INCREMENTAL AGGRADATION ON THE OKAVANGO DELTA-FAN, BOTSWANA

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Abstract


Disturbatory 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 km² 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”
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 believed to be of the order of 300 m (Hutchins et al., 1976). Figure 1 shows that inflow at the apex of the delta occurs via the Okavango River also confined by a northwesterly striking fault, forming the so-called "panhandle"
A typical channel system within the perennial swamps is confined by extensive areas of peat accumulation which underlie actively growing Cyperus papyrus sedge (Fig. 3). The flow rates between 0.5 and 0.9 m s⁻¹. The vegetation causes perching of the water level in the peat swamps. Over time, channels avulse, causing major changes in water distribution within the delta. Channel avulsion is associated with substantial changes in the delta's surface. Field work in an area in which avulsion recently took place has allowed us to identify the processes associated with avulsion and to quantitatively measure the magnitude of the aggradational increment.

Fig. 2. A NOAA satellite image of the Gomati Delta and environs. This image was taken after sunset (7:30 p.m.) on June 20, 1995.
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 papyrus swamp (Figs. 4 and 5). The channel is some 20 m wide and is flanked by beds about 3 m thick. Peat and living vegetation at the edges to the channel (McCarthy, 1987). The papyrus roots in the peat low the water level while the emergent plants rise up to 2 m above water and maintain a water level gradient of 1:300 away from the channel. This generates an order of magnitude greater than that down the channel axis.

The peat itself consists of a black mineral vegetation in various states of degradation; its surface is composed of a loose entanglement of living rhizomes and dead stalks in a carbonaceous sludge. Deeper down, the peat tends to become more compact (Fig. 5) and the content is high throughout. Detritally reduced very fine quartz sand and silt, mixed with clay (kaolinite) form important components throughout the profile. It is likely that the profiles measured in the Maunachira Channel (Fig. 5) are representative of large channels in the delta.
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 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
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 km². 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 occur deep cracks which develop as the peat cates. Burning induces collapse of the leaves a residue of extremely fine, powdery The surface topography in the burning area becomes extremely rugged due to differential collapse as the various burning fronts meet. The rate of progress of the fires is ap...
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. 7. Aerial view of the area affected by the peat fire.
Fig. 8. A surface elevation profile across the abandoned Nqoga Channel. The insert shows the distribution of material 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 that the present land surface over much of the which was compacted following the peat lies several metres below water level existed at the time this section of the Nqoga Channel was active. In effect, although the land surface has been raised by only a very small amount, abandoned area has not been reflooded and can be ascribed to a combination of groundwater drainage and the damming of the peat and vegetation flanking the filled but moribund portion of the Nqoga Channel close to where it diverges from the active Maunachira Channel (Fig. 4).
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 downdrop 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 rapidly removed by ground water flow. In a sense such as this, the importance of large mammal in creating new channelways, especially popotami, cannot be underestimated. Flows created by these animals in moving water bodies to grazing areas would quickly come channelways and could result in reflooding of formerly abandoned areas. This is vividly illustrated during the present study, when it was necessary to create a path through vegetation (mainly Miscanthus jun. Staph.) which flanks this water body. On the fourth day of use, active flow was occurring along this path away from the lediba. If a breach can be produced by a small body of water, it can be seen that repeated use of a similar path by grazing hippopotami would have a profound effect. Reflooding in this instance would thereby create a low-lying, shallow-water area (malapo) such as that which existed prior to the development of the Nqoga Channel (Stigand, 1923). The formation of a swamp area is possibly an essential prelude to the development of a new channel system, because before a channel can develop it is necessary that the general level of water be raised to support it.

The net increment of sediment on the surface caused by a single cycle of channel formation is of the order of 40 cm. The surface of the delta is broadly conical in form (U. M. 1977) with a very shallow gradient. For switching of channel systems evident in a very even distribution of sediment on the delta surface. The channel system is acutely sensitive to grade and must rest on an extremely delicate balance. With a sufficiently high initial grade and an unobstructed flow, water easily develops its own channel course, provides an axis for papyrus swamp development. However, a rapid but relatively small amount of channel aggradation results in a change in grade and the vegetation that
inadequate to block the channel and make it moribund, ultimately leading to the destruction of the townspeople.

Conclusions

It has been suggested that sudden earth movements may cause channel abandonment of the Okavango Delta. The results of a topographic survey along the abandoned section of the Ngqura Channel suggests that in some instances, earth movements are not the sole cause and an alternative hypothesis for channel abandonment is necessary.

The entire cycle from channel initiation to abandonment in the case of the Ngqura lasted approximately one hundred years. The cycle presents a response to a delicate balance controlled by channel grade. Initially, the area was covered by a shallow swamp, criss-crossed by hippopotamus trails. Ingress of large amounts of water coincided with the decline of the delta. Grades were initially high and the channel and trails directed water flow. In this early phase, the juvenile channels must have been active. These supported vigorous papyrus growth, leading to the development of extensive peat swamps. As the channel matured, accompanied by connection to the supply of sediment being brought into the delta, aggradation of channel bed and flanking peat swamp occurred, reducing the grade to a point where vegetation began to block the channel, leaving it moribund. Flow switched to a new channel and the old channel desiccated and was destroyed.

This detailed study has made it possible to study the aggradational increment associated with the Ngqura Channel. Two stages of aggradation have been identified. The initial stage is characterized by the accumulation of about 4 m occurs during this stage. 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 natural 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 Ngqura Channel has left the entire affected area at a lower elevation than the water level which characterized this area when the Ngqura 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 Ngqura and the efficient drainage by groundwater flow.

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