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# PALAEOENVIRONMENTAL MODELS IN THE EASTERN KAROO BASIN

by

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**ABSTRACT**

Palaeoenvironmental models are based on a three-dimensional conception of sedimentary rock units and their internal geometry. These models are process-oriented and are interpreted by comparison of their attributes with those of modern sedimentary environments. Six models are proposed as a result of observations in the eastern Karoo Basin, three in the Ecca and three in the Beaufort, although some are common to both.

Both regressive delta and beach models are upward-coarsening, but they are readily distinguished on the basis of sandstone composition, texture and sedimentary structures. Beaches probably developed along a non-tidal or micro-tidal coast, but in most areas the relatively rapid sediment influx favoured the formation of deltas which prograded across the shallow shelf. Incised into the delta front sandstones are channels of distributary and alluvial origin. Large fluvial channels were generally meandering, and their deposits record a vertical reduction in flow energy from thalweg through point bar to levee, with the capping coal seams representing an hiatus in detrital sedimentation.

Delta front sandstones within the Beaufort Group resemble superficially those of the Ecca, but display differences in vertical sequence which are tentatively ascribed to changes in density of the basin waters. Whereas the northern and eastern basin margins were characterized by persistent, moderate energy fluvio-deltaic sedimentation, with small prograding lobes separated by shallow embayments subject to crevasse splays, the southern part of the basin was the locus of major fluvial deposition as a consequence of orogenic uplift to the south. High energy braided stream conglomerates and sandstones were deposited contemporaneously with finer-grained meanderbelt and floodplain sediments, which accumulated farther basinward in an area of reduced gradient and more constant discharge.

The value of these models is that most outcrops in the study area can be explained in terms of their relationship to one or more of the models. Future palaeoenvironmental synthesis should incorporate the great variety of biological information available from the Karoo Basin.

**CONTENTS**



## INTRODUCTION

As has been pointed out by Haughton (1970) basic stratigraphic subdivision of the Karoo Supergroup has been long established, and over the years there has been progressive refinement of stratigraphic procedures. Chronostratigraphic, lithostratigraphic and biostratigraphic approaches are being employed without the previous confusion which resulted from attempts to blend objective and inferential criteria into a single classification. Today the only issues involve details of correlation and contacts between units, and these problems are likely to remain.

More importantly, the conceptual approach to stratigraphy has changed from mainly descriptive to dynamically-based. This new approach, which uses the sum total of available rock and fossil data for comparison with present-day environments, circumvents many of the problems which have plagued stratigraphers in other countries. In South Africa, because of the awareness of certain geologists early in the century, we are less committed to the obsolete "layer-cake" model. The increasingly process-oriented approach was foreseen by Alex du Toit and others, and became incorporated into our thinking.

This new approach to analysis of a depositional basin is bound to influence studies of the Karoo Supergroup. The vast store of biological data will be used in conjunction with detailed studies of physical attributes such as rock composition, texture, sedimentary structures, and three-dimensional lithofacies relationships, to provide a precise reconstruction of the changing environments. The basin synthesis which emerges for the Karoo should be the most sophisticated of its kind in the world.

sedimentary models from the Ecca and Beaufort Groups in the eastern Karoo Basin (fig. 1). Some of the models have been presented previously, while others are new. The sedimentary model concept is based on observed patterns of rock textures and structures, which are generally recurring. Ideally the model should be represented in three dimensions, but because of limitations imposed by incomplete exposure, some models can only be established on the basis of repetitive vertical sequences, or "cycles". Often these cycles are immediately obvious in the field; others are less well developed, and are manifest in preferred vertical arrangements of rock types or sedimentary structures, derived by nonparametric statistical procedures (e.g. Cadle, 1974; Hobday *et al.* 1975).

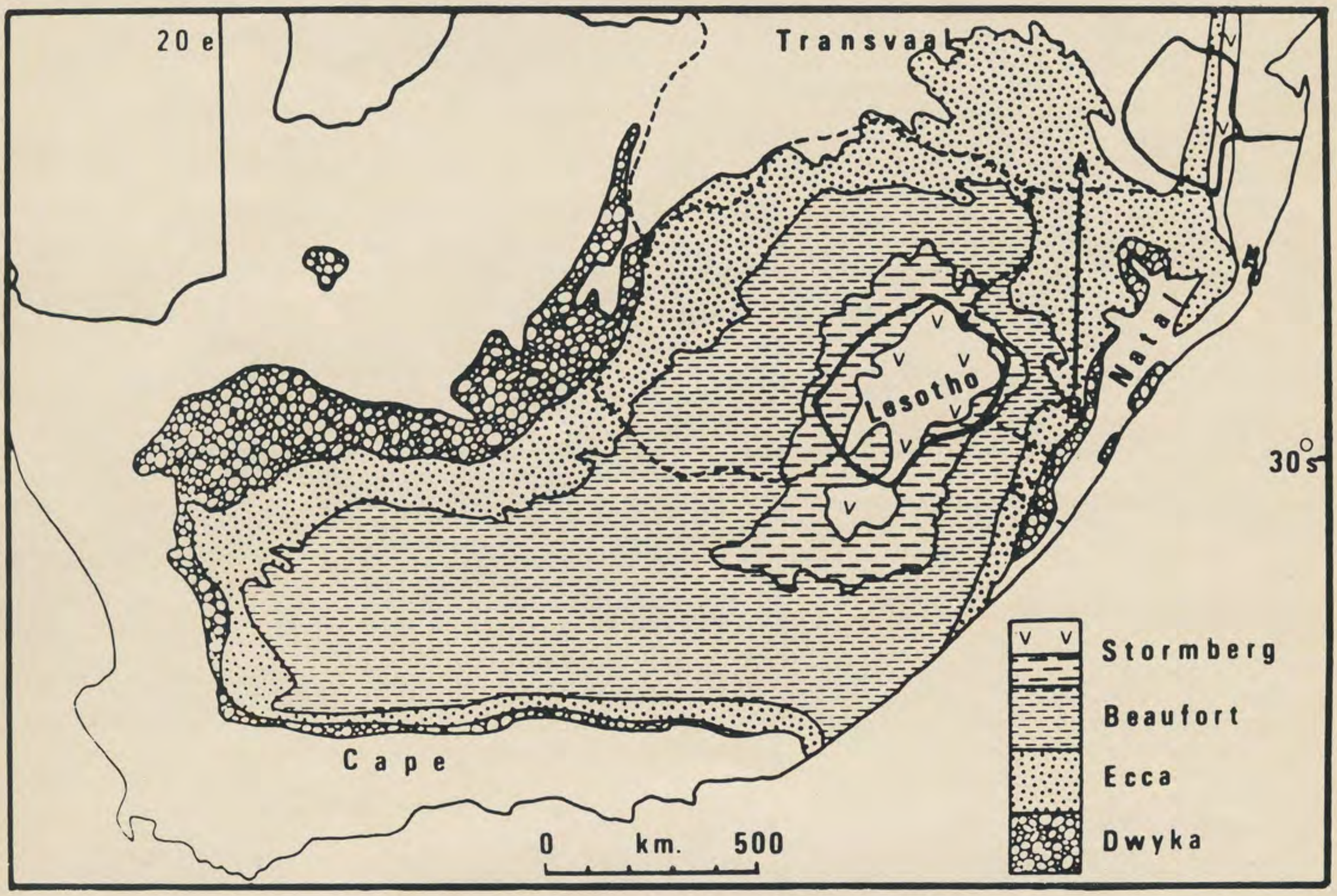


Figure 1. Generalised geological map of the Karoo Basin.

A weak link in this ideal multidisciplinary approach is the scarcity of sedimentological studies of parts of the Karoo succession. The detailed collection of sedimentological data and its interpretation in terms of analogous processes operating in present-day environments has been particularly lacking in the Beaufort Group where, because of the unique importance of vertebrate fossils, sedimentary studies might have been most significant.

The present contribution gives some examples of

## ECCA GROUP

A north–south cross-section through the eastern part of the Karoo Basin (fig. 2) shows that the Middle Ecca (Vryheid Formation) clastic wedge is enclosed by argillaceous rocks of the Lower and Upper Ecca (Pietermaritzburg and Volksrust Formations respectively). The Middle Ecca is divided into two facies, regressive deltaic and "channel".

There is generally an absence of wave and tidal current activity in the eastern Karoo Basin, but re-

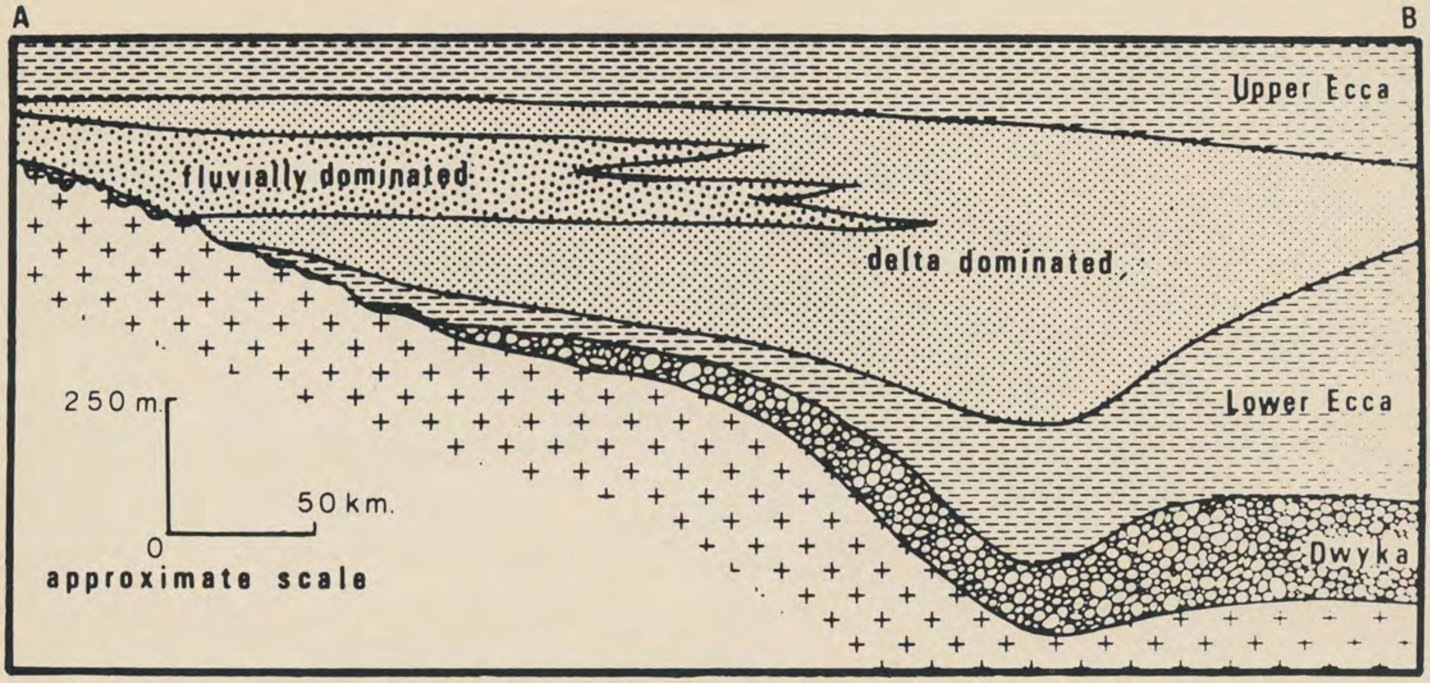


Figure 2. North–south cross-section through the Ecca Group (see fig. 1 for line of section) showing the Middle Ecca clastic wedge enclosed by argillaceous rocks of the Lower and Upper Ecca.

worked shoreline sandbodies developed locally. These represent a third sandstone facies, generally referred to as "beaches".

### Regressive Delta Model

Sedimentary sequences ascribed to delta progradation are recorded in Natal by Hobday (1973), Hobday and Mathew (1975) and Hobday *et al.* (1975). The lowermost sequence overlies Lower Ecca shelf mudstones conformably, and coarsens upward from alternating siltstones and thin sandstones into cross-laminated (sets thinner than 5 cm) and cross-bedded (sets 10–80 cm) sandstone. The sandstones are immature and arkosic, with local pebble concentrations. Trace fossils are abundant and show a change from predominantly horizontal varieties in the lower parts to vertical burrows in the coarser upper portions. In the east this basal sequence is succeeded by up to six similar cycles, each generally between 40 and 100 metres thick. The number of cycles decreases westward (Van Vuuren and Cole, 1977).

These cycles (fig. 3) are attributed to a shallow water deltaic environment. Fine particles were carried in suspension and deposited offshore on the lower parts of a prograding delta lobe. There was periodic introduction of coarser sediment by traction currents of short duration, and by slumping and the generation of minor density flows. The thickness of these sandy intercalations increases upward in the transition from prodelta to distal distributary mouth bar, where the maximum water depth was 100 metres. These sediments were below wavebase, except during storms when they were disturbed by the deep, low energy effects of wave surge. During long periods of relative stability they were reworked by sediment-ingesting organisms. Upward gradation into the proximal mouth bar (fig. 4) is marked by a predominance of traction-deposited sandstone which was burrowed by filter-feeding organisms. The top of the bar was probably submerged, but was shallow enough for plant growth in places.

Adjacent to the main deltas were smaller sediment lobes produced by the lateral projection of sediment-laden water into ponds and bays. This occurred by breaching of the levees, or crevassing, during flood. Some of these crevasse-splays were active for only a single flood (see section under Beaufort Group where they are better developed). Others remained active and resulted in the development of sub-deltas. Sub-delta sequences resemble the major cycles, with bay sediments, which resemble prodelta deposits, overlain by small delta-front sandstones. The thickness of these sub-deltas is between 5 and 25 metres.

Semi-permanent occupation of a crevasse-channel, accompanied by compaction of the underlying sediments and basin subsidence, led to the development of a major delta lobe. This mode of delta-switching accounts for the relationship between sequences in delta-dominated parts of the Middle Ecca.

### Channel Sandstones

Overlying and cutting into the tops of many delta sequences are channels of variable size and character (fig. 5). The thickness of individual channels, and the proportion of channel to deltaic facies, increase northwards through Natal. In the north the central

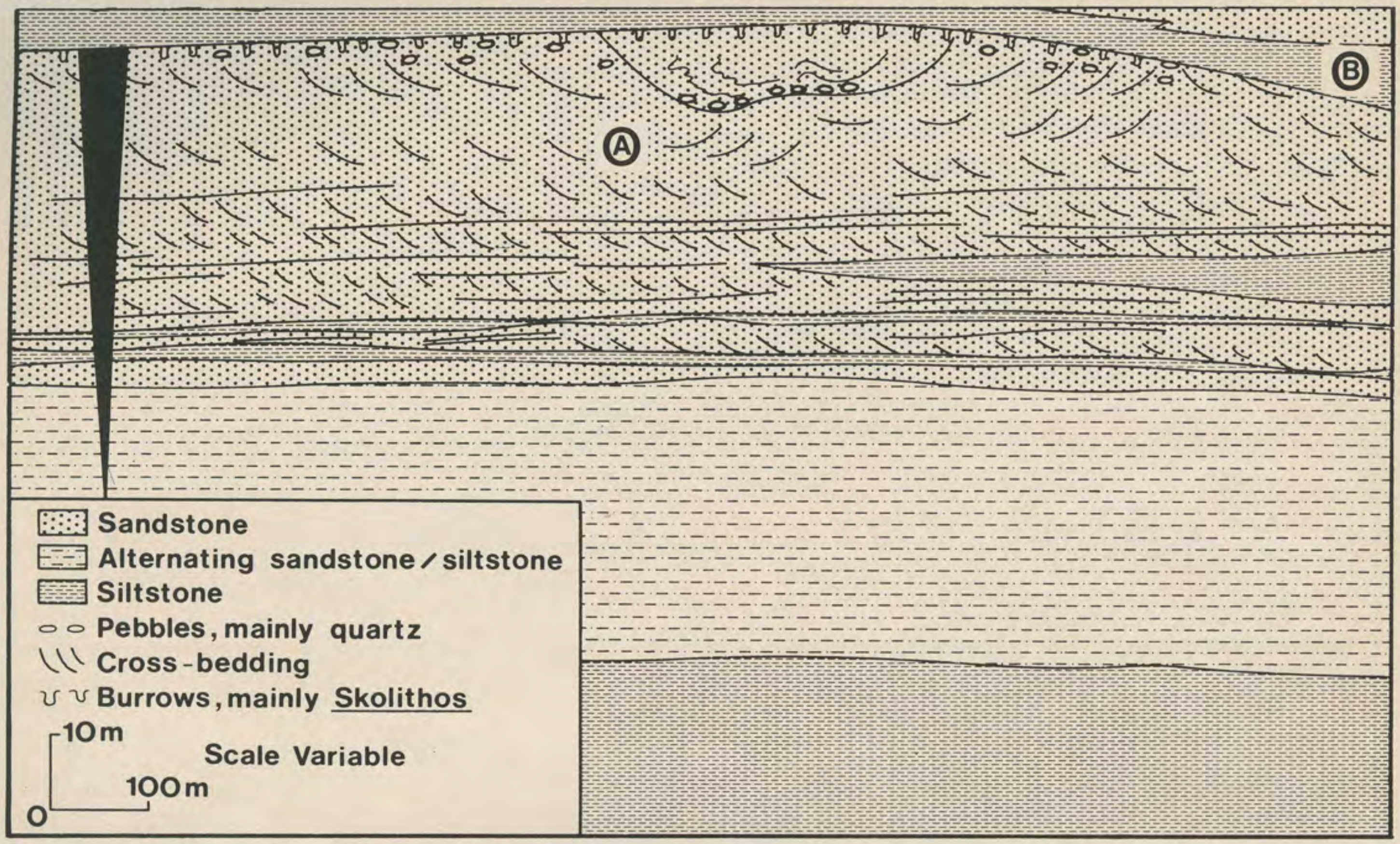


Figure 3. Schematic regressive delta model showing characteristic upward-coarsening pattern of prodelta, distal and proximal mouth bar (A) subfacies thinning laterally into finer-grained "bay" deposits (B). Apex of triangle points in direction of decreasing grain size.

Figure 4. Distal bar subfacies with numerous siltstone partings, overlain by proximal mouth bar with inclined sandstone accretion surfaces resulting from delta progradation.

Figure 5. Upward-coarsening deltaic sequence truncated by channels, probably major distributaries.

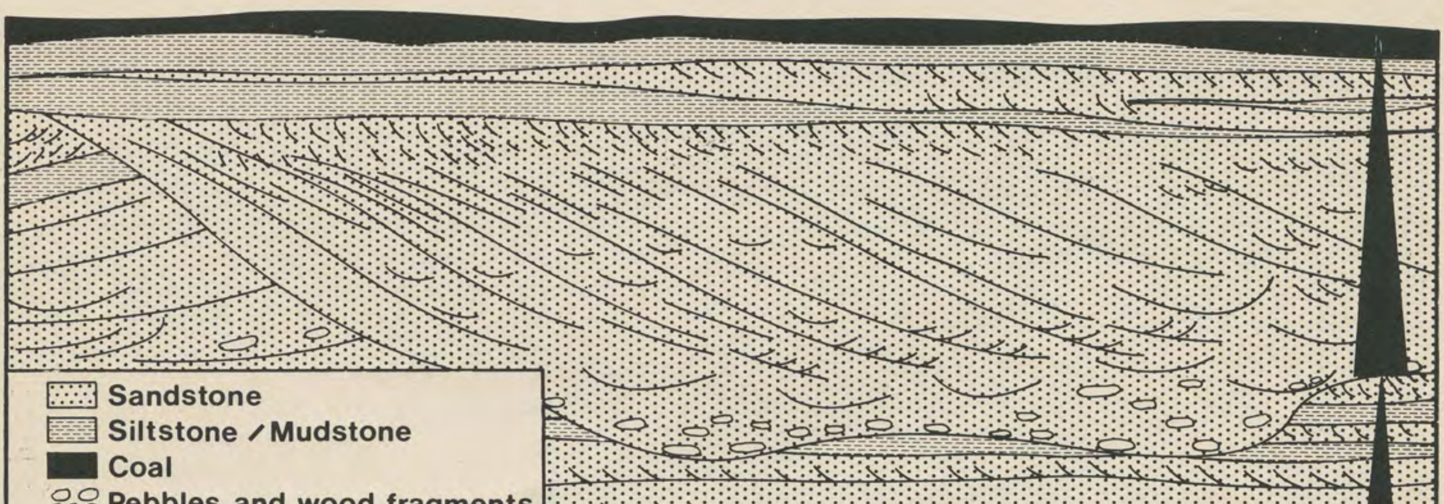


Figure 6. Superimposed upward-fining fluvial channels showing basal lag, side-fill accretion surfaces and capping siltstone and coal.

part of the Middle Ecca consists of channels superimposed one upon the other.

Multiple scours, 1–2,5 m deep, in the top of regressive delta sequences are possibly the basinward subaqueous terminations of distributary channels as they bifurcated and became reduced in size. Larger, steep-sided and commonly slumped channels up to 6 m deep were probably distributary trunk channels. In keeping with many modern deltas the distributaries extended their courses by progradation without much lateral migration.

Rivers of the alluvial plain to landward were far larger, with depths of up to 15 m, and were generally meandering, although subordinate braided stream deposits are in evidence in the eastern Transvaal. The meandering channel deposits are classically erosively-based and upward-fining, with large-scale, side-fill structures recording the successive profiles of the point bar surfaces (fig. 6). A basal thalweg lag consists of extrabasinal pebbles and intrabasinal clasts. The lower trough cross-bedded sandstones are coarse arkoses, and grade upward into cross-laminated finer-grained sandstone. Palaeocurrent azimuths are unimodal and generally southward. Siltstones at the tops of cycles are thin, and display horizontal and wavy lamination with carbonaceous partings. These are interpreted as levee deposits. Where coal is present it terminates the cycle.

As fluvio-deltaic outbuilding progressed and facies tracts shifted basinward, rivers of the alluvial plain overlapped the delta plain and delta front deposits. Where subsidence was slow the upper part of the deltaic record was practically obliterated by deep meandering channels.

### Beach Deposits

Outcropping in cliffs along the Vaal River near Bothaville, O.F.S. are quartzose sandstones with the characteristics of beach and nearshore deposits (Behr, 1965; Vos and Hobday, in press). A borehole study by Behr (op. cit.) showed that the sandstones are up to 50 m thick in the north where they pinch out against the Precambrian basement. To the south the sandstones rest directly upon Dwyka tillite, beyond which they finger out into dark siltstone. The sandstones become coarser-grained upward, with increasing abundance of heavy mineral concentrations (fig. 7).

At the base of the Vaal River exposures (fig. 8) are partly bioturbated fine-grained sandstones with silty partings. Small-scale cross-bedding is of variable azimuth, and alternates with horizontal lamination. Vertical tubular dwelling burrows extend down from erosion surfaces separating bedding units of 5–60 cm thickness. These characteristics accord with observations on the modern shoreface. The overlying moderately sorted medium to coarse sandstone with scattered pebbles is ascribed to upper shoreface deposition. Medium to large-scale trough cross-bedding shows weak bimodality. There is evidence

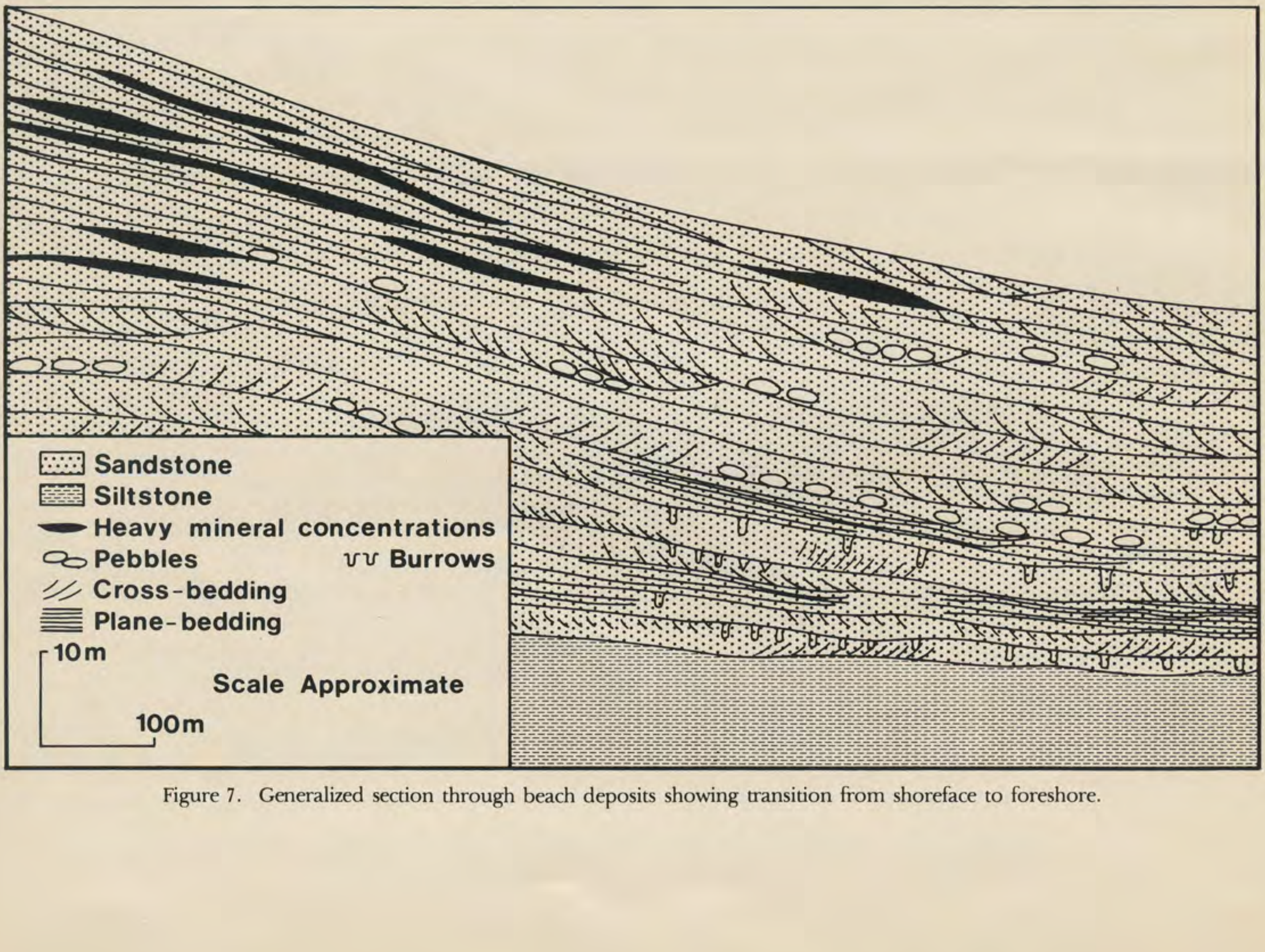


Figure 7. Generalized section through beach deposits showing transition from shoreface to foreshore.

of rip-current channelling and seaward transport of sand, and there was a significant longshore drift component. At the top of the exposure are gently-dipping sets of plane-bedded sandstone of variable texture containing laminae and scour-based lenses of heavy minerals. These features are commonly observed in beach foreshore sands.

The overall sequence is representative of shore-zone progradation, where wave swash deposits overlie sands of the shoreface. The Ecca beach deposits are thought to have originated on a non-tidal or microtidal, storm-dominated coast (Vos and Hobday, in press).

## BEAUFORT GROUP

According to the palaeoenvironmental criteria established by Picard and High (1972) the Beaufort may be classified as a lacustrine basin. Persistent, low energy fluvial influx characterized the northern and eastern basin margins. Relatively quiet conditions prevailed in the south during early Beaufort times, but were succeeded during the Middle Beaufort by rapid fluvial influx consequent upon uplift of the Cape Fold Belt and its eastward extension.

### North-eastern Basin Margin

In Natal one of the prevalent sedimentary patterns is an upward-coarsening sequence which in some respects resembles the Ecca deltaics. As in the case of the Ecca they are thought to represent delta front deposition, but instead of a gradual upward increase in grain-size there is generally an abrupt contact of distributary mouth bar sandstones on "bay" or prodelta siltstones. Gradational contacts are, however, observed beneath the thin lateral terminations of the sandstone bodies (fig. 9).

A possible explanation of this difference between the Ecca and Beaufort sequences lies in the relative density of the basinal and inflowing river waters. Where a marked density difference exists (generally if the basin is to some degree saline), river discharge will override as a seaward-thinning wedge. Fine suspended sediment will settle out of the freshwater wedge and accumulate offshore, and therefore the classical offshore grain-size gradation will result. This situation appears to have existed during Ecca times, although probably in a brackish as opposed to a normal marine basin.

In contrast, the fresh water of the Beaufort lacustrine environment would have had approximately the same density as river water. Intense mixing would have occurred at each channel mouth, scouring the floor and dumping all grades of sediment immediately off the mouth. According to Oomkens (1970) the fine-grained lower units are not developed in a fluvio-lacustrine offlap sequence, thus possibly explaining the Beaufort relationships of the mouth bar sandstones to underlying rocks.

Figure 8. Shoreface subfacies showing burrowing and small-scale structures, Vaal River exposure. (Photo R. G. Vos)

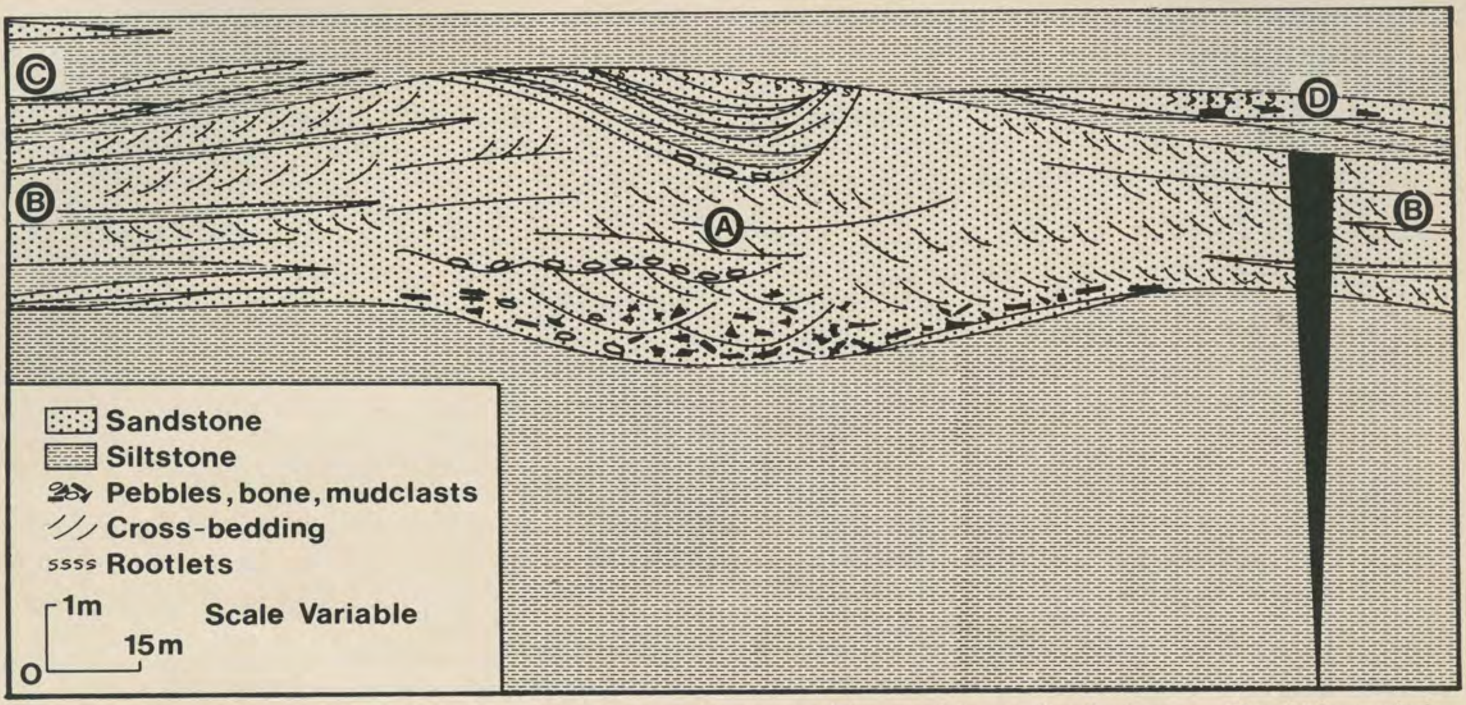


Figure 9. Characteristic geometry of Beaufort delta front sandstones overlying prodelta or "bay" siltstones. The thick, erosively-based central portions (A) grade laterally into thinner sandstones (B) with progressively less erosional discordance. Above are bay siltstones (C) containing lenticular crevasse sandstones(D).

The rapid accumulation of sediment in front of the channels would have favoured the development of large numbers of short-lived distributaries, and rapid changes in the loci of maximum sedimentation. It probably also resulted in widespread crevassing.

*Crevasse Splay Model*

A conspicuous lithological feature of much of the Beaufort is the presence of 10–300 cm thick sandstone bodies which lie with erosive contact on grey, green or red siltstone (fig. 10). Mudclast and bone inclusions are common, particularly towards the base of the sandstones. Occasionally the upper parts are distinctly finer-grained and transitional into siltstone.

The sandstones are generally lenticular or wedge-shaped, although some are tabular. Very rarely their lateral relationship to a thicker distributary sandstone is demonstrable in outcrop, and indicates that they were derived from the channel by crevassing of the levees. The proximal end of the crevasse splay is thicker, narrower and channellized, and thins towards the distal terminations which are more sheet-like, and which interfinger with bay siltstones (fig. 11).

Internally the proximal crevasse splays are massive to irregularly cross-bedded, showing great variation in set thickness. This is probably a result of rapid accumulation of sediment and irregular flow. High rates of sediment fallout are further evidenced by climbing ripples, some of which are the in-phase variety. Large intraformational siltstone clasts were probably eroded from the levee.

The more distal parts of a splay are often irregularly-based and interlayered with siltstone. Where subsequent reworking has occurred the sandstone is better sorted and is cross-laminated with ripple upper surfaces. Small-scale structures and bedforms frequently resemble those of tidal deposits. The operation of semi-diurnal lunar tides is not envisaged, but there may have been "wind tides" of alternating direction and intensity, producing herringbone structures, interference and ladderback ripples and rhythmic clay drapes on foresets and rippled surfaces.

**South-eastern Basin Margin**

Marginal downwarping which accompanied orogenesis to the south caused northward progradation of a thick Middle Beaufort clastic wedge. These rocks attain their maximum thickness in the south (the Katberg Sandstone and part of the Balfour Formation), and are particularly well exposed in sea-cliffs of a Beaufort outlier between Port St. Johns and Coffee Bay. The regional palaeocurrent pattern, which includes data from the Ciskei and eastern Cape, indicates a northward-building alluvial fan with a divergent arrangement of channels (Greenshields and Hobday, 1977).

Two distinct fluvial facies are recognized, an upstream high-energy braided stream facies, and a basinward meanderbelt facies of lower energy. Although there is an overall tendency for the braided deposits to overlie the meanderbelt sediments, there are parts where the two facies are complexly interlayered, indicating minor shifts in the balance between basin downwarping and sediment influx during the general regression.

Figure 10. Erosively-based, lenticular crevasse splay sandstone.

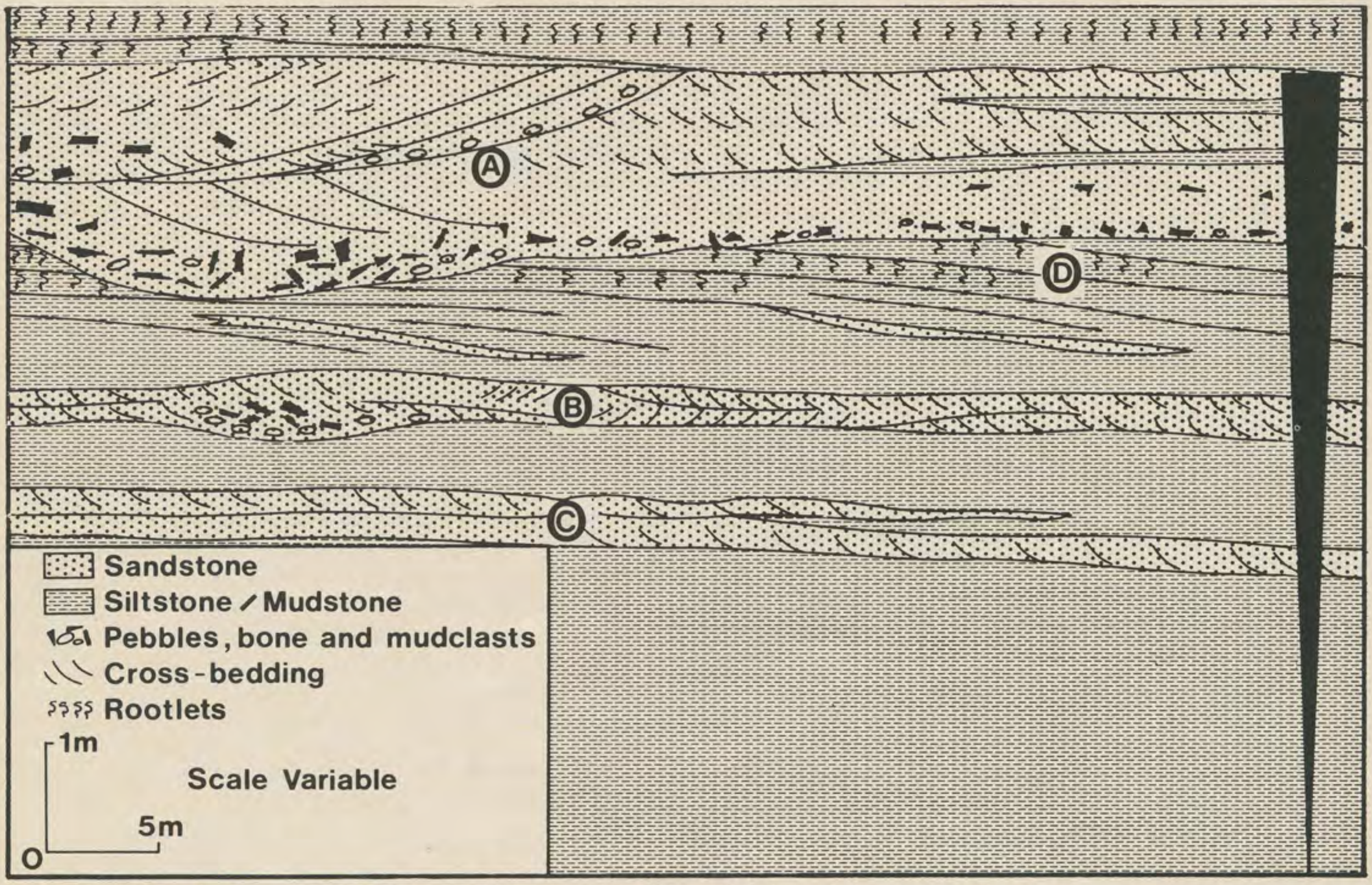


Figure 11. Schematic representation of proximal crevasse lobe (A) eroded through levee (D), with B and C progressively more distal components of crevasse splays.

Figure 12. Soft sediment deformation, including overfolds and microthrusts, in the Beaufort of Transkei.

Penecontemporaneous deformation structures (fig. 12), including water escape features, complex recumbent-folded foresets, convolutions and microthrusts, occur throughout, but are particularly abundant in the braided stream facies. These are possibly to be explained by earth tremors which originated in the orogenic belt, and which generated shock-induced liquefaction (Allen and Banks, 1972). Sediment in this state would have been subject to deformation by diapiric movement of sands with excess pore pressure, by gravity, and by current drag (Hobday *et al.*, in press).

*Meanderbelt and Floodplain Model*

Meanderbelt facies are recognized by a particular sequence in which an erosive base is overlain by a mudflake conglomerate followed by large-scale trough cross-bedded sandstone, small-scale cross-bedded sandstone, plane-bedded sandstone, cross-laminated silty sandstone with climbing ripples, and finally siltstones with rootlets, burrows, mudcracks and concretions. Figure 13 is an idealized portrayal of vertical and lateral relationships. This sequence is ascribed to channel floor, point bar and levee sedimentation.

In some channels rolled *Lystrosaurus* skulls, tusks and extrabasinal pebbles occur in the basal lag. The mudclasts were locally derived (fig. 14), and many channels are incised into fine sediments of a lithology identical to the clasts. Occasional large siltstone slabs were probably derived by slumping of the cutbank. The cross-bedded sequence above records deposition on the inner meander slope, with superimposed megaripples largest near the base of the slope where the velocity was highest. The plane-bedded sandstones resulted from a combination of smaller grain size and increased Froude Number due to shallowing near the channel margin. Structures in the fine-grained sediments above this are typical of point bar top and levee, which were subject to periodic inundation and desiccation, high rates of suspension settling, bioturbation, and soil-forming processes.

Closely associated with the meanderbelt sandstones (fig. 13) are floodplain deposits of maroon to gray-green mudstones and siltstones. Rare articulated tetrapod remains are encountered, along with fish and burrows. Interspersed with the siltstones are crevasse splay sandstones and small channel mouth bars (fig. 15).

*Braided Stream Model*

Thin superimposed and overlapping channel sandstones ranging in thickness between 0,5 and 3 metres, with an average of about one metre, occur in thick successions of over 100 metres. As illustrated

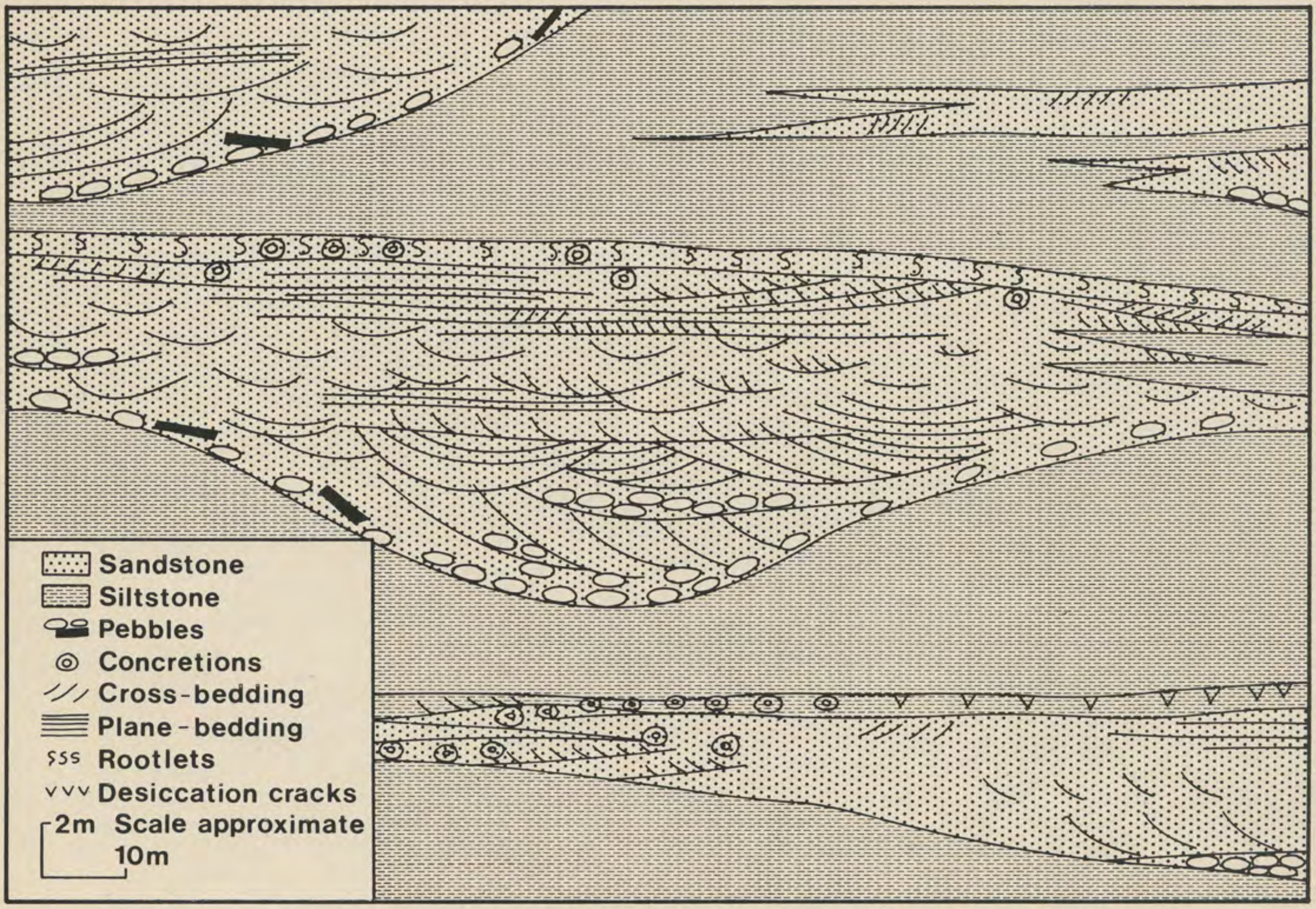


Figure 13. Schematic illustration of relationships between meanderbelt and floodplain deposits, Transkei.

Figure 14. Interlaminated sandstone and siltstone of the levee subfacies overlain by channel sandstone with locally-eroded mudclasts and large-scale cross-bedding.

Figure 15. Floodplain and lacustrine siltstones containing numerous small crevasse splay sandstones and incipient channel mouth bars.

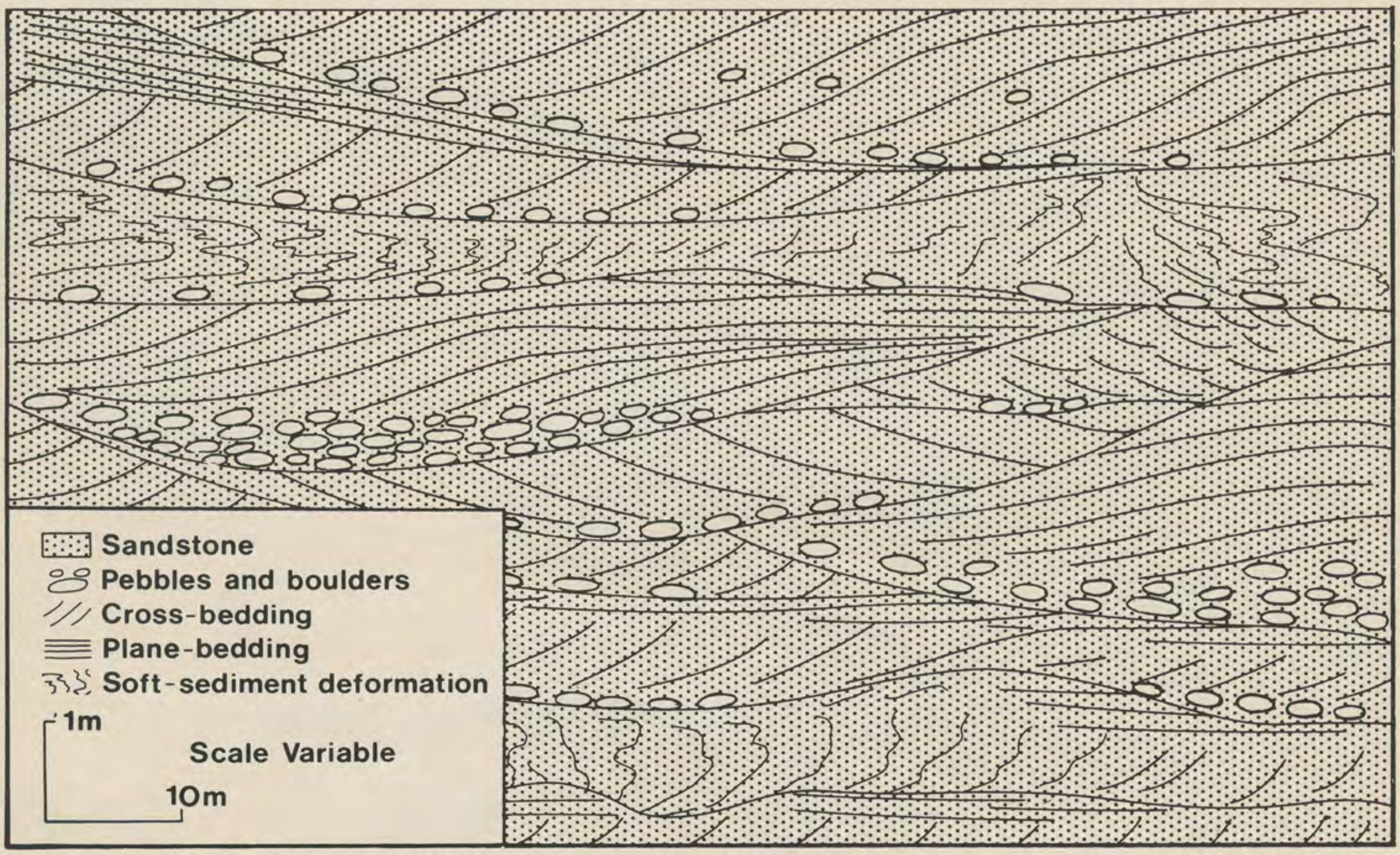


Figure 16. Mutually-erosive, stacked braided stream deposits with conglomeratic base and soft sediment deformation.

in Figure 16, each channel has a truncating base with sporadically distributed clasts similar to those of the meanderbelt channels but somewhat coarser. Above this is a solitary set or coset of planar cross-bedding which merges vertically into plane bedding. A thin siltstone unit at the top is seldom preserved because of erosion by a subsequent channel.

Vertical patterns of this type are common in braided stream environments (e.g. Smith, 1970). The planar cross-bedding probably records downstream braidbar accretion, with plane-bedding developed on the bar top. Siltstones at the top may have accumulated after channel abandonment by overbank sedimentation from an adjacent channel. The relatively uniform grain size of the sandstone, the nature and arrangement of the sedimentary structures and the geometry of the channels together indicate a braided environment characterized by transverse rather than longitudinal bars (Greenshields and Hobday, 1977).

## CONCLUSIONS

The above models of deltaic, channel and beach deposits in the Ecca, and crevasse splays, meanderbelt, floodplain and braided stream facies in the Beaufort represent a preliminary sedimentological contribution towards the reconstruction of the Karoo environmental milieu. These models will certainly be refined as a result of further fieldwork, and the interpretation placed on them may change. Severe testing of the validity of the models will be provided by the biological evidence from plants, spores, pollens and other microfossils, amphibians, reptiles, fish and trace fossils, each field imposing its own constraints.

As the models and their possible variations and combinations become improved the next step will be to clarify the relationships between them, first objectively and then genetically. A difficulty arises here because of incomplete exposure, disruption of strata by dolerites and local faulting and warping. Further problems stem from the difficulty of recognizing time lines, particularly where the degree of environmental control on fossil distribution is not known. Palynology may provide part of the solution (Anderson *et al.,* 1977). Only when these practical difficulties become resolved, and every form of relevant information becomes incorporated, will the overall palaeoenvironmental, palaeoecological and palaeogeographical synthesis emerge.

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