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Low sinuosity and meandering bedload rivers of the Ol Fan: channel confinement by vegetated levées without fine sediment

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ABSTRACT

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The river systems of the Okavango Fan negate present fluviological perceptions that fluvial geomet
dependent upon the type of sediment load being carried by the river. In northwest Botswana, meandering an
rivers, both of which may show anastomosis, are distinctly bedload in character. This is mainly because of a r
of clastic sediment, consisting of aeolian sand from the Tertiary to Recent Kalahari Basin. All that seems
therefore, to control low sinuosity and meandering geometries is adequate confinement of channels. In the
this is provided by heavily vegetated levées comprising peat, formed from and colonised by a *Cyperus papy*
flora: fine sediment plays almost no role in the confinement process.

Active and abandoned examples of low sinuosity river channels were studied. An inversion of topography
latter, caused by the low survival probability of metres thick peat levées. Desiccation and burning of peat ul
degraded ash layer only tens of centimetres thick. The channel sand then stands as a ridge rising above the
surface. In both examples studied, no crevasse splays occur, but hippopotami trails breach the levées
distributary channels which become filled with sand. The sand ultimately grades backwards to plug the bre

Meander belts are also developed, particularly in the upper fan and entry corridor. Cut banks incise
substrate and scroll bar topographies can be discerned beneath their peat cover. Fine sediment plays
confinement of these channels, which are maintained by peat levées similar to those encountered in the low
channels. The recognition of these bedload low sinuosity and meandering river channels now completes the
any geometry of river channel can be developed in bedload, mixed load and suspended load rivers.

Important aspects of the modern channels for the study of ancient river systems are (1) the confining effe
which have low preservation potential geologically, and (2) in helping to explain river systems which sho
evidence of semi-arid and more humid climatic conditions. The latter may be explained as perennial riv
otherwise semi-arid climatic regime from a distant source, which provide a shifting "more humid" overprint
environmental characteristics.

Introduction

The geometry of river channels and their flow style are controlled by a complex interplay of factors, including discharge, slop
vegetation, amongst others. From s
ern rivers has come a widely held
type of river channel depends t
degree on the types of sediment
river is carrying (e.g. Schumm, 19
to many workers bedload rivers
braided or modified braided patt
pended load/bedload rivers tend
dering pattern, and suspended loa

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have a stable, sinuous channel pattern, commonly with anastomosing networks (Schumm, 1981). Our studies of the fluvial channels of the Okavango Fan have revealed that they conspicuously "break the rules" of sediment load control on channel geometry and thus offer new insights into the relative importance of different factors which control river morphology. In order to document these important new end members in the continuum of river channel types, specific reaches of

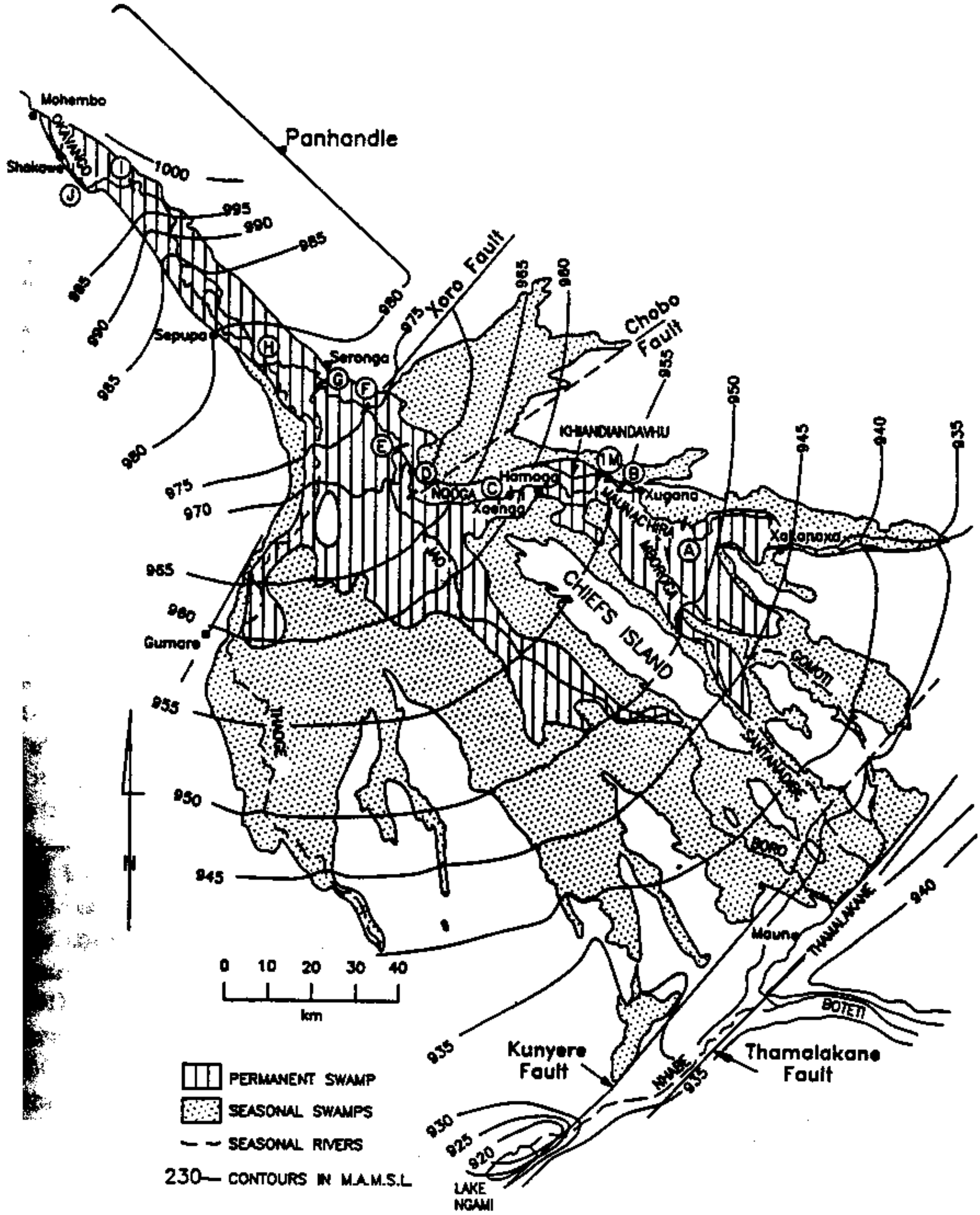


Fig. 1. Map of the Okavango Fan (UNDP, 1977) showing the areas of permanent and seasonal swamps with study sites *A* to *J* and *1M* located.

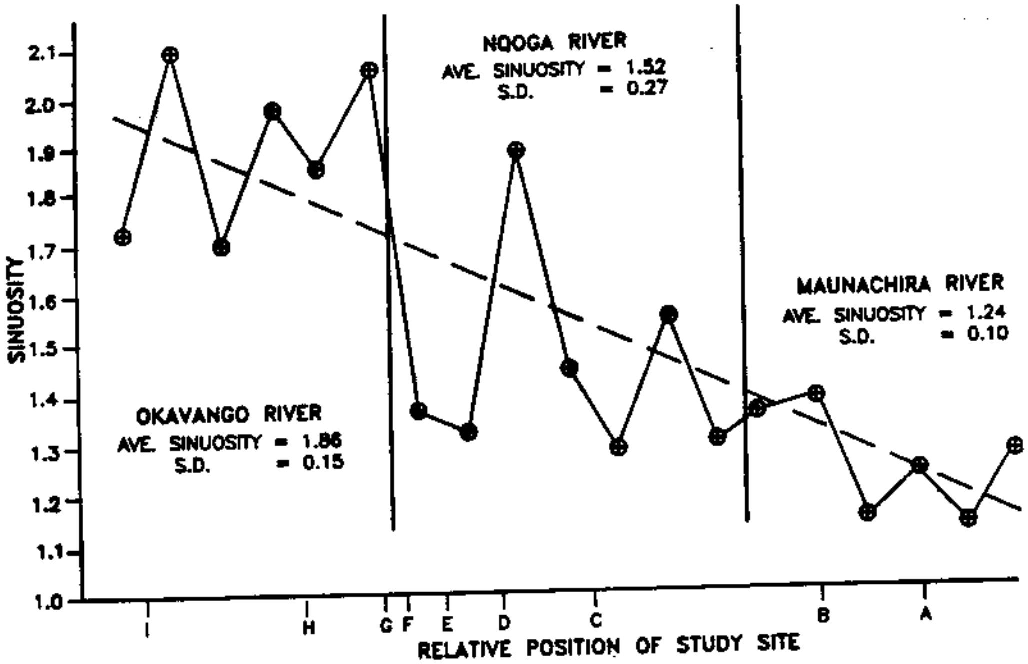


Fig. 2. Variation in sinuosity down the active channel system on the Okavango Fan and Panhandle.

both active and abandoned river channels on the Okavango Fan were mapped and studied to establish their characteristics.

Figure 1 illustrates Okavango Fan in Botswana whose general characteristics are described by Stanistreet and McCarthy (1993). The fan surface has been subdivided into three: (1) an area of perennial wetlands referred to as the permanent swamps; (2) an area of annual vegetative

associated with the annual flood referred

the seasonal swamps; and (3) the remainder

is covered by woodland and grassland (W

1973). Sedimentologically the fan can be

vided into the entry corridor for the Oka

River called the "panhandle", and the

(apex to 960 m contour), middle (960 m to

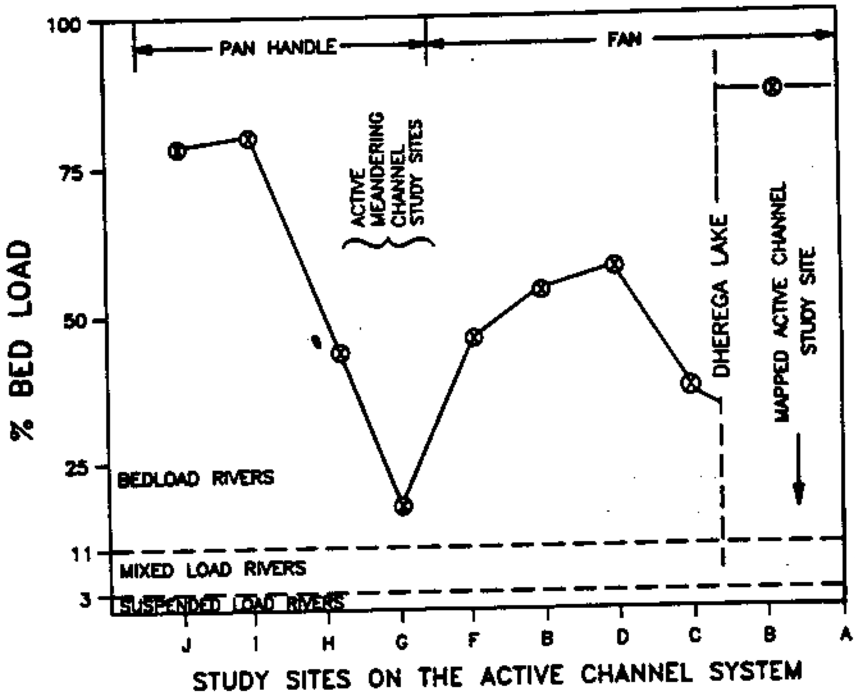


Fig. 3. Variation in minimum bedload/suspended load ratio down the panhandle and active major fan distributary chan

McCarthy et al., 1991).

contour) and lower fan areas on the basis of the style of the channels and their interchannel deposits. The panhandle and upper fan are characterized by stacked meander belts and intervening vegetatively covered thick peat, whereas the middle and lower fan are characterised by low sinuosity single and anastomosing channel systems. Figure 2 records the overall reduction in sinuosity of the channels down the active channel system. The specific areas chosen for detailed study will be dealt with separately in the sections which follow.

Sediment load characteristics of the active channel system on the Okavango Fan

The hydrology of the presently active channel system of the Okavango Fan has been described by McCarthy et al. (1991, table 1). Of particular relevance here are the measurements made of bedload and suspended load down the channel system.

The chief sources of sediment for the Okavango Fan are the unconsolidated, largely aeolian sands of the Tertiary to Recent Kalahari Basin, so that the external supply of terrigenous fine sediments onto the Okavango Fan system is small. Fines are, however, produced biologically within the system and include diatoms, phytoliths and macerated organic matter (McCarthy et al., 1989). These are augmented by erosion of previously deposited clays and pedogenic precipitates. The amount of suspended load in the presently active channel is difficult to assess because it is so low, so low in fact that the movement of bedforms can be observed through 3-4 m of water depth in almost all locations along the channel length. Figure 3 shows the variation of minimum bedload percentage down-channel derived from an indirect measurement of suspended load (McCarthy et al., 1991). At study sites B–J the lowest bedload percentage encountered in the active channel system was 18.1% (Fig. 3) and 7 out of 9 were greater than 40%. Even measurement at site A, where no bedload was carried, had the lowest suspended load reading in the entire system and is therefore considered a null reading in this regard. The entire active channel system on the Okavango Fan can therefore be defined as a bedload channel system with bedload percentages far greater than the 11% threshold (Schumm 1977, 1981) between bedload and mixed load river systems.

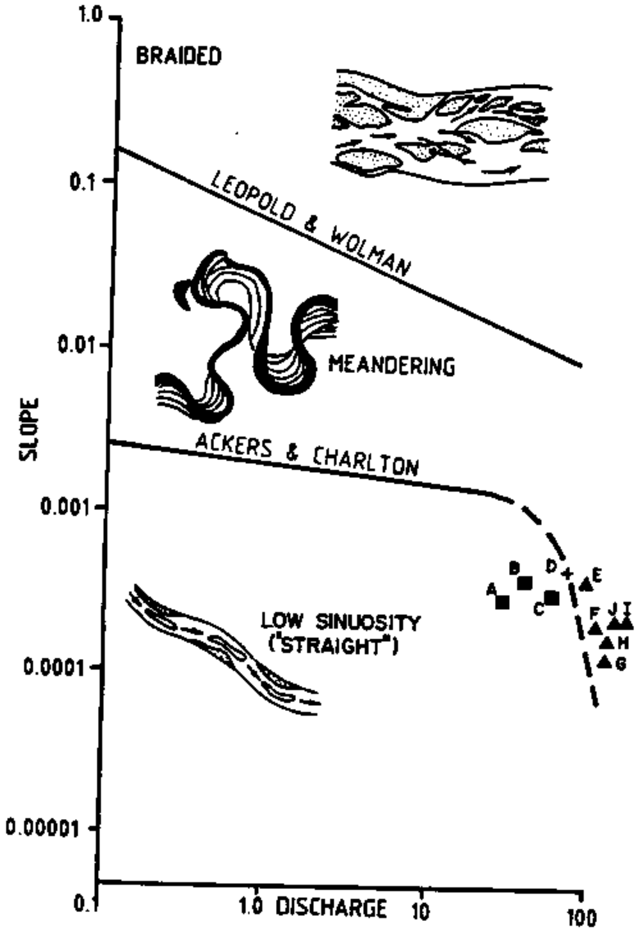


Fig. 4. Slope/discharge graph for plotting fields of river types with Okavango Fan data plotted: triangles are meandering channels, squares are low sinuosity channels; dashed line based on data presented in this work.

The compiled slope and discharge characteristics also derived from data published by McCarthy et al. (1991) allow the hydrological characteristics of the study sites A to J to be plotted on the slope/discharge graphs of Leopold and Wolman (1957) with data derived from Ackers and Charlton (1971) discriminating fields of braided, meandering and low sinuosity rivers (Fig. 4). Interestingly, the discrimination line between meandering and low sinuosity channels from the Okavango Fan data is much steeper than that of Ackers and Charlton (1971), suggesting that they are far more discharge-dependent than those previously measured.

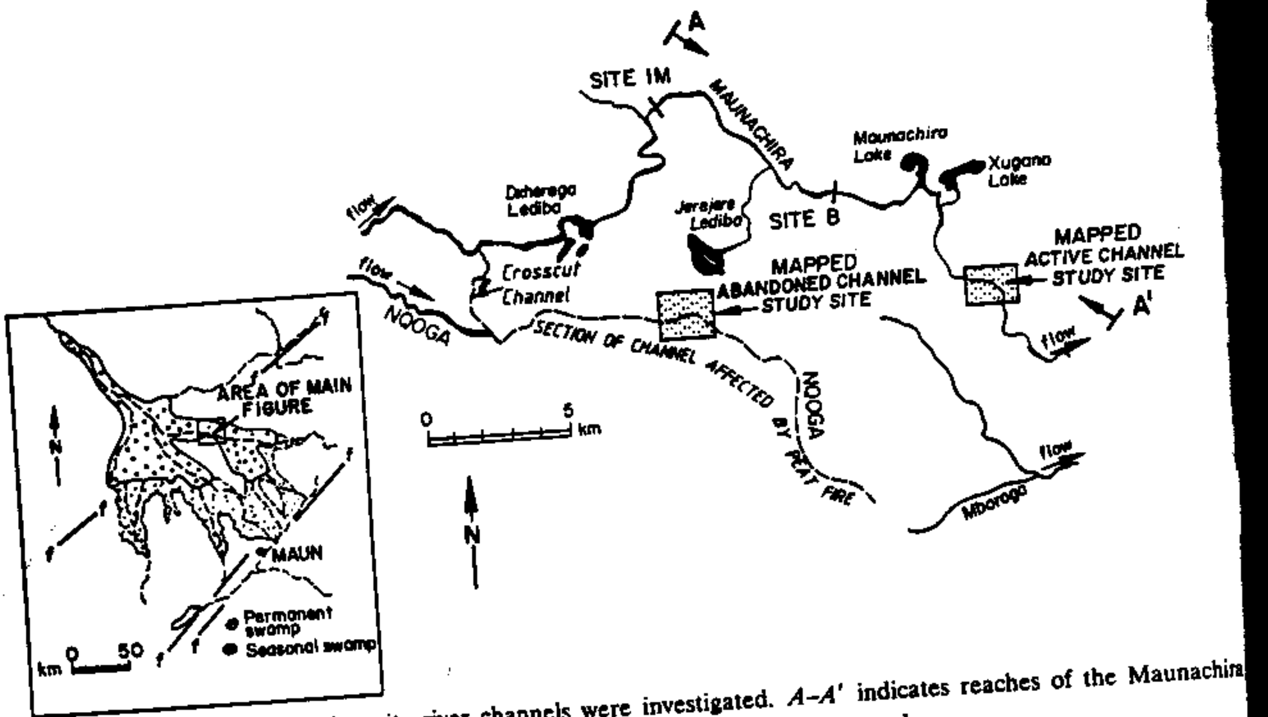


Fig. 5. Map of area in which low sinuosity river channels were investigated. *A–A′* indicates reaches of the Maunachira studied and areas of detailed study are also indicated.

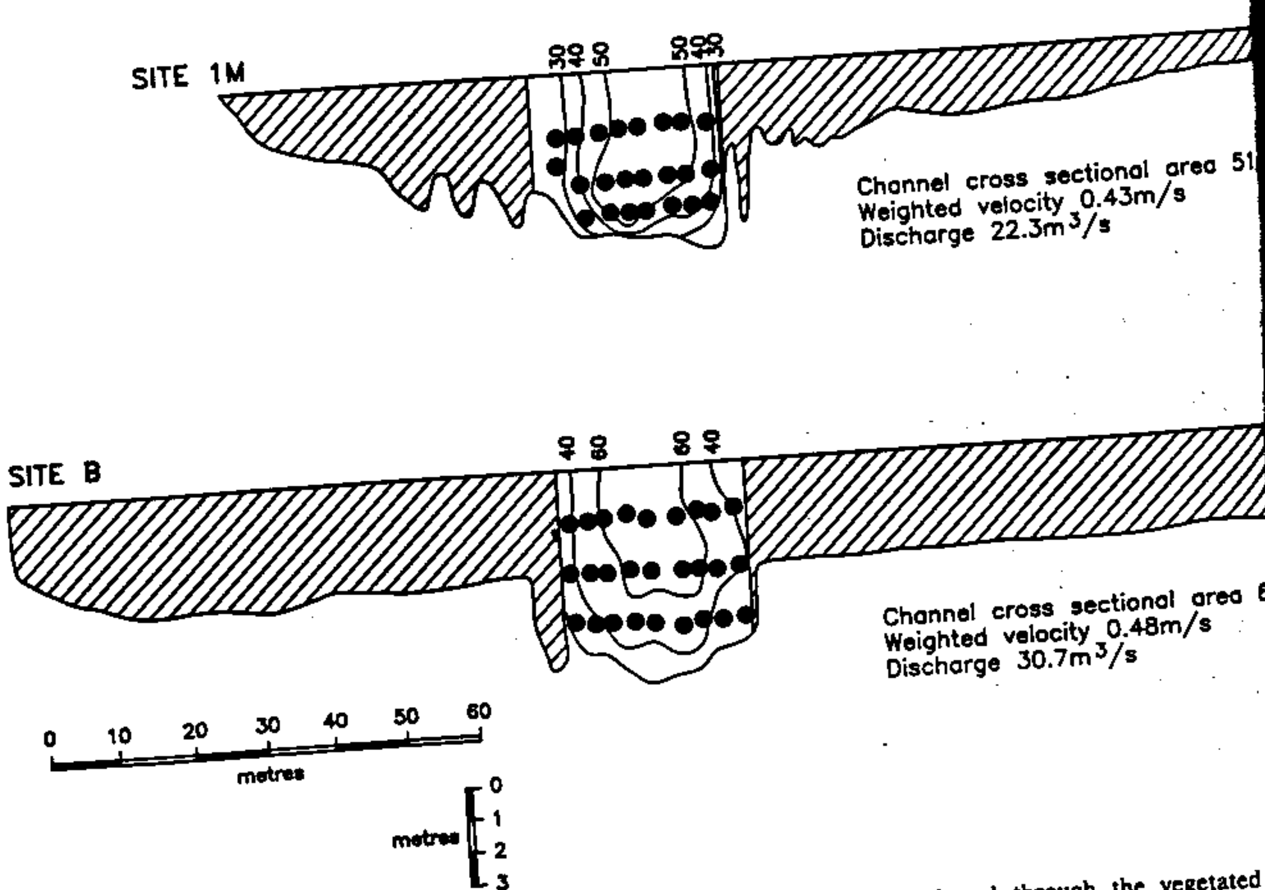


Fig. 6. Velocity and depth probe profiles across the active low sinuosity channel and through the vegetated (cross-hatched). Heavy dots mark positions where flow velocity was measured.

The fluvial channels on the Okavango Fan therefore represent two types: (1) low sinuosity bedload channel systems, and (2) exclusively meandering bedload channel systems. These will be recorded more fully below.

Low sinuosity bedload channel systems

The middle fan area of the Okavango Fan consists of active, low sinuosity fluvial channels in which bedload is being transported and deposited as indicated by the 86% bedload measured at site B (Fig. 3). The channels anastomose in certain reaches. In these anastomosing reaches channel abandonment occurs frequently as has been observed in historical time (Ellery et al., 1989). Abandoned ribbon sand bodies are therefore a common feature of the middle fan (McCarthy et al., 1988a) and are available for study through mapping and trenching.

In order to characterize the low sinuosity river channels, an active and an abandoned example were chosen for study (Fig. 5). These will be described in detail.

Presently active low sinuosity channel characteristics

The study reach chosen was the Maunachira River (Figs. 1, 5) in the area centred on Xugana Lake extending up to the Khiandiandavhu mouth and the same distance downstream. Mean water discharge along this reach is 33.9 m^3 s^{-1}, mean total bedload discharge 0.21 kg s^{-1} and mean suspended load is 0.040 kg s^{-1} (maximum), while mean flow velocity is 0.46 m s^{-1}.

The channel is flanked and confined by peat deposits 3 m thick as shown by depth probe studies of the bank (Fig. 6), and the peat is stabilized at the surface by a plant community dominated by *Cyperus papyrus* (Fig. 7). This community also stabilizes the channel margin (McCarthy et al., 1988b) and prevents erosion of the peat. The surface of the water slopes away from the channel; for example at site B the slope was 0.0014 on the right bank and 0.0034 on the left bank. Initially this seems insignificant until it is realized that it is almost an order of magnitude greater than the down-channel gradient. In fact

Fig. 7. Photograph of the vegetated peat levée on the side of the active low sinuosity channel of the Maunachira. The flora is dominated by *Cyperus papyrus*.

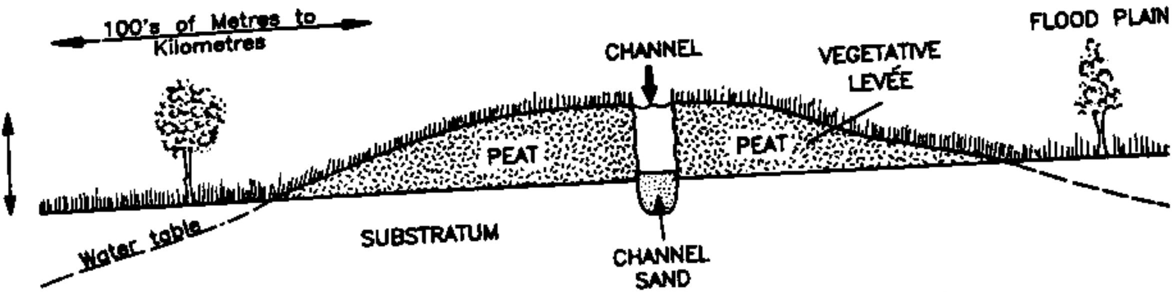


Fig. 8. Schematic cross-section through an active low sinuosity channel.

all such lateral slopes on the vegetatively stabilized peat of the fan surface are away from the channel (McCarthy et al., 1991). This slope defines the surface of a type of channel levée which has not been previously recognized sedimentologically, built almost totally of peat with a living surface community binding and stabilizing it. Water continually percolates through the permeable levée which explains the steady loss of discharge down fan (McCarthy et al., 1991). The levées vary in width from hundreds of metres to kilometres. Such levées have gradients up to 0.0062 and may be defined as occupying the space between the active channel and the neighbouring flood plain or flood basin (which may be occupied by standing bodies of water either permanently or seasonally). The flood plain has a gradient at least
order of magnitude less than the levée. The
portance of this levée is that its chances
preservation in the geological record may be
as will be discussed below.

Figure 6 also shows that the channel init
eroded into the underlying substrate, prior to
present depositional mode in which the sand
is aggrading. Figure 8 shows a schematic c
section through an active low sinuosity cha
on the middle fan. During times of flood,
mean water velocity in the channel increases
marginally because of the regulatory activity
vided by flooding into the permanent and
sonal swamps upstream, especially in the Pan
dle. At the same time the water depth incr

Fig. 9. View of the Maunachira low sinuosity river channel in flood, just west of Xugana.

less than 20 cm (Wilson and Dincer, 1976), because floodwater overlaps the peat levées and flows between papyrus stems to spill freely onto the surrounding floodplain (Fig. 9), where it floods depressions referred to locally as malapos and initiates a vegetative bloom in these seasonal flood-basinal areas (Wilson, 1973).

In order to investigate the active low sinuosity channel, a section of the Maunachira River channel was mapped in detail (Fig. 10). The section was chosen to include a minor distributary channel, which was accessed by an outlet from the main channel, in order to assess the effect of this outflow on the main channel. Five probe lines were constructed across the channel in order to assess water depth variation and peat depth variation of the levées on either flank (Lines 1–5 in Fig. 11). A similar probe line was constructed across the distributary channel (Line 6 in Fig. 11). These probe lines suggest that the initial incision of the Maunachira channel was over a greater width than that of the present channel, as indicated by the resultant depth contours in Fig. 10. This incision may have been enhanced by the development of sinuosity in the river channel and localized cut banks (e.g. left bank of lines 4 and 5). In any case the ultimate colonisation by the *Cyperus papyrus*-dominated flora has stabilized the river channels at an average width of 17 m so that lateral migration of the channel margins is now extremely low. This is shown by the fact that since aerial photography of the fan began in 1937 there has been no discernible lateral migration of the channel in this area.

During and subsequent to the channel stabilization mentioned above there has been active deposition of bedload sand between the levées as shown particularly in lines 3, 4 and 5, although line 4 shows a preservation of an erosional thalweg near the middle of the channel (Fig. 11). Rounded bars with an oval plan view have been deposited in the channel, which are termed knoll

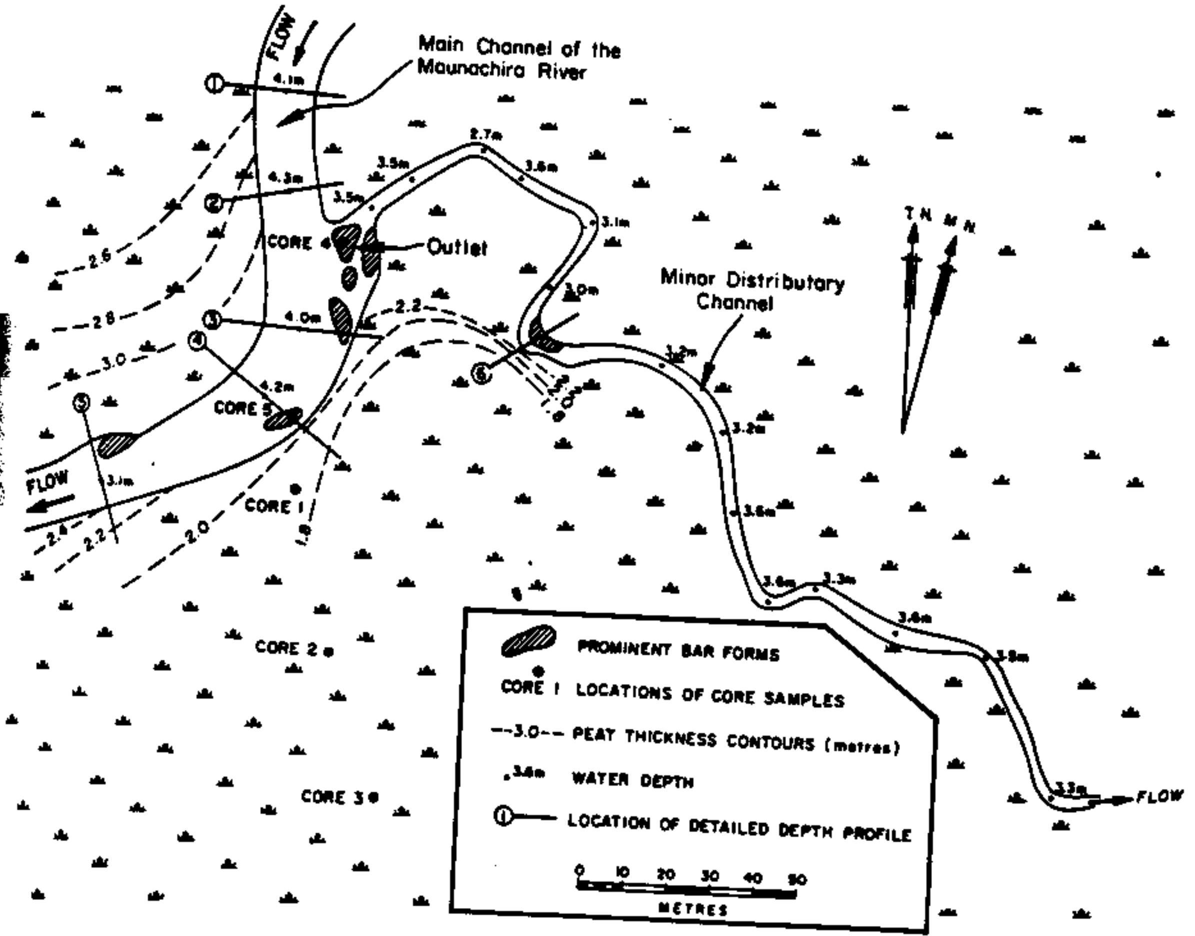


Fig. 10. Map of a section of the low sinuosity channel and a minor distributary channel leading into the backswamp area.

bars to reflect their external geometry (Figs. 10, 11 and 12). In the area of the outlet to the distributary channel, accreting bars were also encountered of a less regular shape; these are termed outlet bars. Cores extracted from these bars (Fig. 12) contained sequences in which channel sand at the base became interbedded upwards with peat layers reflecting intermittent colonisation of at least some of the bars by plants, notably *Eichhornia natans* and *Vossia cuspidata*. The interplay between channel sand, peat levée and plant colonisation of the knoll bar is in Fig. 13.

The minor distributary channel is a rel rare feature of the main channel and h average width of 4 m and an average depth m giving a width: depth ratio of 1:2. The i lar shape of the channel in plan may refl maintenance by hippopotami moving fro main channel into the backswamp areas, b plan shape has probably been modified draulic processes to its present low sin

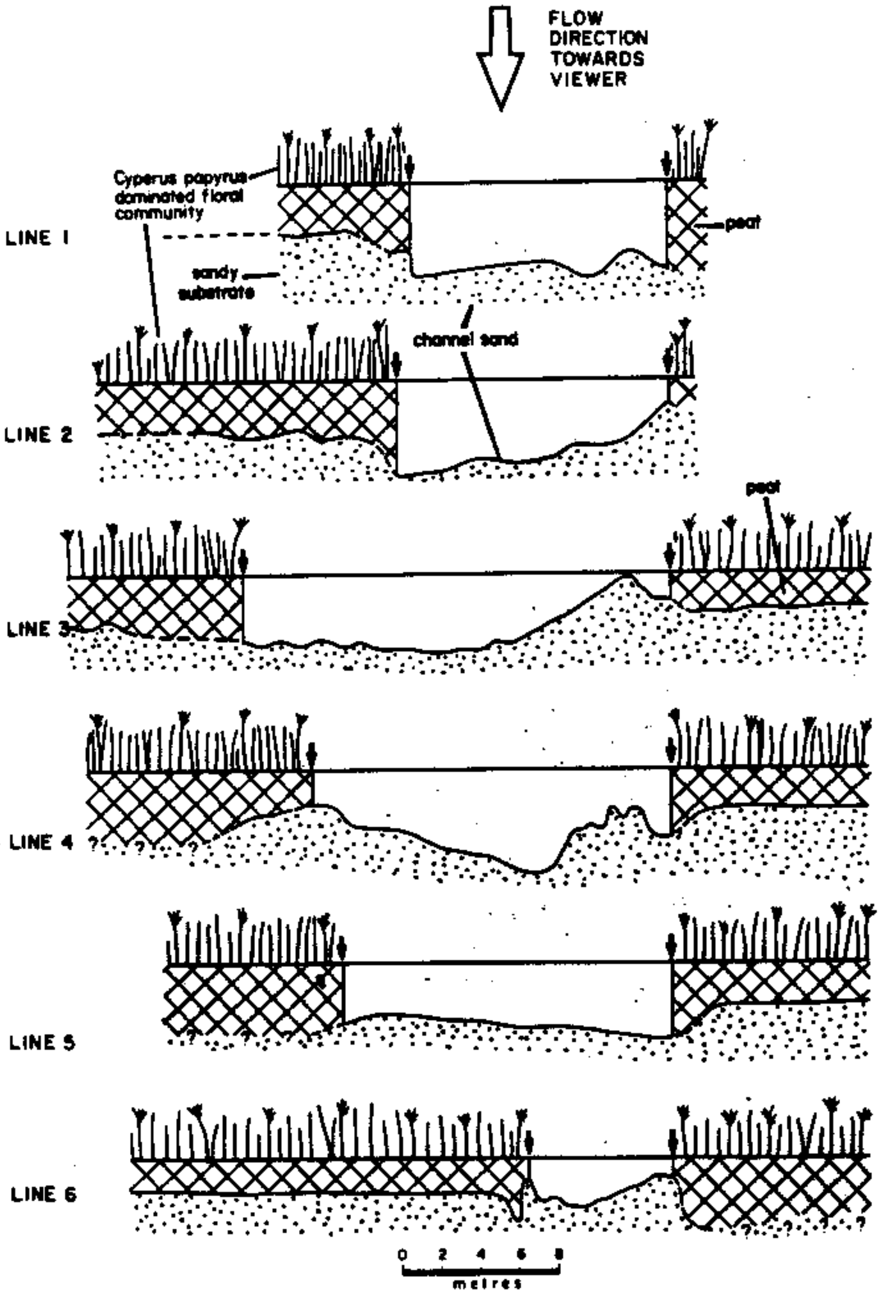


Fig. 11. Main channel, minor distributary and peat levée depth profiles derived from depth probe analysis. See Fig. 10 fo of profiles.

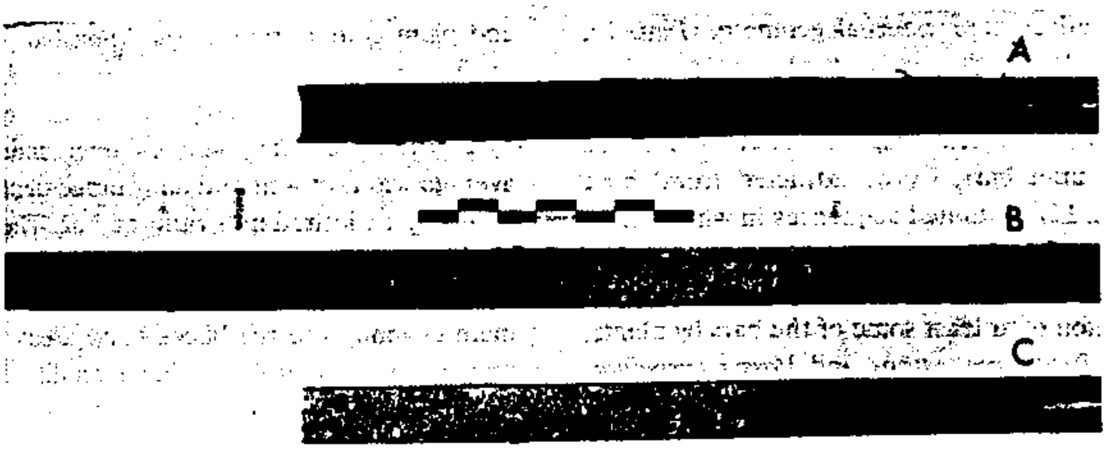


Fig. 12. Plastic tube cores into a knoll bar (B) and outlet bar (A and C) at the mapped study site (see Fig. 10 for location). Scale interval 50 mm.

Water is drawn off the main channel into the distributary via the outlet, resulting in deposition of the outlet bar forms. Sand is actively transported down the minor distributary as shown by the development of a slight point bar through which line 6 (Figs. 10 and 11) was constructed. Figure 11 shows that sand is aggrading rapidly in the minor distributary and it is this sand fill which will ultimately heal the breach in the peat levée to the main channel.

It is noteworthy that the minor distributary channel leaves the main channel at an obtuse angle. Distributary channels of the Okavango Fan in general leave the main channel typically at right angles or at such an obtuse angle (McCarthy et al., 1991) reflecting the order of magnitude

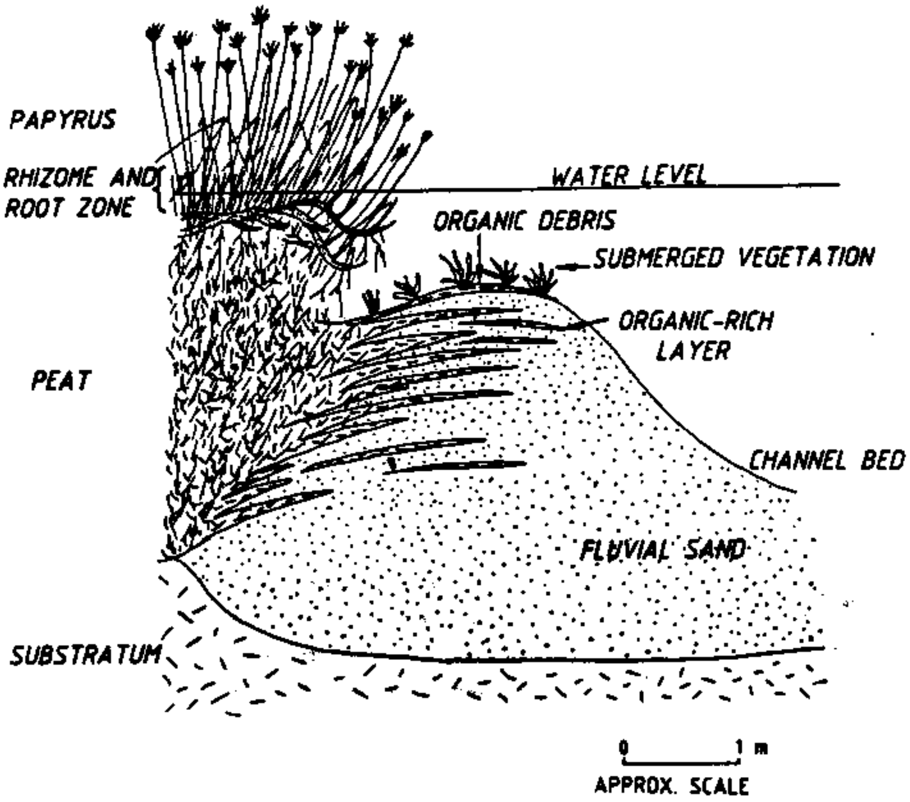


Fig. 13. Inferred relationship between channel sand, peat levée and plant colonisation of a knoll bar (no vertical exaggeration).

difference between the lateral water gradient and the down-channel gradient of the main channel.

Features of abandoned low sinuosity channels

The presently active Maunachira channel replaced the channel of the pre-existing Nqoga River channel which once paralleled it (Fig. 5). The old Nqoga channel was still in existence in the 1930's (McCarthy et al., 1988a) although it was rapidly being abandoned. In the 1970's and 1980's the area of the old Nqoga channel experienced a fire (Ellery et al., 1989) which gradually burned away the peat levées flanking the channel, leaving the channel sand as a positive topographic ridge with respect to the surrounding flood plain. In order to document the internal characteristics of the low sinuosity fluvial channels, a section of this channel sand ribbon was chosen to be surveyed and excavated to record its internal characteristics. The section cho
cluded an abandoned minor distributary
(Fig. 14) similar to that mapped on th
Maunachira (Fig. 10) although on the o
bank.

Figure 14 shows that the channel wa
sinuosity channel and this is confirmed
photograph of Fig. 15 which shows that in
this was the geometry, but that occasio
lated point bars and meander bends did
along the system. Five cross-channel topo
level surveys were made to record the topo
of the abandoned channel and minor distri
Three of these crossed the main channel a
crossed the minor distributary channel (F
locations in Fig. 14). Pits were dug on or
these lines in order to determine facies a
tailed stratigraphic relationships. The
graphic surveys (Fig. 16) show that an i
topography has developed compared wi

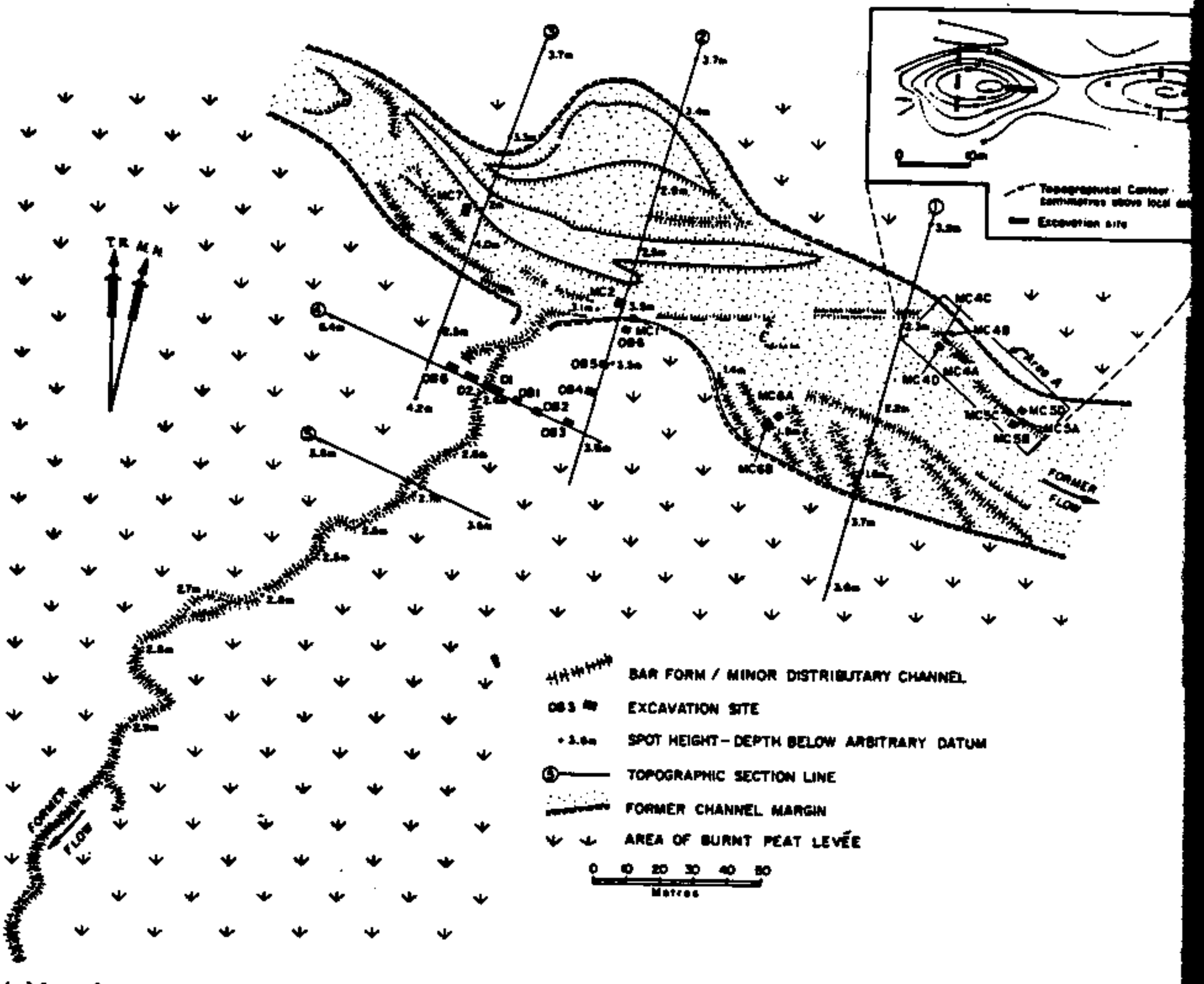


Fig. 14. Map of a section of an abandoned low sinuosity channel (Nqoga River) which had a minor distributary channel le
right bank.

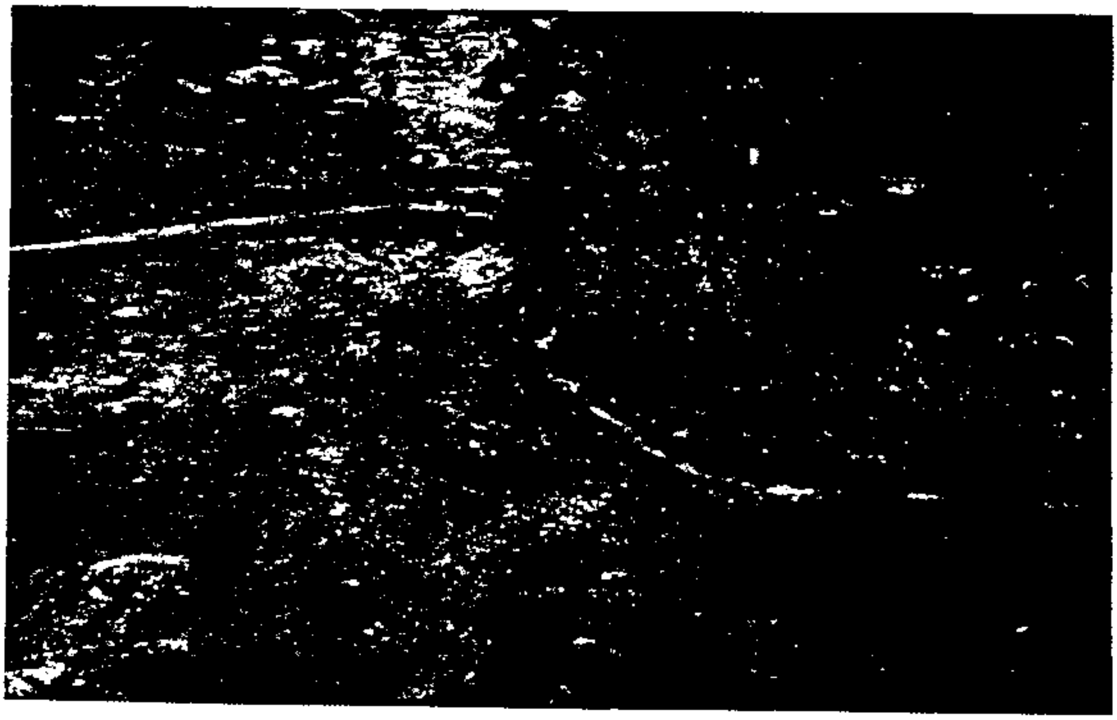


Fig. 15. Oblique aerial view of the abandoned channel showing the development of an isolated point bar.

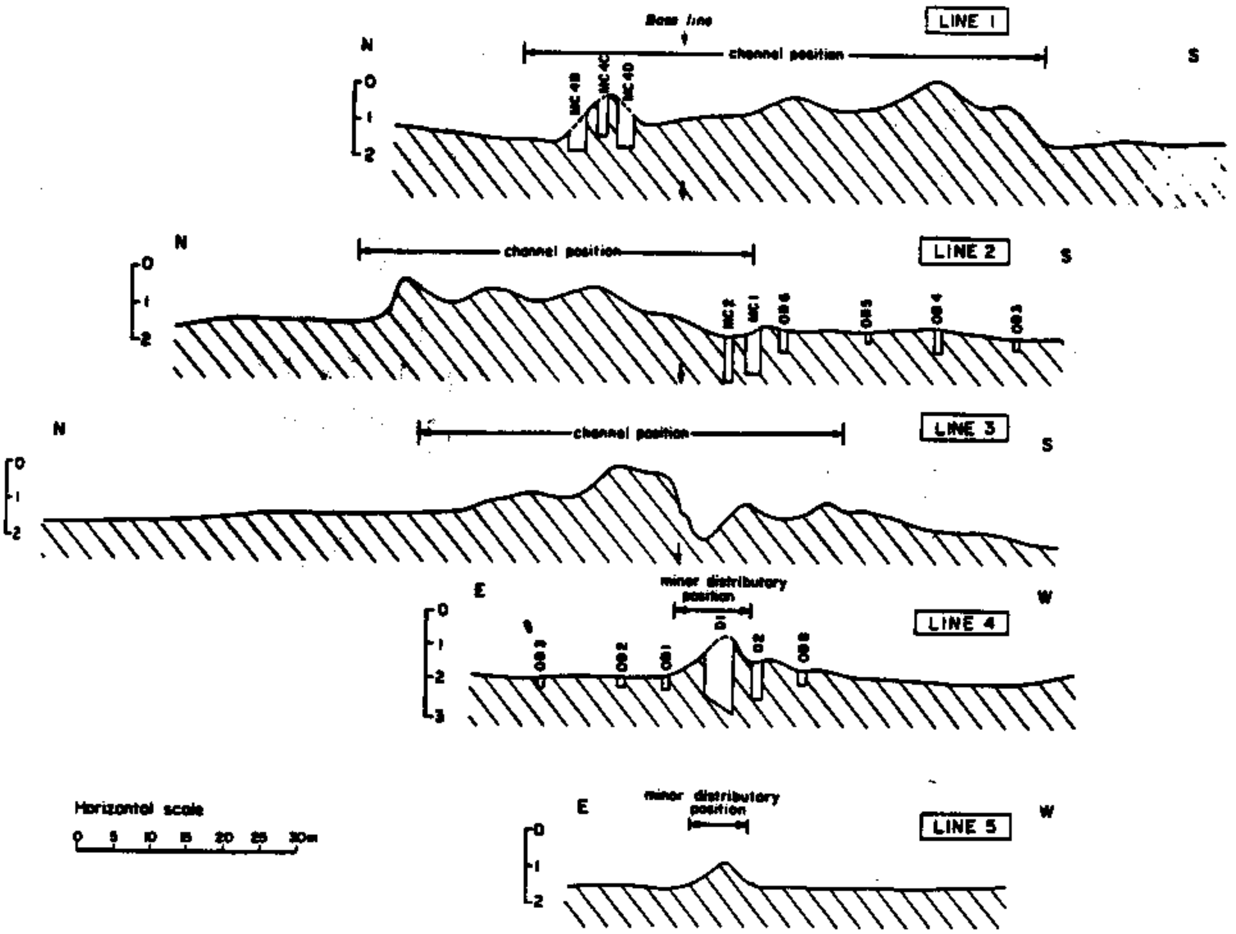


Fig. 16. Topographic profiles located in Fig. 14 across the main abandoned low sinuosity channel and the minor distributary channel showing the inversion of the abandonment topography.

which would have existed when the channel was active. On some section lines (1 and 3) the position of the old thalweg in the main channel is still well defined. Pit MC7 into the margin of the thalweg (Fig. 14) revealed its erosive character into pre-existing planar cross-bedded units.

The mapping and the topographic levelling revealed the preservation of abandoned bedforms, particularly in the main channel, some of which were still identifiable. In the southeastern area, sand waves could still be discerned trending northwest. In the northeastern part of t channel, rounded knoll bars were id analogous with those identified in th Maunachira channel. These were exca reveal a complex bar form composed of a planar cross-bedded sets on the upstre These amalgamate onto the avalanche fa bar to generate large scale cross-beddi overall geometry and architecture of the l as derived from these pits is shown in The location of the bar close to the river

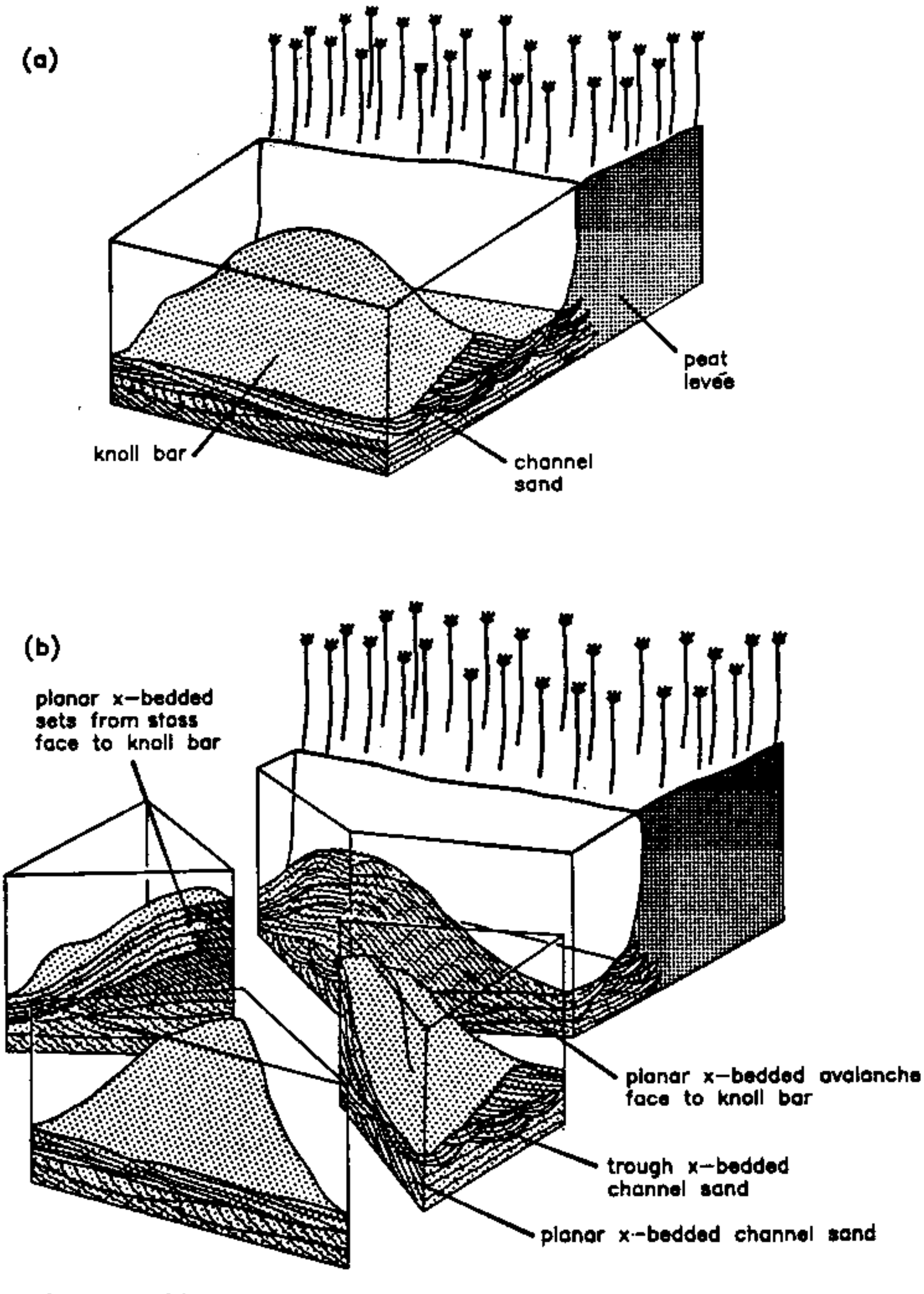


Fig. 17. Dissected external geometry (a) and internal architecture (b) of a knoll bar derived from excavations into abando bars located in Fig. 14.

both the active and abandoned river channels and the inclination of the avalanche face towards the river bank shows that it has strong affinities with a variety of a transverse bar named by Smith and Beukes (1983) a "bank-hugger". The knoll-shaped rounded form of the overall bar is, however, a distinctive feature and may reflect the relatively constant hydraulic regime in these midfan, low sinuosity channels throughout the flood/non-flood cycle.

The abandoned minor distributary (Fig. 14) left the main channel at an extremely oblique angle in a similar fashion to that at the active channel study site. Figure 16 shows that the minor distributary channel has also developed an inverted topographic relief compared with its geometry during its active phase. The shape of the channel shows that, like the active minor distributary off the presently active Maunachira River, it probably originated as a hippopotamus trail out of the Nqoga channel.

The abandoned minor distributary was excavated across almost its entire width in pits D1 and D2. The mapped cross-sectional pit wall is shown in Fig. 18. Seven facies were recognised in the architecture of this distributary channel sand: (i) planar cross-bedded sand caused by sand wave migration, although the largest set may represent minor epsilon cross-strata; (ii) trough cross-bedded sand produced late in the history of the channel when decreased water depth caused a higher Froude number; (iii) carbonaceous sand, containing high proportions of organic matter (this facies developed on the channel margin during its active phase and progressively covered the channel during its gradual abandonment); (iv) peat deposits well preserved within the channel; (v) grey fine sand and silt which formed the substrate to the channel and also ultimately covered the channel during abandonment; (vi) burnt ash representing the residue after the burning of the peat (this material also fills an animal burrow near the crest of the sand body); and (vii) fine superficial aeolian silty dust, deposited by wind after the burning of the peat (this material also fills an animal burrow off the crest of the sand body).

The burnt ash layers which overlie the peat lateral to the channel resulted from the burning of the upper part of the peat which originally flanked this minor distributary channel. Thus 3 or 4 m of peat bank have been degraded by the fire to layers of ash 10 to 40 cm thick. With further compaction this may ultimately result in preservation of carbonaceous silt layers 10 cm thick or less thick geologically. This realisation led to pits

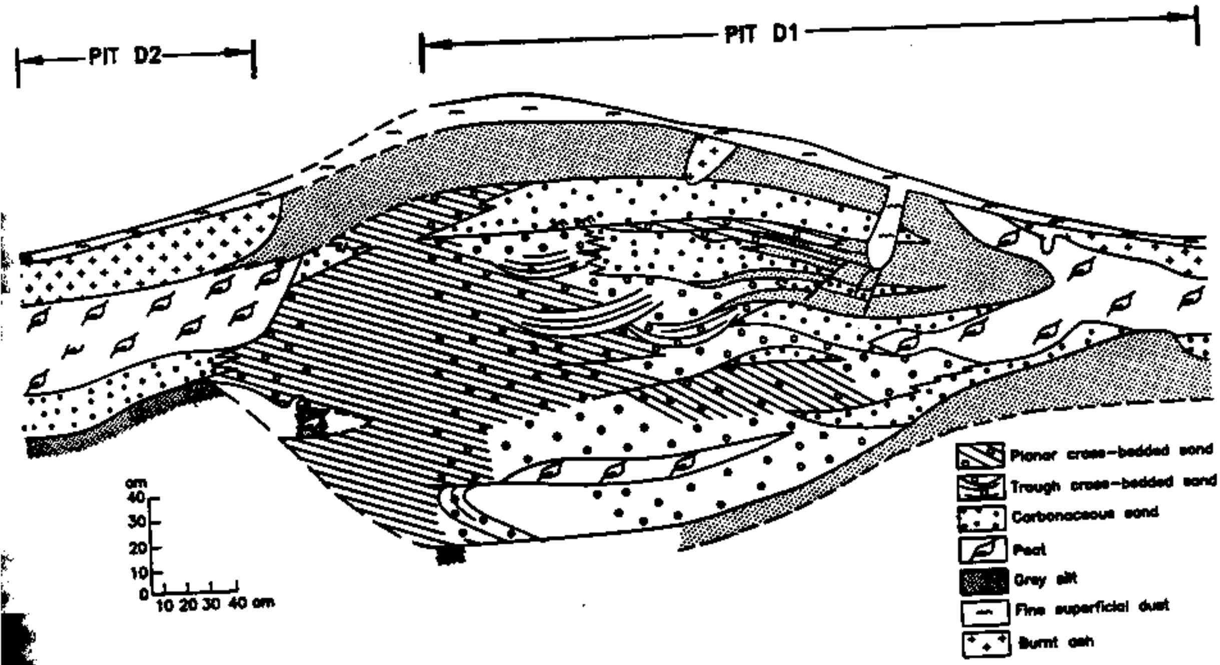


Fig. 18. Excavated cross-section through the abandoned minor distributary channel as located in Fig. 14.

being dug into the main channel margin in order to document the relationships between the main channel ribbon sand body and the degraded peat levée which once flanked it.

A cross-section through the channel margin is shown in Fig. 19. The depths of pits in the area of the levée were extended down to the underlying grey silty sand substratum; the depths of pits in the main channel were, however, limited by safety considerations. Covering the entire profile was a thin layer of superficial wind-blown silt and fine sand, which characterizes the surface of much of the Okavango Fan outside the permanent and seasonal swamps. This probably reflects the winnowing and redistribution effects of "dust devils" particularly during the dry winter months and the turbulence of thunderstorms in the summer months. Beneath this the transition between the sand of the main channel and the peat levée occurred over a distance of 5 m in which interlayered peat and sand was encountered (see pit MC1; Fig. 18). However, well sorted channel sand did spread initially beyond the later-defined margin, as shown by a sand layer which was en tered below the peat sequence up to 30 m from the channel margin in pits OB6, OB OB4, but which was not encountered in pit It is significant that such a layer was no developed in similar circumstances latera the minor distributary channel.

As with the minor distributary channe original peat which flanked the main ch which would originally have had a thicknes to 4 m, has also been degraded by fire and represented by an ash layer up to 40 cm Relict peat was preserved in pits OB6, OE OB4 but not in OB3, and it is clear th preservation of peat was more effective in tions which were closer to the wetting eff the abandoned channel.

Evolution of low sinuosity channels

The two sections described above a tremely important in understanding the lov osity channel evolution on the Okavang

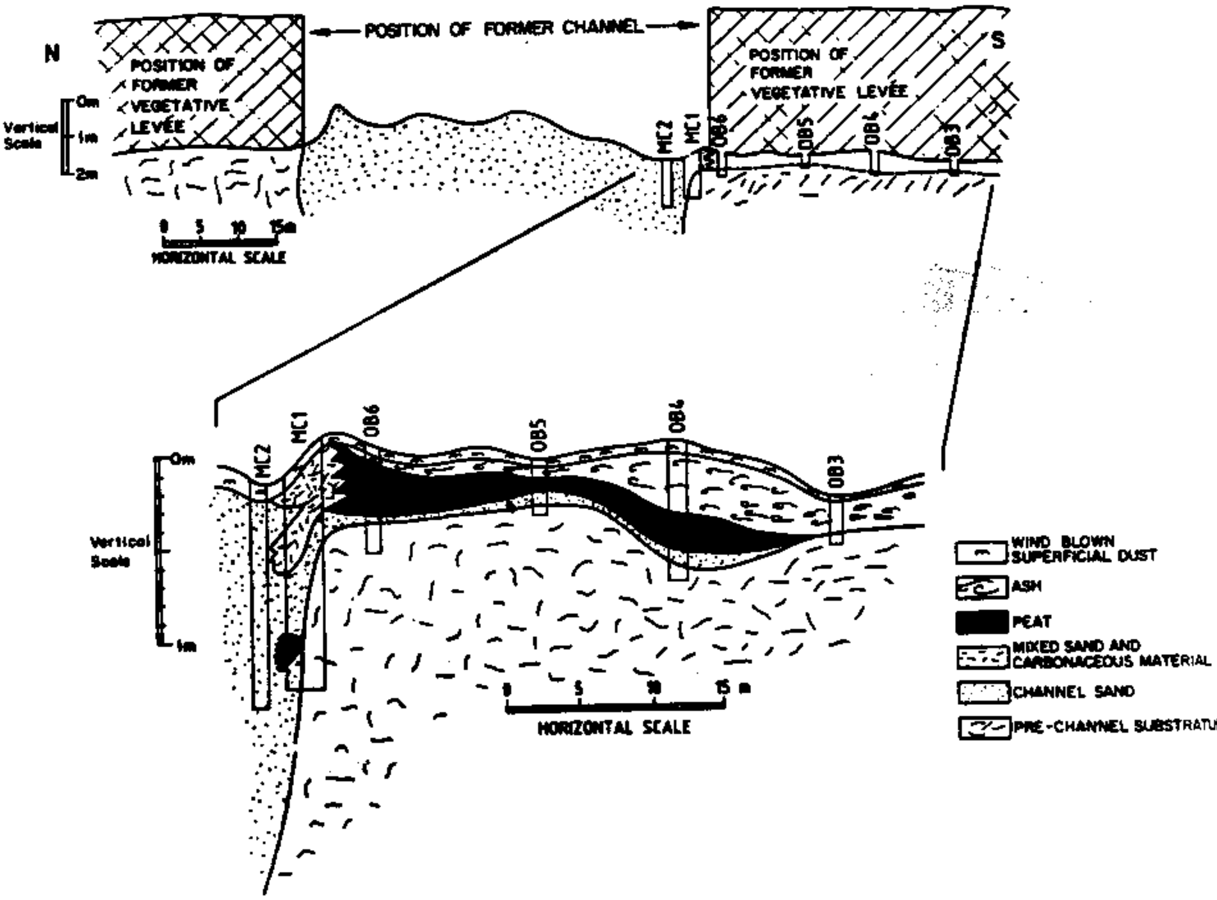
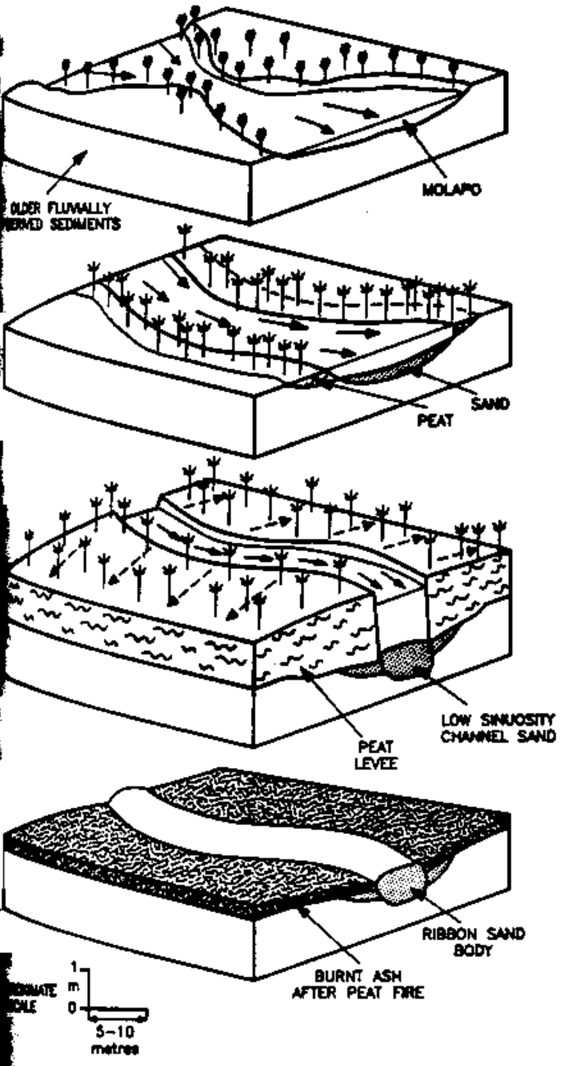


Fig. 19. Excavated cross-section through the margin of the main channel (located in Fig. 14).



20. Block diagrams showing the evolution of a low sinuos- hannel on the Okavango Fan to become an abandoned ribbon sand body.

oth active and abandoned channels show that ring initial development, the channel was wider an the ultimately incised and vegetatively coned channel system (Fig. 20). This would exain the widespread thin sand layer which underes the marginal sequence. Initial vegetation obably comprised ground rooting sedges and her marsh flora which would have gradually croached upon and constrained channel flow using incision and channelisation of the flow, in rn resulting in increased flow depth (Fig. 20). the pioneer plant communities were replaced papyrus-dominated communities, the flow beme further constrained between the aggradanal, vegetatively stabilized peat levées. Sediment aggradation within the channel interplayed with the aggradation of the peat leveés in a feedback manner to the point where the water surface in the channel/levée was metres higher than the surrounding flood plain. Because the levées were extremely permeable, water loss from the channel increased with this evolution to the point where avulsion became progressively more likely through a filter system as described by McCarthy et al. (1992).

The minor distributary developed after the levée became a distinct entity as shown by the relatively greater confinement of contained sand throughout its evolution. It probably initiated as a hippopotamus trail as discussed previously, and would have provided a through flow for the passage of a small proportion of the channel water into the back swamp areas.

The peat levées are extremely strong and resistant to erosion; they are only breached by animal tracks, particularly hippopotamus trails which are used daily to move to the backswamp areas for nocturnal grazing. It is interesting that breaches in the levées of the low sinuosity channels of the Saskatchewan River (Smith and Smith, 1980; Smith, 1983; Smith et al., 1989) developed where canoe portages and beaver trails disrupted the levées. Because of the strong vegetative confinement, crevasse splays such as described by Smith et al. (1989) from the main channels are rare and only two have been observed, in the lower fan area, where peat levées are not developed. In the middle and upper fan areas crevasse splays are nonexistent. The sand-filled minor distributaries just described are the equivalent feature on the Okavango Fan river channels, but splaying is prevented by the confining role of the peat levées and the absence of a fine suspended load.

Characteristics of meandering channel reaches

Meander belts on the Okavango Fan become abandoned much less frequently than the smaller, low sinuosity channels. Ancient abandoned systems such as the Xugana meander belt described by McCarthy et al. (1993) are rapidly bioturbated (chiefly by termites) and become affected diagenetically by subsurface calcrete and silcrete formation. So although the surficial form of scroll bar and point bar surfaces are well defined thousands of years after their abandonment, and indeed these topographic characteristics may be enhanced by diagenetic processes, their internal structures are not easy to analyze.

Furthermore, in the upper fan and panhandle areas meander belt formation, avulsion and abandonment are clearly continuously active (Fig. 21). This is shown by the recognition of meander belts in a variety of evolutionary states. The modern, active channel has associated point and scroll bars. Recently abandoned meander belts are apparent and even bioturbated; more ancient channel sands preserve meandering channel traces within them. However, because of the extreme vegetative confinement of the permanent swamps, abandoned features, even of the presently active system, are buried beneath peat.

Cross-channel depth probe surveys have been undertaken in this area (Fig. 22). The cross-sectional profile at Site G shows a well-developed modern point bar on the right bank and complementary cut bank on the left, where the river is incising up to 3.5 m into the substrate. The
tively smooth peat-covered surface of the
strate on the left bank contrasts sharply wi
irregular peat-covered scroll bar surface
right bank. The absence of fine-grained sed
in the confining peat levée is pronounced
cross-sectional profile at Site H (Fig. 22
measured at the downstream end of a poi
developed on the left bank of the river.
close to a point of meander inflection, t
bank is eroding laterally into the right ban
levée and is not incising into the substra
irregular scroll bar surface is discernible,
ever, under the peat levée of the left ban
modern point bar is vegetated, as shown
interlayering of sand and carbonaceous silt
down stream face.

The significance of bedload low sinuosity meandering channels in the fluvial geometr trix

Schumm (1981) presented a matrix o
geometries defined by two axes, compri

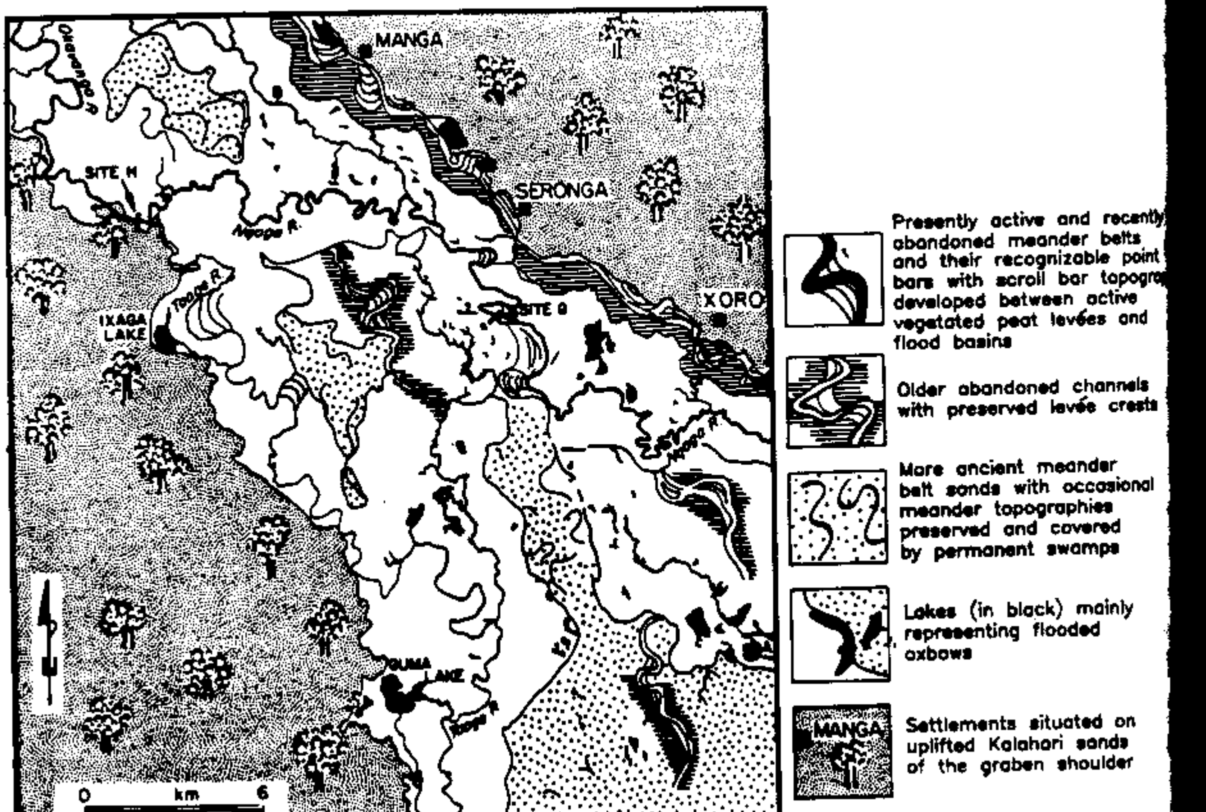
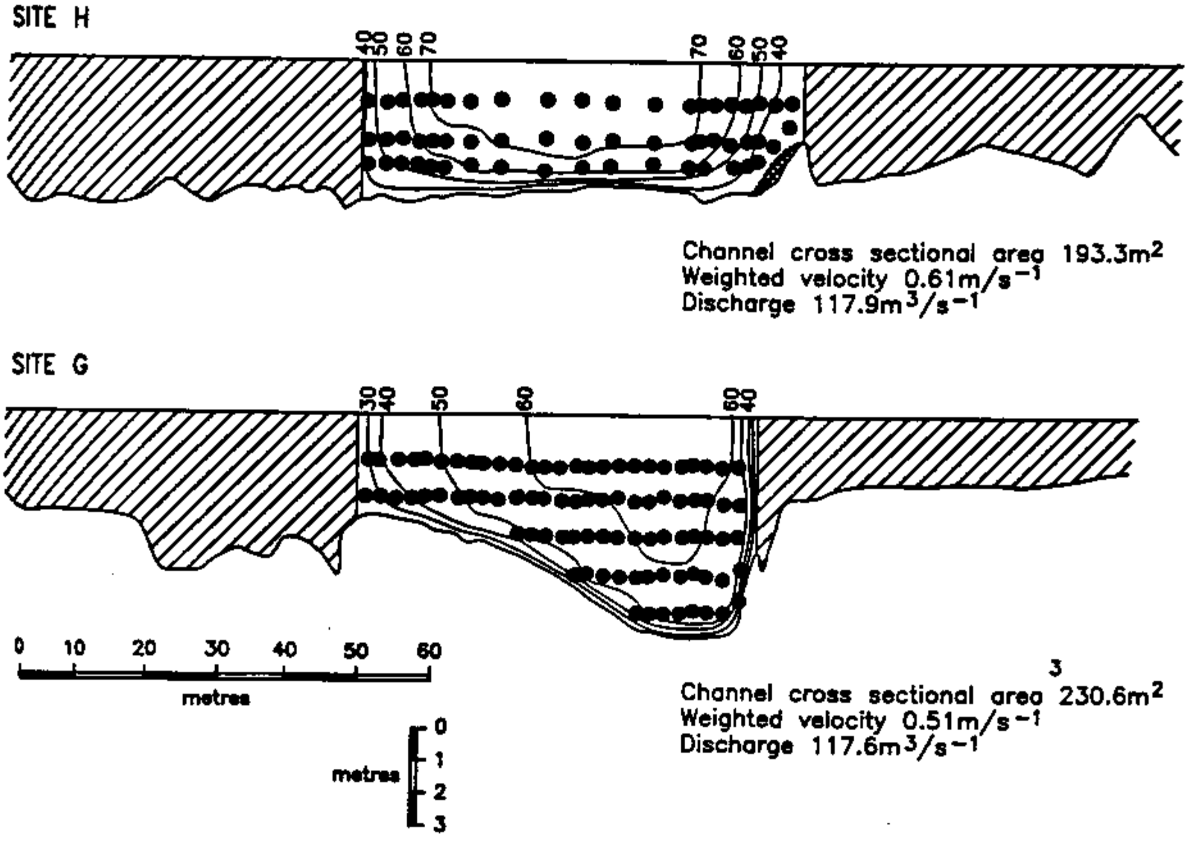


Fig. 21. Map of the lower panhandle and uppermost fan showing various generations of abandoned meander be

load characteristics (suspended, mixed and bed loads) and (ii) relative stability (dependent upon sediment size, sediment load, flow velocity or stream power). Within the matrix, different river geometries then recognized define a broad trend across the matrix, whereby suspended load rivers tend to be characterized by straight to high sinuosity, mixed load rivers tend to be characterized by meandering character, and bedload rivers tend to be characterized by a braided character. Inherent in this broad correlation between load characteristics and fluvial geometries is the realisation that rivers carrying higher proportions of fine suspended load are able to produce constraining levées of interlayered mud and silt, which tends to confine flow in well-channelized conduits achieving its ultimate in sinuous single channels and anastomosing networks.

For many years it has been realized that vegetation can play an important role in stabilizing such levées and channel banks in general (e.g. Smith, 1976; Smith and Putnam, 1980). Until description of the river channels in this paper, however, it has not been widely realized that vegetation and its degraded product peat can, by themselves, produce highly stable levées. In such a system it is unnecessary to have high proportions of deposited fine suspended load to constrain waterflow. In this paper both meandering and low sinuosity bedload rivers have been described which complete the top right hand corner of the matrix of fluvial geometries (Fig. 23). Only the bottom left hand corner of the matrix is unoccupied. This might be filled by silt dominated braided systems reported by Rust (1978), i.e. the Slims River, Yukon and the Yellow River of China. It is interesting to note that like the river channels on the Okavango Fan, it is a restricted sediment source which controls the load characteristics of the Yellow River in the form of fine-grained loess which covers vast areas of the Yellow River Basin. Another analogue for a silt-dominated braided, anastomosed system is that described by Rust (1981) from the Cooper's Creek area of Central Australia.

If the river channels of the Okavango Fan are



Channel cross sectional area 193.3m^2
Weighted velocity 0.61m/s^{-1}
Discharge 117.9m^3/s^{-1}

Channel cross sectional area 230.6m^2
Weighted velocity 0.51m/s^{-1}
Discharge 117.6m^3/s^{-1}

22. Depth probe profiles of channel and peat levée, together with contoured velocity measurements, across an active meandering channel. Profiles are located in Fig. 21. Flow out of page.

significant in extending the range of recent fluvial systems, the significance of their developmental history cannot be underemphasized when ancient equivalent systems are considered. The vegetatively stabilized peat levées of such systems may have a low probability of preservation in the geological record: the original 3–4 m thick peat levées in the case of the Nqoga River may, after peat fire degradation and subsequent compaction, be at best represented in the geological record only by a thin carbonaceous siltstone 10 cm or less thick. It is to be expected therefore that the confinement available to account for equivalent channel systems in the geological record may have remained totally unassessed.

Ancient river systems possibly analogous to those of the Okavango Fan types

Ancient river channels which are totally analogous with those of the Okavango Fan have not yet been recognized, or if they have, their true nature has not yet been appreciated. Several types of ancient low sinuosity channels depositing ribbon sand have been identified, however, which approach those described in this paper.

Low sinuosity channels in the Carboniferous Cli
Formation, New Brunswick, Canada

These were described by Rust and L
(1983) to make a partial comparison with
anastomosing channels of Central Australia. T
are about 15 m wide and 5 m thick, filled ch
with fine to medium sandstone but have sm
mud-filled channels superposed on them. Cr
se splay sand bodies are absent. A major di
ence from the Okavango Fan channels is
large quantities of mud deposited in the f
plains of the channels. However, a characte
which is very reminiscent is the repeated alt
tion between calcrete layers, frequently in
form of root replacements or rhizoliths, su
tive of a semi-arid climate (also supporte
commonly developed desiccation cracks) and
carbonaceous and coal layers suggestive of p
of wetting. This was interpreted to be relat
fluctuations in the water table, but discharge
perennial river into a semi-arid environme
in the Okavango, could well account for
contrasts. More proximal channels in the s
are represented by 875 m wide and 12 m
lensoid sandstone bodies. In this case, how

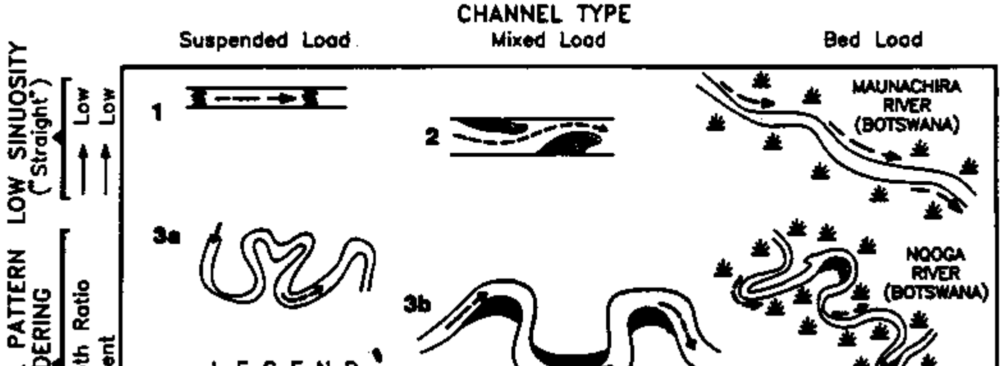


Fig. 23. The matrix of fluvial geometries. Modified from Schumm (1981).

they are interpreted as confined, braided river channels.

Permian low sinuosity channels of the Ecca Group, Southern Transvaal, South Africa

Anastomosed fluvial channel deposits have been described from the Lower Permian coalfields of South Africa (Le Blanc Smith and Eriksson, 1979; Winter, 1985; Cairncross, 1989) and these have been compared with the channels of the Okavango Fan (Cairncross et al., 1988). The Permian palaeochannels can either be present as ribbon-like (shoestring) bodies entirely encased by coal, or the coal seams overlie the abandoned channel sandstones which then project up into the coal from below (see fig. 10 of Cairncross et al., 1988). In both cases, vegetative confinement and accompanying stabilization of the channel banks was the prime factor in controlling the channel forms, irrespective of whether the channels were conveying coarse sediment (sand and gravel) or whether they were transporting fine material (fine sand and silt). The sedimentary structures of these palaeochannel sediments consist essentially of stacked, planar cross-bedded ets, together with lesser amounts of trough ross-bedded sandstone and cross-laminated finer material. Large-scale lateral accretion surfaces point bars) have not been observed, thereby indiating that sediment was effectively confined to vithin the channel and that accretion took place y vertical aggradation and not by lateral migraion or combining of the channel systems. The alaeochannel geometries were essentially of low inuosity as defined by subsurface mapping of the hannel clastic isoliths (Le Blanc Smith, 1980). 'ertical grain size profiles of the channel-fill is lmost exclusively upward fining. Upward-coarening trends, a pattern which would indicate the resence of crevasse splay deposits, are rare. The ost common overbank material consists of thin, to 5 cm, laterally persistent layers of highly rbonaceous clay-rich material, which may represent sheet-flood overflow through the vegetated annel banks during flood stages.

Several thousands of drill-hole records have en used from the South African coalfields to delineate the three-dimensional morphology of these palaeochannels. Single, large trunk rivers, 5 km wide and 15 m thick, pass basinwards into a network of anastomosed channels 500 m wide and 4–5 m thick, although smaller channels as narrow as 3 m wide and 1.5 m thick have been documented. A concomitant decrease in sediment grain size occurs from coarse sandstone forming the bulk of the channel-fill in the proximal deposits to a mixture of fine sandstone and siltstone in the distal channel sequences.

Although the dimensions of the Permian South African palaeochannels are somewhat larger than those of the Okavango Fan, their mechanism of formation was similar. Clastic sediment was effectively trapped within channels that had vegetation-stabilised banks, thereby producing an interconnecting network of channels within the Permian peat swamp. These channels ultimately became abandoned and enveloped by the vegetation which encroached over and ultimately covered the abandoned channel sediments. A noticeable lack of crevasse splay deposits adjacent to the palaeochannel fills attests to the effectiveness of the confinement of the channel clastics to migration along the beds of the rivers, well below the shoulders of the vegetated levees.

Tectonically and climatically, the setting of the Permian channels was different from the Okavango examples. The former existed during a humid, cool temperate regime and were flowing over a stable cratonic platform (Cairncross, 1989). This emphasizes the fact that vegetation controls on the morphology of channel patterns can occur under a varied and diversified geological and climatological setting and that sediment grain size can not be considered the prime controlling factor in determining fluvial channel morphology.

Conclusions

(1) Bedload meandering and low sinuosity fluvial channel systems are possible where vegetation is sufficient to produce confining peat levées.

(2) The peat levées may be permeable, thereby allowing constant percolation from the channel laterally through the peat levée into the interchannel areas.

(3) Taking into account the recognition of fine-grained braided systems such as the Yellow River of China, an entire matrix can be erected in which any river geometry can evolve independent of its sediment load characteristics.

(4) Breaches through vegetation-stabilized peat levées may be plugged by deposition of sand so that crevasse splays are not developed laterally to the river channel system as is the case with more normal levée systems.

(5) Hippopotamus trails breaching the peat levées of the Okavango Fan river channels are the equivalent of beaver drag trails and canoe portages which nucleate breaches in the sediment levées of comparable river channels in Canada.

(6) The importance of peat levées may be totally unrecognized in ancient equivalent sequences because they are frequently destroyed by peat fires. In this regard 4–5 m peats may be degraded to thin carbonaceous layers 10 cm or less thick.

(7) In perennial, relatively constant flow river channels such as the Maunachira, rounded bars called knoll bars form, comprising internally stacked sets of planar cross-bedding. They may bear some affinities with "bank-hugger" bars previously described.

(8) River channels on the Okavango Fan evolve from a system of connected flooded pools (malapos) in which rooted swamp vegetation grows and confines water flow causing incision. The resulting channel encourages further plant growth and the take over of a pioneer flora by a papyrus-dominated flora. Peat levées develop which further confine flow, allowing aggradation of the channel and its sediment fill to the point where water loss becomes acute and avulsion becomes probable.

(9) Ancient analogues and partial analogues of the Okavango Fan fluvial channels are provided within the Upper Carboniferous Clifton Formation of New Brunswick and the Lower Permian Ecca Group of the Southern Transvaal.

(10) In ancient sequences where there is an overall dichotomy between arid to semi-arid climatic indicators in the sequence (such as calcrete soil profiles) together with indicators of a more humid setting (such as thin coals and carbonaceous layers), the possibility exists that the latte are caused by the entry of a perennial riv system into an area in which an arid to semi-ari climate prevailed.

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