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Palaeochannels (stone-rolls) in coal seams: Modern analogues from fluvial deposits of the Okavango Delta, Botswana, southern Africa

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Abstract

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Two varieties of fluvial sandstones are associated with coal seams in the Permian Witbank Coalfield of South Africa. The first comprises lenticular channel-fill sandstone, minor conglomerate and siltstone encased entirely within the coal seam. Medium- to coarse-grained arkosic sandstones are structured by planar cross-bedding and fine upwards into carbonaceous siltstone and overlying coal. These palaeochannel-fill deposits are 5 km wide in proximal basin areas and narrow down palaeoslope to less than 1 km in width. The second variety of channel fill consists of medium- to coarse-grained sandstone which occurs below the floor of the coal seam. These deposits form undulating ridges that occur either in sub-parallel groups or as isolated shoe-string type bodies at the coal-floor rock contact. Both features are referred to as stone-rolls in colliery terminology. These ancient deposits are compared with active and abandoned fluvial systems from the Okavango Delta in Botswana, southern Africa. Active channels are flanked by extensive peat swamps which effectively confine and stabilize the channel margins. Clastic sedimentation is therefore completely confined to the channels by the vegetation and deposition occurs by vertical aggradation.

Recently abandoned channels in the Okavango Delta display a variety of well preserved bed-forms which alternate with scoured depressions along the thalweg producing an undulating topography to the channel floor. These features provide a modern analogue for the stone-rolls in the coalfield deposits. The subsequent channel abandonment, vegetation encroachment and peat formation over the sand bodies would form a coal seam superimposed on the irregular surface, provided channel abandonment was followed by subsidence, overlying sediment deposition, compaction and coalification of the peat. Although the Okavango rivers are narrower and transport finer-grained sand than their Permian counterparts, the mechanism of formation and style of deposition was similar for both systems.

Introduction

Coal deposits in southern Africa are primarily of Permian age and occur in the Vryheid Formation of the Karoo Sequence (South African Committee for Stratigraphy, 1980). In the Witbank Coalfield, the Vryheid Formation averages 120 m in thickness and contains five mineable bituminous coal seams which are numbered from No. 1 seam at the base of the succession to No. 5 seam at the top (Fig. 1). Mining operations in the Witbank Coalfield of South Africa have, over the years, revealed numerous clastic deposits associated with the coal seams. These occur either as

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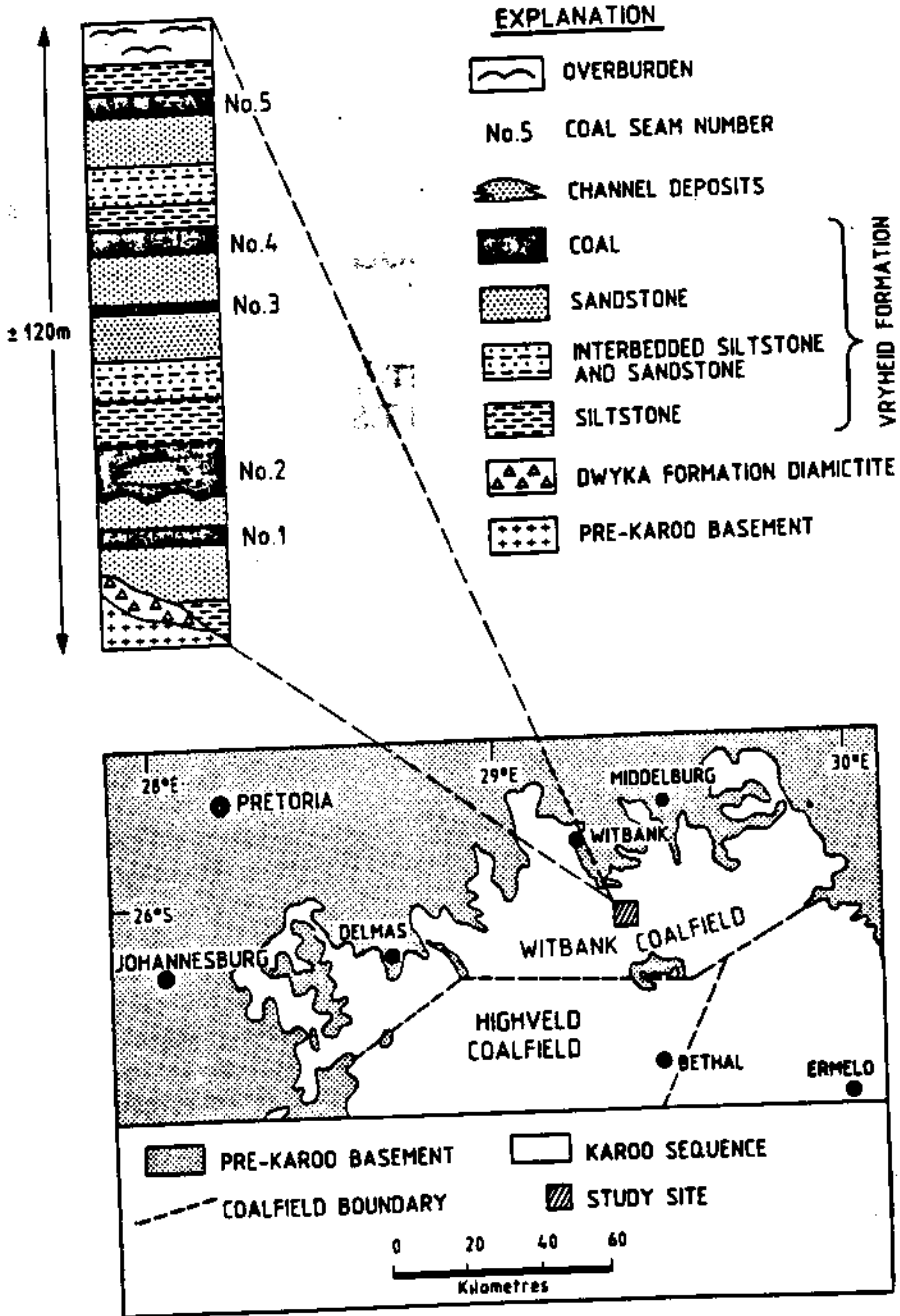

Fig. 1. Location of the study site in the Witbank Coalfield and the stratigraphic column of the Vryheid Formation from area.

in-seam partings completely enveloped by surrounding coal, or as irregular positive topographic ridges at the coal-floor rock contact. These are both referred to as stone-rolls in the local mines. They are elongate sand bodies that form undulating ridges on the floor of coal seams. Both varieties of these clastic units pose several mining and mechanical problems, particularly when encountered during underground mining operations. Similar ancient fluvial channels have been described from other coalfield localities by Horn (1978, fig. 28) from West Virginia coal mi by Fielding (1986) from the Durham coa England. Cairncross (1980) has docu aspects of the in-seam palaeochannel depos the central Witbank Coalfield in South Af described some of the mining problems quality variations caused by these clastic

Documented examples of stone-rolls floors of coal seams are relatively unc

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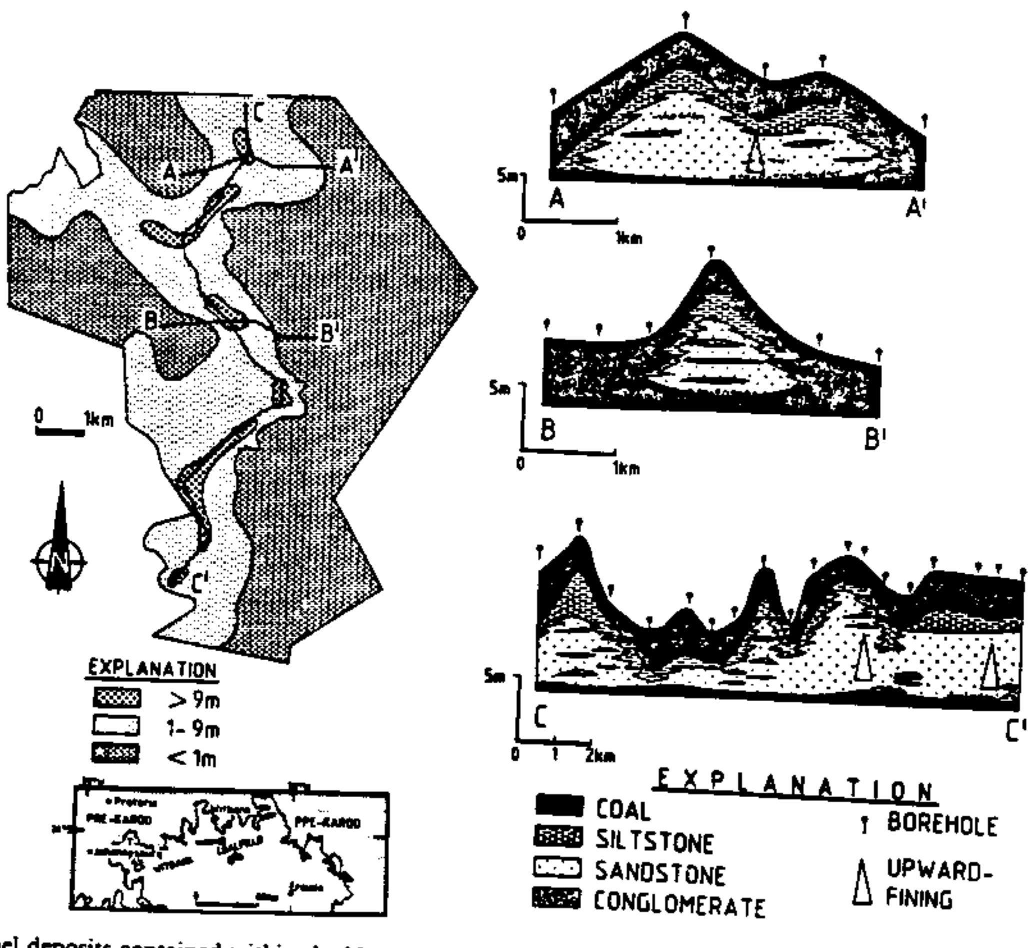
Macfarlane (1985), however, has mapped several of these stone-rolls and described their geometry, morphology and internal structure. In addition, Macfarlane discusses some of the mining problems created by these stone rolls during underground mining operations.

The palaeochannels contained within the coal seams of the Witbank Coalfield have been interpreted by Cairncross (1979, 1980), Le Blanc Smith and Eriksson (1979), Le Blanc Smith (1980) and Winter (1985) as anastomosed river deposits. These workers invoked the models described by Smith (1977) and Smith and Smith (1980) to account for the formation of the palaeochannels associated with the Permian coal seams. Macfarlane (1985) interprets the floor contact stone-rolls as originating from preserved scroll bars in meandering river point bars, but this appears unlikely and will be discussed later in the text.

This paper examines the palaeochannel sandstones and coal-floor rock stone-rolls in the light of recent evidence obtained from studies of active and abandoned sections of river channels in the Okavango Delta in Botswana.

Palaeochannel sandstones in the Witbank Coalfield coal seams

Detailed sedimentologic studies of the stratigraphy and palaeoenvironments of the Permian Vryheid Formation of the Witbank Coalfield have been undertaken by Cadle (1974), Cairncross (1979, 1986), Le Blanc Smith (1980), and Winter (1985). The Vryheid Formation, which hosts five minable bituminous coal seams, has been interpreted as resulting from sedimentation which occurred initially in a progressively de-glaciated environment, accompanying and following the retreat of the Permo-Carboniferous (Dwyka) ice sheets (Crowell and Frakes, 1975; Tankard et al., 1982). Environments of deposition ranged from glaciofluvial and glaciodeltaic in the lower portions of the stratigraphy (Le Blanc Smith and Eriksson, 1979) to high-constructive lobate delta deposits (Cairncross and Winter, 1984) and associ-



2. Palaeochannel deposits contained within the No. 2 coal seam in the Witbank Coalfield, South Africa. See Fig. 1 for location.

ated bed-load dominated (braided) fluvial sequences (Cairncross, 1986; Cairncross and Cadle, 1987).

During accumulation of peat which later formed the No. 2 coal seam, fluvial deposition was confined to a network of channels which transected the swamps. Channel dimensions vary from 5 km in lateral extent in proximal basin margin areas (Le Blanc Smith, 1980; Cairncross, 1986) to 1 km or less in more distal localities (Le Blanc Smith and Eriksson, 1979; Cairncross, 1980). Width to depth ratios vary between 50:1 to over 500:1 in the proximal areas. Lithologic detail and distribution of one of these palaeochannel sandstones is illustrated in Fig. 2. The isopach map delineates a sandstone–siltstone deposit which occupies a sinuous tract defined by the 1 m contour line. Central parts of the channel exceed 9 m in thickness and these are shown in the two borehole cross-sections across the channel fill (AA′ and BB′) and one section line oriented down the axis to the fluvial deposit (CC′). Flow was from north to south. Coarse-grained arkosic sandstone erosively overlies the coal and conglomeratic pebble lags commonly form the base of upward-fining sequences (Fig. 2, sections AA′ and CC′). Sedimentary structures are predominantly planar cross-bedded sets stacked vertically and decreasing in set thickness. This implies downstream migration of straight-crested sand waves suggesting that braiding took place within the confines of the channel margins. On the basis of palaeochannel geometry, facies assemblages and the association with flanking peat swamps, Cairncross (1980) interpreted these channel sandstone deposits to have originated as anastomosed rivers. The mechanism of channel formation and sediment deposition by vertical aggradation was similar to the deposits described from Canada by Smith (1977). Differences do however exist between the two systems. The palaeochannels in the coal seams are orders of magnitude wider than the modern Canadian streams; palaeochannel fill consists predominantly of coarse-grained sand and gravel; the palaeochannel deposits result predominantly from bed-load deposition from downstream migrating sand waves; and crevasse splay deposits and interchannel clastic accumulates are relatively uncommon in the Permian deposits, while crevasse s provide a significant proportion of the mo anastomosed sequences described by Smith Smith (1980).

Stone-rolls at the coal-floor rock contact

Quantitative data on stone-roll occurrenc mensions, distribution and orientation are tively scarce. One of the authors (B. C.) ha served series of parallel ridges of sandstone i floors of opencast coal mines in the Wi Coalfield. The floor-contact stone-rolls mainly at the base of the No. 1 and No. 2 seams (Fig. 1). These stone-rolls at the floor tact of the No. 1 and No. 2 coal seams symmetrical in cross-section and attain a heig 2 m, lengths of 40–50 m and widths of 2–3 m these features occur below the coal seam, the seldom penetrated by drilling and the int structure and configuration is therefore us not well known. In collieries where the u portions of the No. 2 seam are being selec mined, the upper surface of the encl palaeochannel sandstone projects out of the after the coal above has been removed. For e ple, the upper part of the No. 2 seam was m out in the region of section BB′ shown on F resulting in an undulating floor at this parti colliery. The contact between the coal and th of the stone-rolls (both in-seam and floor v ties) is characteristically sharp and abrupt little evidence of fossilized plant roots. This tive absence of seat earths or rootlet horizo however, a common feature of these Lower mian coal seams.

Macfarlane (1985) describes the presen stone-rolls from an underground colliery i southeast Witbank Coalfield. Three of these tures were mapped and are illustrated in F The lithologies comprising these bodies are e sively medium to coarse sandstone which is monly structureless (massive). Elongate va exceed 50 m in length (Fig. 3, top diag heights of 1.5 m and widths of 3 m. These stone stone-rolls can occur in isolation as string type features or can be present as s sub-parallel ridges.

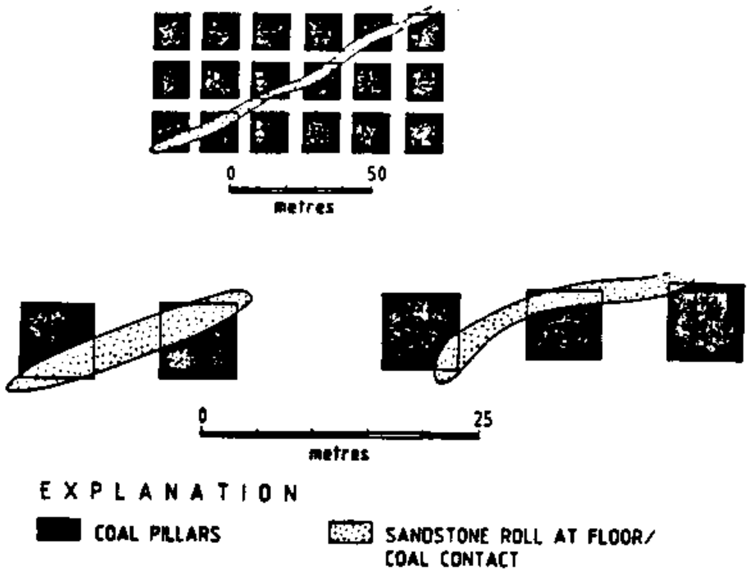


Fig. 3. Plan of stone-rolls in the coal-floor rock contact from a colliery in the Witbank Coalfield (from Macfarlane, 1985).

The presence of these floor contact stone-rolls rojecting into the coal can cause a hinderance to ining activities, particularly in underground op-ations where work space is restricted. These roblems are: (a) dangerous floor conditions re-lt from the steep sides of the sandstone ridges;) a decrease in the rate of coal transport from e working face to conveyors by shuttle cars curs due to (a) above; (c) production and grade ntrol problems are caused by sandstone incor-ration with coal handled by the coal cutters; (d) ntinuous miners' effective capabilities are re-ced by the undulating floor and the rock abra-n, resulting in increased bit consumption; and drainage problems are caused by ponding of ter in depressions between the sandstone rolls All of these factors frustrate mining operations d result in reduced efficiency of equipment and rsonnel at the working face.

tive and abandoned channels in the Okavango lta

A modern analogue which can accommodate h types of coal seam stone-rolls (i.e., in-seam tings and coal-floor rock contact varieties) may provided by the river channels which transect t deposits of the Okavango Swamps in swana (Fig. 4). The Okavango Delta is an nd depositional system which is located in the tral region of the Kalahari Basin of southern Africa. The location of this system is primarily tectonically controlled (Hutchins et al., 1976) with the main body of sediment confined by a graben defined by the northeast to southwest trending Gomare and Thamalakane faults (Fig. 4). The upper portions of the delta, where the Okavango River enters from the northwest (the panhandle), is similarly defined by a series of faults which are oriented perpendicular to the major graben to the southeast and which effectively confine the Okavango river to a narrow flood plain.

Even though the prevailing climate is essentially semi-arid, with the Kalahari Desert located to the west and south of the delta, extensive peat deposits have formed in the permanent swamp areas (Fig. 4). This is brought about by prolific overspill of flood waters from channels into the adjacent backswamp and flood-plain regions which subsequently sustains plant growth, peat accumulation and preservation.

The active Maunachira River

Sedimentary processes in the distributaries and the formation and abandonment of channels have been described by McCarthy et al. (1986). These authors have documented the mutual relationship between vegetation growth and sedimentary processes as causes for channel formation, characteristics and abandonment. Further evidence on river channel configuration and formation was

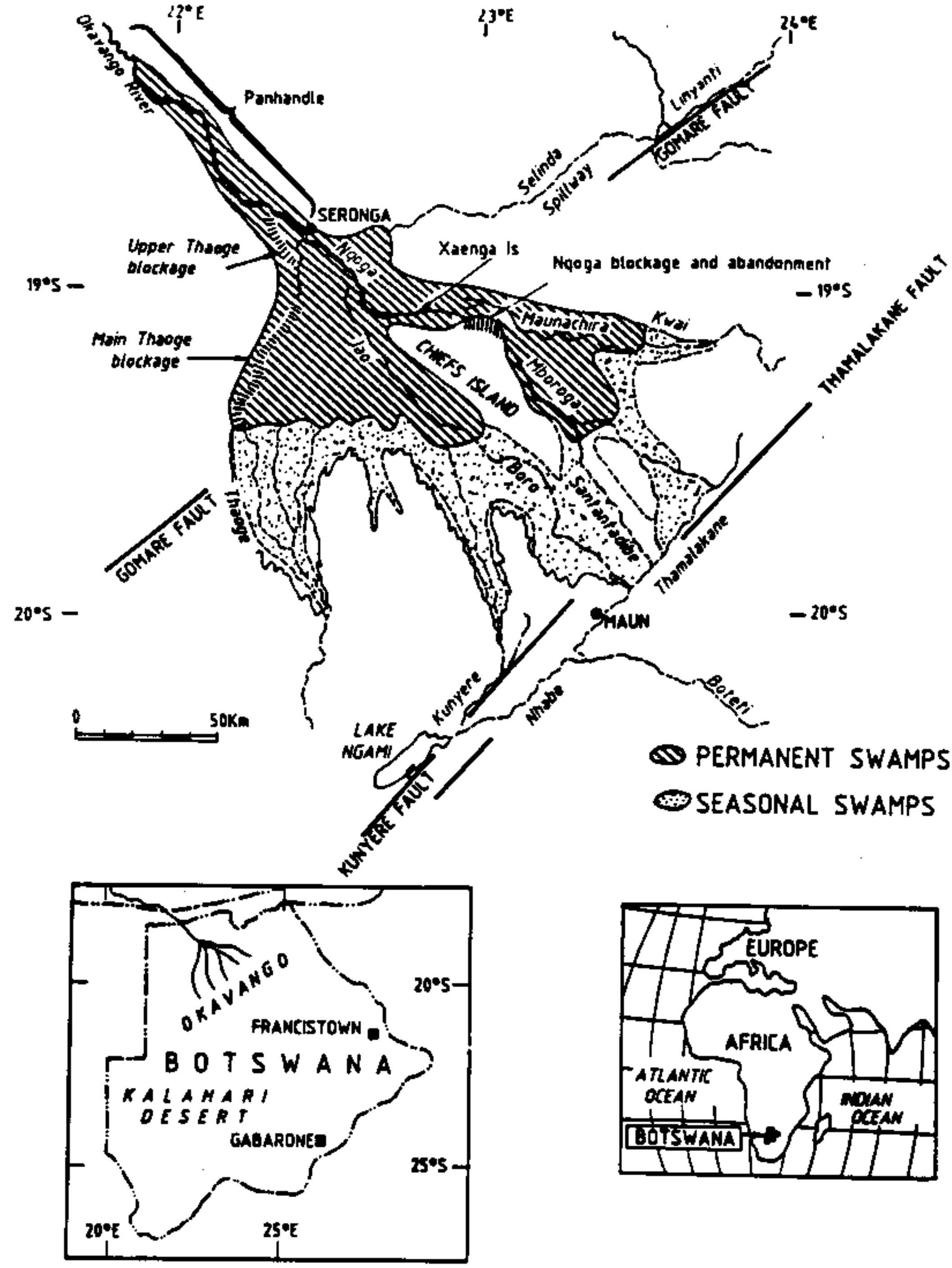
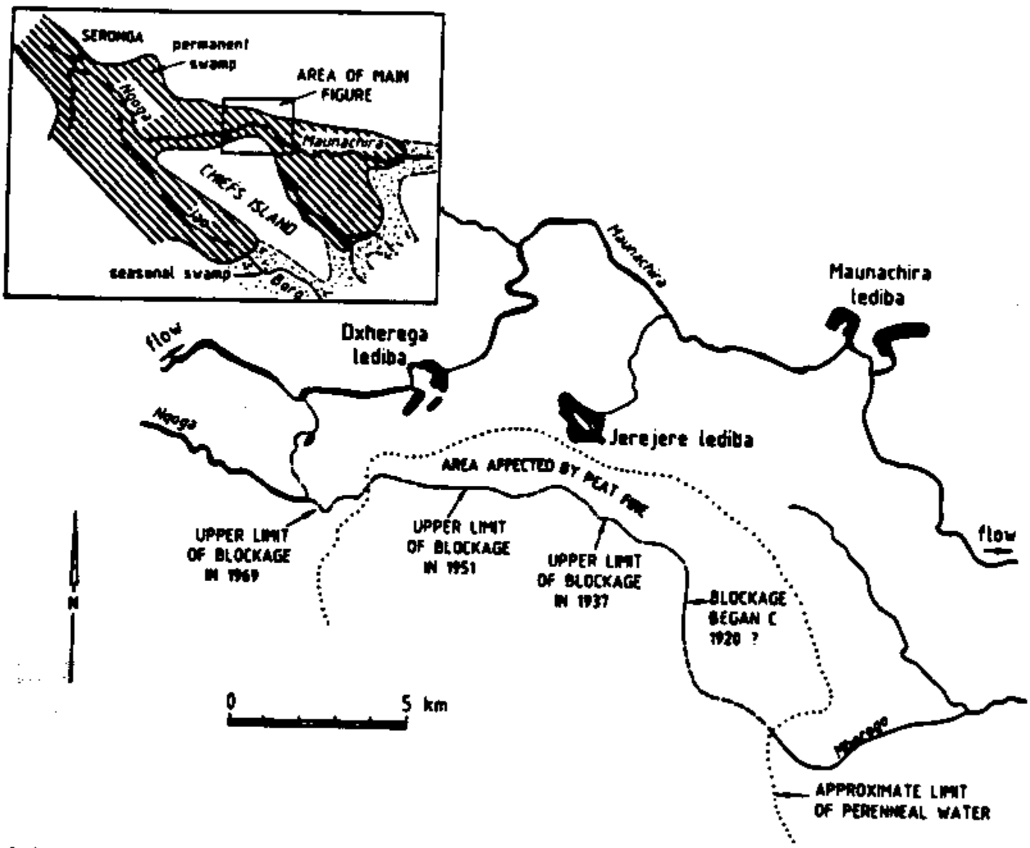


Fig. 4. Major geomorphologic and tectonic elements of the Okavango Delta, Botswana, southern Africa.

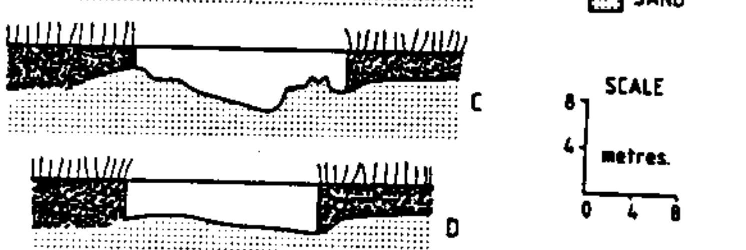
acquired during detailed mapping of an area of the active Maunachira River downstream from the Maunachira Lediba (lake) and an abandoned section of the Nqoga River south of the Jerejere Lediba (Fig. 5).

The sediment load carried by the river is composed almost exclusively of fine to very fine sand (Wilson and Dincer, 1976; McCarthy et al., 1986). The source of this bed-load sand may be of aeolian origin from a region in the catchment Okavango River. Depth profiles in the Maunachira River and flanking vegetation levees show clearly the controlling effect th ing vegetation, dominated by *Cyperus pap* has on confining the channel (Fig. 6). N there is no vertical exaggeration in sectio in Fig. 6. The water level is perched an tained several metres above the sandy chan



5. Location of the active Maunachira River and the abandoned Nqoga channel on the northeastern side of the delta (from arthy et al., 1986).

he peat and papyrus (Fig. 7). During high flow e, flood waters percolate through the vegetated s and this results in extensive overspill flood r flow outside of the confined channels. This l water is totally devoid of sand load and ins only small proportions of suspended clays which tend to become deposited on the vegetation mat immediately adjacent to the channel thereby reinforcing the confining role of the plants on the channel margin. Deposition of sand occurs only in the channels by vertical aggradation at rates calculated by McCarthy et al. (1986) of up to 5 cm



Depth profiles across a section of the active Maunachira river. Note: there is no vertical exaggeration in the diagrams; the profiles of the peat which flank the channel; the perched water level several metres above the sandy channel bed.

Fig. 7. The portion of the Maunachira River where sections A–D in Fig. 5 were measured. The river is approximately 30 m
the foreground. *Cyperus papyrus* vegetation flanks both sides of the channel and flow is toward the viewer.

yr^{-1}. Flanking vegetation keeps pace and in fact precedes channel bed aggradation. As the channels narrow downstream, however, the water upstream is ultimately forced out of the channel by overspill resulting in a reduced downstream hydraulic gradient. As nutrient supply is greatest at the water–channel margin interface, *C. papyrus* growth within this region is most vigorous. While the channel water is actively flowing, it is able to prevent papyrus from growing out into the channel and blocking it. In the areas of reduced hydraulic gradients, the flanking papyrus begins to encroach into the moribund channel and, together with floating vegetation debris drifting down the channel, causes a vegetation blockage. Progressive upstream divergence by overspill is accompanied by progressive vegetation blockage. This occurs at historically measurable rates (see Fig. 5 for portion of blockage in the Nqoga from ca. 1920 to 1969). It is significant, therefore, that vegetation blockages herald the dying phase of the channel and are not the direct cause of abandonment. Vegetation plugs the channel only after bed-load deposition has taken place due to rapid sedimentation, caused by a reduction in the hydraulic gradient.

The abandoned Nqoga River

An investigation of the abandoned Nqoga R
revealed certain aspects of the channel geo
and bed-forms that were not immediately
parent in the active Maunachira section. A
tensive peat fire (Fig. 5) has burnt out the
which flanked the Nqoga River. The fire pro
began several decades ago and persists until
(Ellery et al., in prep). The peat fire result
considerable mass reductions from unburnt
to residual ash causing 3 m of peat to be re
to a 20 cm ash layer. These volume reductio
in the order of 15 × reductions in thickness.
result, considerable deflation and inversion
flanking burnt out peat has highlighted the
phology of the Nqoga and its distributaries
8). These now exist as positive topographic
and clearly show the marked confinement
sand within the channels.

The abandoned Nqoga River is between 2
100 m wide from bank to bank, while
tributaries seldom exceed 10 m in width. A
plex and diverse set of bedforms are present
main channel. Large-scale sand waves and rou
(hummocky) shaped sand bars are intersp

Fig. 8. Elongate bed form in the abandoned section of the Nqoga River.

h relatively deep-scoured depressions (Fig. 9). e maximum relief from the top of the bar forms the base of scour depressions is 2–3 m. These ressions appear to be related to papyrus raft ckages which existed when the river was still ve. With the development of a surface block-, water becomes more confined as it flows underneath the floating blockage. As the dimensions of the channel are thus reduced, flow rate increases and erosion takes place on the sandy substrate underneath the blockage, scouring a depression in the channel base. This process is confirmed by the turbulent flow of the water as it emerges on the downstream side of the blockage

Fig. 9. Scoured depression in the abandoned Nqoga channel together with hummocky bed form in the centre.

and the dumping of the eroded sand at this downstream position as flow rates diminish in the widened channel.

Discussion

The association of sandy fluvial channel-fill and confining flanking vegetation and peat, provides a modern analogue for the mechanism of formation of the sandstone palaeochannel fills in the Permian age coal seams in the Witbank Coalfield. This applies to both varieties, i.e. the channel sandstone stone-rolls completely enveloped by coal and the sinuous stone-rolls at the floors of the seams. The morphology and geometry of the Maunachira and Nqoga rivers parallels those of the coal seam palaeochannels. Although braiding took place in the sandy substrate of the Permian rivers, the channel course was effectively defined, maintained and confined by the adjacent peat swamp. The mechanisms and geobotanical processes operating in the Okavango delta channels explains the configuration of these fluvial deposits and those described from the Permian coalfield. Abandonment of channels followed by overgrowth of swamp flora would produce a channel-fill enclosed in peat (coal) similar to that illustrated in Fig. 2. Similarly an abandoned channel such as the Nqoga River located in the floor of a coal seam would produce sinuous, elongate shoe-string like sandstone ridges such as illustrated in Fig. 3. The variability of bed forms and scoured depressions such as those shown in Fig. 9 would result in a series of positive topographic sandstone features of restricted lateral extent similar to the grouped sandstone rolls in the coal-floor rock contact described by Macfarlane (1985). The preservation of bed-forms in the abandoned Nqoga River suggests that under a sedimentary sequence comprising sediment deposition in the channel, aggradation, abandonment, subsidence and encroachment by plants, the underlying sandy channel and its undulating bed form morphology would be preserved intact. Following continued sediment deposition above, compaction, and coalification, the coal immediately overlying the channel-fill bed forms would undergo differential compaction and the sands
would project up into the coal above.

Figure 10 illustrates the origin of both variet
of stone-rolls from analogues in the Okava
Delta. The top three block diagrams account
channel sandstone completely enclosed within p
(coal in the Permian example). An active chan
(Fig. 10, block 1) erodes into existing peat,
posits sand and, with time, becomes abando
(Fig. 10, Block 2). This is followed by vegetati
encroachment over the abandoned channel-
and, following compaction and coalificati
would produce a sequence similar to that
lustrated in Fig. 2. The lower two block diagra
of Fig. 10 show the formation of stone-rolls in
floor of seams. A completely abandoned chan
(Fig. 10, block 4) is present as a topograp
sandy ridge flanked by residual peat such as e
in the blocked area of the Nqoga River (Fig.
When this region becomes reflooded at a l
stage, vegetation once again covers the strata
low with peat. This sequence would produce
time, the stone-rolls in the floor contacts of
coal seams.

The ability to predict the occurrence, distri
tion and orientation of these palaeochannels a
ciated with coal seams in the Permian sequence
dependent on the amount of data available fr
borehole descriptions and mine data. Yet an
derstanding of the mechanics of formation of
channel provides clues to dimensions and vert
thickness of channel deposits. Channel dimensi
decrease basinwards from proximal trunk stre
5 km in lateral extent to less than 1 km wide
distances of 30–40 km. An understanding of
sub-regional basin configuration and palaeotop
raphy upon which the peat and channels w
deposited would also permit certain predicti
with respect to channel orientation. The prese
of stone-rolls in contact with overlying coal ab
can be recognized from borehole core. This can
discerned by an angular contact between coal
floor rock, by coal structurally deformed by
cro-faulting at or near the angular contact or
slickensided coal caused by differential comp
tion along the angular contact.

An understanding of sedimentation and ch
nel formation processes leads, therefore, to

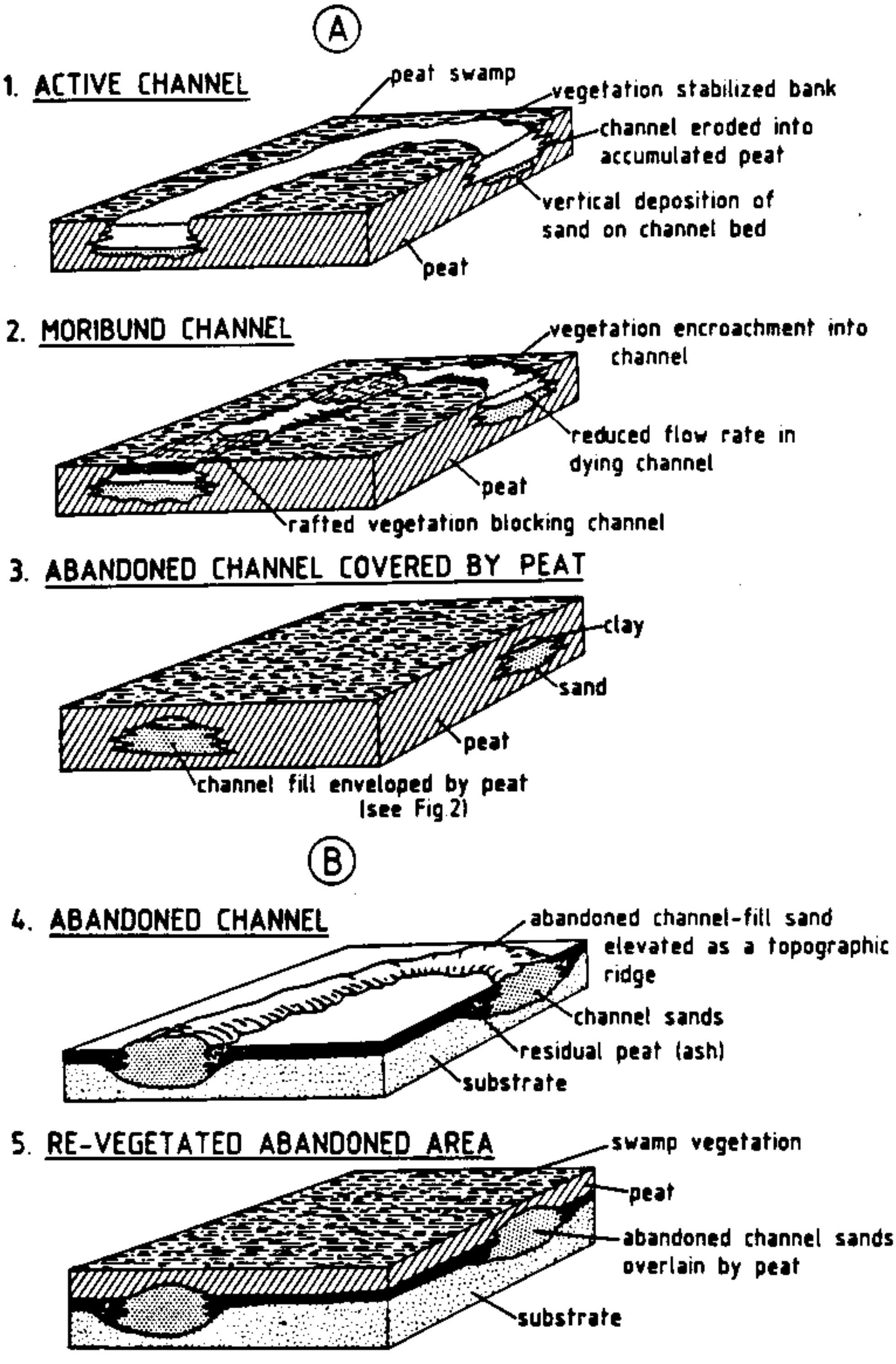


Fig. 10. Modern analogues from the Okavango Delta of stone-rolls associated with the Permian coals. (A) Abandoned channel-fill sand becomes completely enclosed by peat to produce an in-seam stone-roll which would result in a sequence similar to that shown in Fig. 2. (B) Abandoned channel-fill sand overlain by peat would produce stone-rolls at the coal-floor contact.

increased ability to anticipate the geometry and distribution of these clastic units. As such, these channel fill sequences provide further evidence for additional styles of fluvial systems other than the conventional models. The present-day channels of the Okavango Swamps and the ancient counterparts of the Witbank Coalfield have a combination of depositional elements controlled by interacting geobotanical processes. These elements give rise to characteristic fluvial styles which differ significantly from braided and meandering river deposits.

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