycle of chann[illegible] lution is of the order of 40 cm. The surf[illegible] the delta is broadly conical in form (U[illegible] 1977) with a very shallow gradient. Fr[illegible] switching of channel systems evidently [illegible] in a very even distribution of sediment [illegible] the delta surface. The channel system [illegible] acutely sensitive to grade and must refl[illegible] extremely delicate balance. With a suffic[illegible] high initial grade and an unobstructed [illegible] water easily develops its own channel cou[illegible] provides an axis for papyrus swamp de[illegible] ment. However, a rapid but relatively [illegible] amount of channel aggradation result[illegible] change in grade and the vegetation th[illegible]

ads to block the channel and make it mori-
nd, ultimately leading to the destruction of own livelihood.

onclusions

It has been suggested that sudden earth vements may cause channel abandonment the Okavango Delta. The results of a topo- phic survey along the abandoned section of Nqoga Channel suggests that in this in- nce at least, earth movements are not the se and an alternative hypothesis for channel ndonment is necessary.

The entire cycle from channel initiation to ndonment in the case of the Nqoga lasted roximately one hundred years. The cycle resents a response to a delicate balance con- lled by channel grade. Initially, the area was ered by a shallow swamp, criss-crossed by popotamus trails. Ingress of large amounts water coincided with the decline of the age Channel system in the western portion e delta. Grades were initially high and the nal trails directed water flow. In this early e, the juvenile channels must have been ive. These supported vigorous papyrus wth, leading to the development of exten- peat swamps. As the channel matured, ac- panied by direct connection to the supply ediment being brought into the delta, aggra- ion of channel bed and flanking peat swamp urred, reducing the grade to a point where vegetation began to block the channel, leav- it moribund. Flow switched to a new chan- and the old channel desiccated and was troyed.

This detailed study has made it possible to ntify the aggradational increment associ- d with the Nqoga Channel. Two stages of ag- dation have been identified. The *initial stage* at which is associated with the active chan- and is responsible for determining gra- nts within the evolving channel. A maximum radation of about 4 m occurs during this se. Although in the present study, this figure is based entirely on accumulated peat thickness, it is likely that an equivalent amount of aggradation occurs on the channel bed. In this latter case, the aggradation would be represented by the thickness of channel sand measured from the eroded substratum to the average height of the bedforms in the channel.

It is likely that the fire which destroyed most of the accumulated peat is a normal part of the channel evolutionary cycle in the delta. The effect of this fire was to reduce the thickness of the accumulated peat to less than 0.5 m. This thickness therefore represents the net aggradation on the delta surface associated with a single cycle of channel evolution, and thus constitutes the *ultimate stage* of aggradation. Net aggradation within the channel itself is not influenced by peat fires and is between 1.0 and 1.3 m, on average, but is extremely variable due to the irregular topography of the channel bed.

Destruction of the peat flanking the old Nqoga Channel has left the entire affected area at a lower elevation than the water level which characterized this area when the Nqoga Channel was still active. The entire area is thus potentially available for reflooding. The fact that such reflooding has not yet occurred can be ascribed to the damming effect of the peat and vegetation flanking the still active portion of the Nqoga and the efficient drainage by groundwater flow.

Acknowledgements

The authors gratefully acknowledge financial support for this research from the University of the Witwatersrand. C.M. Breen and T.P. McCarthy kindly loaned essential equipment. Judy Wilmot, Adele Workman-Davies, Di du Toit and Mark Hudson provided technical support. The authors gratefully acknowledge fruitful discussion with Mr. P.A. Smith and Mr. S. Child. Anglo American Corporation is acknowledged for permission to publish the survey data.

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