

CHAPTER 6

GENERALIZED SUMMARY SECTION

Figure 51 summarizes, diagrammatically, vertical distribution of the sedimentary structures, lithological variation, and fossils in the stratigraphic interval studied in this report. The generalized section is synthesized from data collected from the various highwalls of the open cuts.

It is clear that there are at least two areas of gross facies contrast present within the large scale crossbed-set in the area over which the set is exposed by the open cut mines:

6.1 SOUTHERN AREA (HOWICK OPEN CUT AREA)

At the Howick Open Cut the lithology of the inclined strata is homogenous (dominantly fine-to-medium sandstone, Table 4, Fig. 51). The concentration of organic material into discrete lenticular bodies was observed only at this open cut. The presence of many (in most cases demonstrably in situ) fossil logs, upright with respect to the large scale crossbeds and the top surface of the main Liddell Coal Seam, is observed at Howick only; the presence of many flat-lying fossil logs within the basal unit of the first 3 m of the large-scale crossbeds above the main Liddell Coal Seam is observed only in this area. Small-scale coal flexures and coal fishtails (Raistrick and Marshall, 1939) were seen only at the upper bounding surface of the Liddell Coal Seam and the overlying inclined bedding structure at the Howick Open Cut. The geometry of the inclined strata differs, too, from that developed elsewhere in the area: the strata are dominantly straight with short, flexed upper and lower segments - asymptotic to the upper and lower bracketing stratigraphic units, and the overall angle of inclination of the strata is smaller than that displayed in the other open cuts (Figs. 24 and 25).

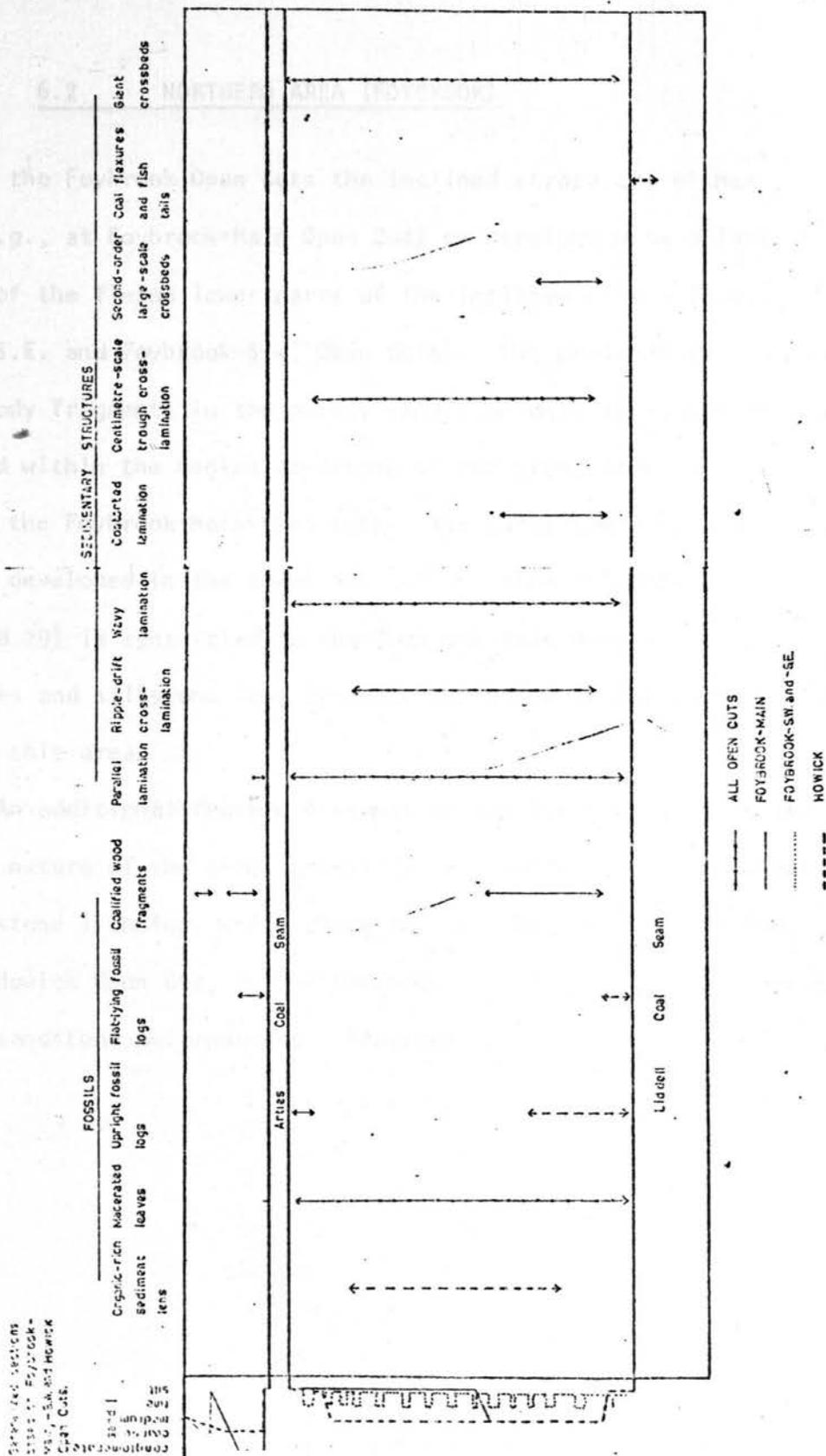


FIGURE 51: Generalized section of the stratigraphic interval studied in this report. The vertical arrows are keyed to each of the different open cuts. The length of the vertical arrow indicates the stratigraphic distribution of each of the features designated.

6.2 NORTHERN AREA (FOYBROOK)

In the Foybrook Open Cuts the inclined strata are either sigmoidal (e.g., at Foybrook-Main Open Cut) or straight with a larger development of the flexed lower parts of the inclined strata (e.g., at Foybrook-S.E. and Foybrook-S.W. Open Cuts). The presence of coalified woody fragments in the pebbly sandstone unit above the Arties Coal Seam and within the medium sandstone of the giant crossbeds is seen only in the Foybrook-Main Open Cuts. The large scale composite crossbedding developed in the lower part of the giant crossbed set (Figs. 28 and 29) is restricted to the Foybrook-Main Open Cuts. Calcareous shales and siltstone form discrete and quite laterally-extensive beds only in this area.

An additional feature distinct to the Foybrook area is the heterolithic nature of the giant crossbeds. In contrast to the rather uniform sandstone lithology which characterizes the crossbeds in the area of the Howick Open Cut, in the Foybrook area the crossbeds comprise interbedded sandstone and mudrocks (siltstone and shales).

C H A P T E R 7

INTERPRETATION OF THE INCLINED STRATA AS PRODUCTS
OF MOBILE DIFFERENTIAL COMPACTION

There are no indications that the expectations of Britten's mobile differential compaction model (outlined in Chapter 3) accord with the field evidence gathered during the present study, viz:-

(1) there is no evidence for soft-sediment deformation save for very isolated examples of syn-depositional disruption developed on a scale of centimetres (Fig. 39). Disruption to primary bedding structure on a larger scale is everywhere absent including at the coal-split zone (Fig. 8) in the Foybrook-Main Open Cut (North) where, according to Britten's model, bedding should have undergone the largest amounts of disruption and rotation. Sedimentary injection structures are absent except for small scale coal fish-tails and coal flexures at the interface of the Liddell Coal Seam and the overlying sediments at Howick Open Cut. Faulting is minimal, affects the rocks in a brittle style and is therefore evidently post-lithification (Panorama P3a) and the only structures that could be mistaken for folds are the composite large scale intraset bedding structures (Figs. 28 and 29), developed in the Foybrook-Main Open Cut (discussed earlier).

(2) The regional facies change observed between the area of the Howick Open Cut and the Foybrook area (discussed in the previous chapter) does not exhibit the interplay of lithology and geometry that one might expect to be developed in a sedimentary complex of fluvial origin (e.g., association of channel-like sandstone bodies with encompassing sheet-like units of mudstone). Given the south-to-north lithological gradation from sandstone (at Howick) to shale (at Foybrook-

S.W., Foybrook-Box and Foybrook S.E. Open Cuts) to mixed sandstone/shale (at Foybrook-Main Open Cut), the south-to-north coarse-to-fine/proximal-to-distal facies change expected in a fluvial environment that is advancing to the north (as envisaged by Britten's model, see Fig. 15) is not seen.

(3) Britten's statement about the lateral variation in bed thickness within the fluvial clastic wedges (i.e. systematic lateral decrease in bed thickness normal to the axes of the clastic wedges; see Fig. 16) is not substantiated in the field. However such an interpretation could be seen to be derived from the sigmoidal shape of some of the sandstone and siltstone large scale crossbeds in the Foybrook-Main Open Cut (discussed earlier in the section "Geometry of the Inclined Strata in Dip-Section").

(4) There is no evidence of deformation in the Liddell Coal Seam. The presence of thin undeformed laterally-continuous "dirt bands" (these are almost certainly volcanic ash layers - discussed in Chapter 10) throughout the vertical extent of the Liddell Coal Seam, does not indicate wholesale geometrical rotation or disturbance of this stratigraphic unit during its history of compaction as postulated in Britten's model.

A primary depositional origin for the inclined bedding structure might therefore seem to be more plausible, as already suggested by Booker and others (1953), Booker and McKenzie (1956), Tompkins (1961), Bunny (1967) and Rattigan and McKenzie (in Packham, 1969). Indeed,

consideration of the characteristics of the set of inclined strata suggests it has much in common with the deposits of classical delta systems (Appendix 1, Table A1.1).

CHAPTER 8

CHARACTERISTICS OF DELTA DEPOSITS

Modern deltas occur in diverse environmental settings and are conveniently classified on the basis of hydrological regimen: wave-dominated, tide-dominated, river-dominated marine environments and river-dominated continental (lacustrine) environments (Miall, 1976; see Fig. 52). Consequently the deposits of modern delta systems exhibit great material variation (Table 6) as well as variation in scale. The deposits inferred to have been generated in ancient deltaic systems are recognized by matching characteristics (Table 7).

With modern examples important distinctions exist between the relatively smaller scale deltas which prograde into lacustrine environments and most of the classic large scale deltaic systems which prograde into the oceans and marginal seas (as, for example, the Niger, Orinoco, Mississippi, Nile, Mekong, Rhine etc.). There are two main differences:

- (a) scale
- (b) relative contrast in density between inflowing land-derived water of delta-top streams and that of the standing water body in which the delta occurs.

(a) The scale of the lacustrine delta is relatively small, possibly having an areal extent of up to 1,000 sq kms; but the other deltas commonly measure 1,000 - 10,000 sq. kms or even more. The scale distinction clearly has important implications for studies of ancient deltaic terrains and has been emphasised by several workers in the recent literature. For example, Fisher and others (1969) state "Herein, principally large scale deltas which form as independent depositional systems are considered; not considered are smaller deltas commonly developed as parts of other larger depositional systems

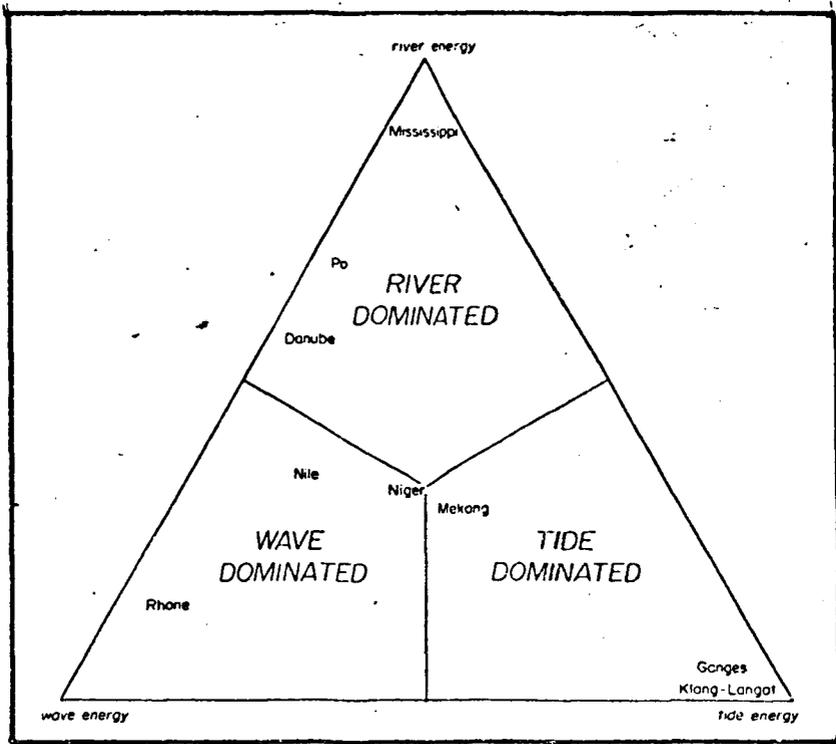


FIGURE 52:

Classification of delta types based on variation in transportation patterns, (the hydrological regimen of the delta, from Miall, 1976; p. 216).

TABLE 6:

GROSS CHARACTERISTICS OF MODERN DELTAS, BASED LARGELY
ON STUDIES OF LARGE SCALE EXAMPLES

DELTA PLAIN FACIES (from Allen, 1965; Born, 1972)

- Sedimentary Structures - even laminations less than 1 cm thick, cross stratified channel sands and point bars.
- Palaeontology - plant shreds, bioturbation, rootlets in situ root mottling, various types of fauna.
- Lithology - fine sands to very coarse channel and point bar deposits, very fine sand and silt in backswamps - marsh and plain deposits.
- Geometry - sheet or intricate network of anastomosing ribbons.

DELTA FRONT FACIES (from Fisher and others, 1969; Coleman and others, 1964; Allen, 1965 and Born, 1972)

- Sedimentary Structures - multidirectional trough cross laminations, wave or current ripples may be found.
- Palaeontology - thin laminations of plant material, wood fragments.
- Lithology - coarse sediments 75% or more is sand size, clays and organics are rare except in the form of occasional clasts and macerated material, respectively.
- Geometry - sheet, wedge 10 - 20 m thick.

PRO-DELTA FACIES (from Fisher and others, 1969)

- Sedimentary Structures - parallel to lenticular laminations are common; some cross laminations and current ripples occur.
- Palaeontology - finely divided plant particles some burrowing activity.
- Lithology - silty to very fine sand, clay
- Geometry - gently sloping into basin of deposition sheet.

TABLE 7:

GROSS CHARACTERISTICS OF INFERRED ANCIENT DELTAIC DEPOSITS

DELTA-PLAIN FACIES - (Defined by Cotter, 1975 but based on data in Dott, 1966; Cotter, 1975; Taylor, 1963; Greensmith, 1965; Laury, 1968 and Born, 1972)

This facies is the most varied of the three, it may be subaerial or subaqueous and within this division there may be such deposits as delta plain, marsh, distributing channel, levee bank or crevasse splay deposits. Consequently the gross characteristics of this facies may be very complex and one studied example will merely represent the development of one certain type of subenvironment. Nonetheless the gross characteristics of some delta plain facies are presented under the subenvironment headings.

Distributary Channels

- Sedimentary Structures - scour and fill, contorted strata, medium to small scale cross stratification, load and clastic intrusion structures.
- Palaeontology - abundant plant material allochthonous and autochthonous.
- Lithology - coarse sandstone fine conglomerate fining upward into siltstone.
- Geometry - thick lenticular beds vertical and lateral bedding characteristics depending on whether deposit was point bar or abandoned channel.

Inter-Distributary Lagoons, Tidal Flats, Swamps and Marsh

- Sedimentary Structures - finely cross laminated sands, ripple marks, minor contorted strata irregular lime sideritic or iron nodules and concretions.
- Palaeontology - burrowing organisms and structures, carbon or fine sediment filled root casts, fireclay, ganisters.
- Lithology - carbonaceous mudstone, fine sandstone, siltstone.
- Geometry - sheet or ribbon-like geometry overlying delta front facies.

TABLE 7 (Continued):

DELTA FRONT FACIES - (Defined by Cotter, 1975; but includes data in Cotter, 1975; Miall 1976; Taylor, 1963; Greensmith, 1965 and Born, 1972)

- Sedimentary Structures - dominantly trough cross lamination, other structures may include ripple laminations, ripple drift cross lamination and some medium scale crossbedding.
- Palaeontology and Palaeocurrents - comminuted plant material, rare biological activity; ripple trends can be directly related to the direction of foresets: the dominant ripple trend is very similar in orientation to the dominant foreset dip direction (Greensmith, 1965).
- Lithology - dominantly sandstone with some occasional interbeds of siltstone; the gross vertical change from pro-delta facies is an increase in grain size of sand and increase in bed thickness.
- Geometry - sheetlike thick development of facies (one example 12 m); sandstones lenticularly bedded 1.3 m to 2.4 m thick which wedge in and out over certain lateral distances.

PRO-DELTA FACIES (Defined by Cotter, 1975; but includes data in Miall, 1976; Taylor, 1963 and Born, 1972)

- Sedimentary Structures - even parallel laminations, ripple laminations ripple drift cross lamination.
- Palaeontology and Palaeocurrents - comminuted plant debris, strong unimodal pattern.
- Lithology - fine sandstone siltstone and shale.
- Geometry - tabular sheet 1.5 m to 3 m thick, in deposits that are overlain by steeply inclined beds, the pro-delta beds sometimes form the toesets (Cotter, 1975).

(e.g. lagoonal, bayhead and tidal deltas, lacustrine Gilbert-type deltas and submarine canyon deltas or fans)." More recently, Busch (in Le Blanc, 1975) pointed out that "Gilbert's tripartite subdivision of deltaic sediments (topset, foreset and bottomset) was a result of deposition in quiet bodies of water (lakes); and he recognized that this type of delta structure was not characteristic of deltas developed in marine environments."

(b) Lacustrine deltas are usually freshwater (disregarding hypersaline lakes), and therefore lack water-density contrasts between the inflowing and standing body of water, the larger deltaic systems prograde into a marine environment and are therefore characterized by contrasts in water density. Studies in modern deltas show that this relative contrast in water density exerts an important influence on the distances that sediment is transported beyond the delta-top margin and this, in turn, together with sediment grain size and pro-delta water depth, determines the areal development (width) and slope gradient of the delta-front zone.

The relative width and surface relief (height and slope-gradient) of the delta-front zone can be expected, in turn, to influence the internal structure of the delta sediment pile as reflected particularly in the presence of large scale foreset beds merging respectively upwards and downwards with less steeply inclined deposits of the topsets and bottomsets. In most larger scale marine delta settings, the relatively high-density contrast between the saline standing water and incoming

fresh water leads to epihalassism (flotation of sediment-laden fresh water atop the more dense marine water) and therefore to wide shallowly-inclined delta front zones of fine grained sediment. It therefore follows, together with the regional-scale dimensions of these large marine deltas, that the topset/foreset/bottomset internal geometry that might be generated would not be sufficiently distinctive to be evident in any single large scale vertical exposure.

In relatively small scale lacustrine deltas the water-density contrast is usually small and mean grain size fed into the delta is commonly rather high because of locally steep stream gradients and common proximity of high relief terrain. These circumstances (together with the relatively shallow water depths) lead to rapid mixing of the stream water with the lake water and to rapid sediment dumping at the edge of the delta-top. This, in turn, leads to relatively narrow steep delta front zones with high slope angles that approach the repose angles of the constituent sediment (Bates, 1953; Carrigy, 1970; Fig. 53). Such delta deposits are characterized by the presence of relatively steep coarse-to-fine grained foresets merging upward and downward respectively with less steeply-inclined fine-grained topsets and commonly coarser grained flat-lying topsets. This tripartite structure of the smaller scale deltas was first recognized by G.K. Gilbert (1885, 1890; Figs. 54 and 55) and documented with classical examples from Pleistocene Lake Bonneville, Utah - ancestor to the modern Great Salt Lake (Fig. 56). This type of relatively small scale delta has since

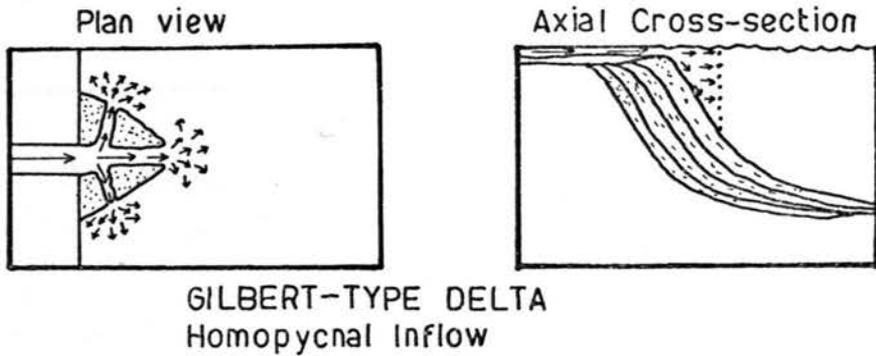


FIGURE 53:

Schematic diagram of homopycnal inflow into a basin and the subsequent deltaic deposit.
 "Homopycnal inflow can best take place where a river flows into a well mixed lake having a water temperature about the same as that of the river ... Under such conditions three dimensional mixing permits deposition to take place immediately off each stream mouth" (Bates, 1953; pp. 2131-2132; the Figure comes from the same paper, p. 2124).

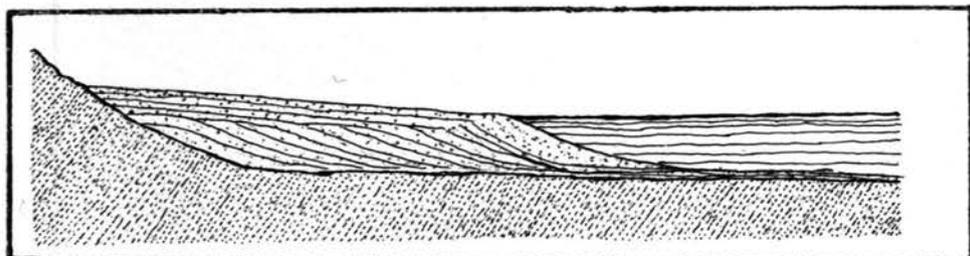


FIGURE 54: Hypothetical section of delta based on field observations during the study of the Logan Delta, Utah. The section shows clearly the tripartite geometry of the inclined strata forming the topsets, the foresets and the bottom-sets (from Gilbert, 1890, p. 68).

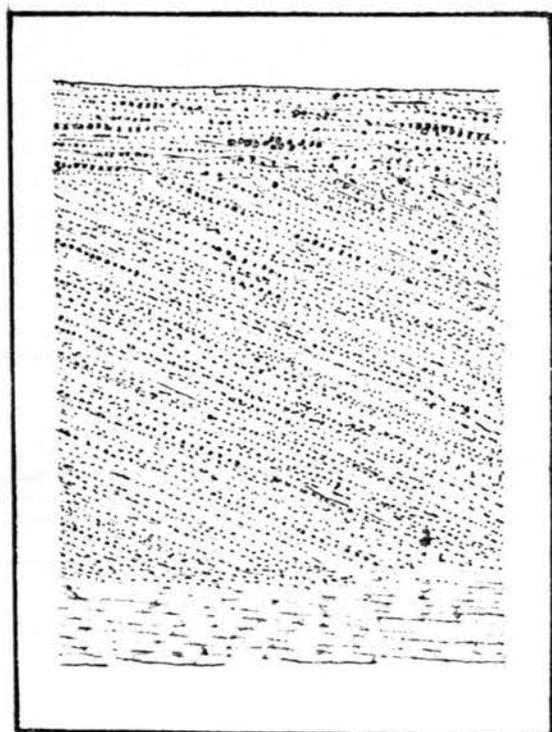


FIGURE 55: Hypothetical vertical section in a delta showing the typical succession of strata. The topmost sub-horizontal strata are termed the topsets, the steeply inclined strata are termed the foresets and the bottom-most sub-horizontal strata are termed the toesets. (From Gilbert, 1890, p. 70).

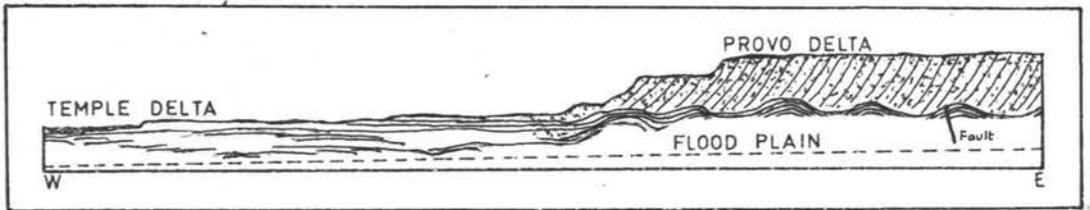


FIGURE 56: Partial section of deltas at Logan, Utah; figured in Gilbert (1890). The vertical scale is greater than the horizontal scale.

become known as "the Gilbert-type" delta. In describing the Lake Bonneville relic deltas Gilbert elaborated upon the sedimentary mechanics that could be reliably reconstructed from these examples and stressed the fact that the delta must have grown outwards into quiet bodies of standing water because redistribution of the sediment dumped by the delta-top distributary streams was evidently not reworked by the lake waters subsequent to its deposition.

8.1 THE GILBERT-TYPE DELTA

G.K. Gilbert's reports (1885, 1890) are now considered to be classical geological studies of deltaic deposits and sedimentation. His work centred around Pleistocene Lake Bonneville, Utah, U.S.A. and it is in this area that he documented for the first time deltaic deposits in the vertical and lateral aspects. His study showed that when clastic detritus had reached the lake margin, deposition of that detritus occurred in several distinctive morphological and spatial patterns:

- (1) The heavier and coarser load is deposited into the lake, and slides down the face of the delta under its own weight.
- (2) The slope of the delta face reflects the angle of repose of the coarse material - subject to modification by waves generated by winds.
- (3) The finer material is carried further out beyond the delta face. The thickness of this deposit of finer

material is greater near the delta and diminishes gradually outward distal to the delta system.

Gilbert describes the deltaic structure that he saw: "As the delta is built lakeward, the steeply inclined layers of the delta face are superimposed over the more level strata of the lake bottom and, in turn come to support the gently inclined layers of the delta plain, so that any vertical section of a normal delta exhibits at the top a zone of coarse material, the laminations of which incline at a high angle, and at bottom a zone of fine material, the laminations of which are gently inclined and unite by curves with those of the middle zone [Fig. 56].

The characters of a fossil delta or the delta as it exists after the dessication of the lake concerned in its formation, are as follows: the upper surface is a terrace with the form of an alluvial fan. The lower slope or face is steep, ranging from 10° to 25° ; it joins the upper slope by an angle and the plain below by a gentle curve ... The structure as seen in section is tripartite. In the upper division the lines of deposition are parallel to the upper surface of the delta; in the middle division they are parallel to the steeper outer face, and in the lower division they are gently inclined. The separation of the middle division from the lower is obscure. Its separation from the upper is definite and constitutes a horizontal plane." Gilbert (in Axelsson, 1967, p. 36; Figs. 54 and 55).

C H A P T E R 9

INTERPRETATION OF THE INCLINED STRATA AS DEPOSITS
OF A GILBERT-TYPE DELTA

9.1 CRITERIA FOR RECOGNITION OF GILBERT-TYPE
DELTA DEPOSITS

Having looked at the Gilbert-type delta specifically as a possible environmental analogue for the formation of the large scale inclined beds studied in this report, it is important that the criteria regarded as diagnostic of the deposits of Gilbert-type deltas are emphasized. A survey of known and inferred examples of Gilbert-type deltas (Appendix 1, Table A1.1) suggests the following criteria to be important:

- (1) Grouping in vertical section of the large scale inclined beds is commonly solitary.
- (2) The set thickness of the crossbeds is predominantly very large scale - averaging about 20 m but with a range of 1.5 m to 40 m in the various studies.
- (3) The gross three-dimensional geometry of the large scale cross-stratified set is sheet-like.
- (4) The gross configuration of the lower bounding surface of the large scale crossbed set is planar suggesting no significant erosion or scour at this interface.
- (5) The gross relationship between the lower bounding surface of the crossbed set and stratification in the underlying sediment is sharply defined and grossly concordant with this stratification suggesting no significant erosion at this contact.
- (6) The contact relationship between the large scale cross-strata and the lower bounding surface of the set (as seen

in dip-section) is asymptotic and depending on the degree of asymptoticity it may be grossly concordant or grossly discordant.

(7) The gross configuration of the upper bounding surface of the set is planar.

(8) The contact relationship between the cross-strata and the upper bounding surface is generally discordant.

(9) The gross configuration of the cross-strata in vertical section (parallel to dip) ranges from straight with flexed concave-up toesets to dominantly curvi-linear concave-up.

(10) The angle of inclination of the large scale cross-strata ranges predominantly between 15° to 25° and shows a direct relationship with mean grain size.

(11) The gross configuration of the cross-strata traces in plan-view (whether continuous or discontinuous, regular or irregular) is generally convex towards the direction of foreset dip.

(12) The degree of lithological uniformity of cross-strata is quite varied - some sets in certain studies are homogenous whereas sets in other studies are heterogenous.

(13) The sedimentary structures within the large scale cross-strata are varied but predominant types are: parallel laminations; subordinate amounts of trough- and planar cross

lamination; ripple-drift cross-lamination as well as occasional decimetre-scale trough-shaped intrasets whose trough axes indicate currents predominantly down-dip or oblique-to-dip relative to the foreset face.

(14) Fossils are generally freshwater: abundant comminuted terrestrial leaves, and various freshwater organisms.

9.2 INTERPRETATION OF THE LARGE SCALE INCLINED STRATA OF THE STUDY AREA AS DEPOSITS OF A GILBERT-TYPE DELTA

If the criteria for the recognition of Gilbert-type deltas and the unusual features of the large scale inclined beds of the Foybrook-Liddell-Howick area are compared, the large scale crossbed-set is seen to exhibit all the above features regarded as consistent with a primary deltaic origin.

- (1) The large scale crossbed-set is solitary.
- (2) The scale of crossbed-set ranges between 35 m and 48 m.
- (3) The three-dimensional regional geometry of the crossbed-set (its external form) is essentially sheet-like.
- (4) The gross configuration of the lower bounding surface of the crossbed-set is planar and sharply defined.
- (5) The gross relationship between the lower bounding surface of the crossbed-set and stratification in the underlying sediment is grossly asymptotic to concordant.
- (6) The contact relationship between the cross-strata and

the lower bounding surface of the inclined bedding structure (as seen in dip-section) is asymptotic and concordant.

(7) The gross configuration of upper bounding surface of the inclined bedding structure is planar.

(8) The contact relationship between the inclined bedding structure and the upper bounding surface is concordant.

(9) The gross configuration of the inclined strata within the bedding structure parallel to dip is: curvi-linear concave-up, straight with flexed concave-up bottom portions and sigmoidal or S-shaped.

(10) The angle of inclination of the strata ranges between 6° to 44° but the average is around 20° .

(11) The gross configuration of the inclined bedding structure is locally irregular but generally convex in direction of dip.

(12) The degree of lithological uniformity of the inclined bedding structure varies; at Howick Open Cut it is homogenous, whereas at the Foybrook area it is heterogenous.

(13) There are abundant wavy and parallel laminations, in addition there are also common centimetre and decimetre scale cross laminations, trough cross laminations and less common ripple drift cross laminations within the inclined strata. There are also second-order large scale cross strata as intrasets within the inclined bedding structure (Figs.

28 and 29).

(14) The dominant type of fossil is non-marine plant material: comminuted, plant fragments, stems, trunks and flat-lying and in situ logs.

In addition to the very close agreement between the features of the large scale crossbeds (the term "crossbeds" now implicitly implies a primary depositional origin) and the diagnostic characteristics of Gilbert-type delta deposits, most of the inherent predictions to follow on from this primary depositional model, that were proposed in Chapter 3, are fulfilled - in contrast to the predictions that might be expected to arise from the mobile differential compaction model.

(1) There is a systematic and relative geometric relationship between current produced structures within the master crossbeds and the master crossbeds themselves.

(2) The petrographic analysis of coal samples was inconclusive - a further very detailed study concentrated immediately at the coal seam-split at Foybrock-Main (North) may produce better results.

(3) Geopetal evidence demonstrating that bedding is primary was found:

(a) in situ tree stumps that projected upwards from the underlying siltstone unit into the crossbeds did retain a right angle relationship to the lower bounding surface of the crossbed set.

(b) there is a systematic relationship between bulk

lithology and angle of repose (divergence) of the crossbeds (Figs. 26 and 27).

The significance of the relationship that exists between the palaeocurrent indicators (i.e., the small scale traction structures) and the inclination of the master crossbeds (Figs. 49 and 50) is readily apparent when one examines the types of water currents that may be generated in a deltaic complex. Such studies have been carried out by Nevin and Trainer, 1927; Jopling, 1963, 1964, 1965; Collinson, 1968 and Church and Gilbert, 1975. The primary current in a delta complex is the 'jetting-flow' which deposits the bulk of the sediment in the form of large scale foresets over the margin of the delta-top facies. In addition to 'jetting-flow' there are secondary eddy circulations whose axes may be in a vertical or horizontal orientation (see Fig. 57). The secondary eddy circulations are, in effect, the interference patterns which arise as a result of the 'jetting-flow' entering the standing body of water. The decimetre and centimetre scale traction structures (see Table 5) can be explained as a result of an interplay between the 'jetting flow' and the standing body of water. These secondary circulation eddies that exist in the delta-front zone rework, to a certain extent, the deposits of the large scale crossbeds; this activity is recorded as small scale traction structures which trend up-dip, down-dip, and oblique-to-dip with respect to the large-scale crossbeds themselves. The orientation with respect to the dip-azimuth of the large-scale crossbeds of the flat-lying fossil logs has as similar a significance as the orientation of the traction structures with respect to the crossbed. The dominantly perpendicular orientation of the long-axis of fossil logs at Howick Open Cut and the approximately parallel

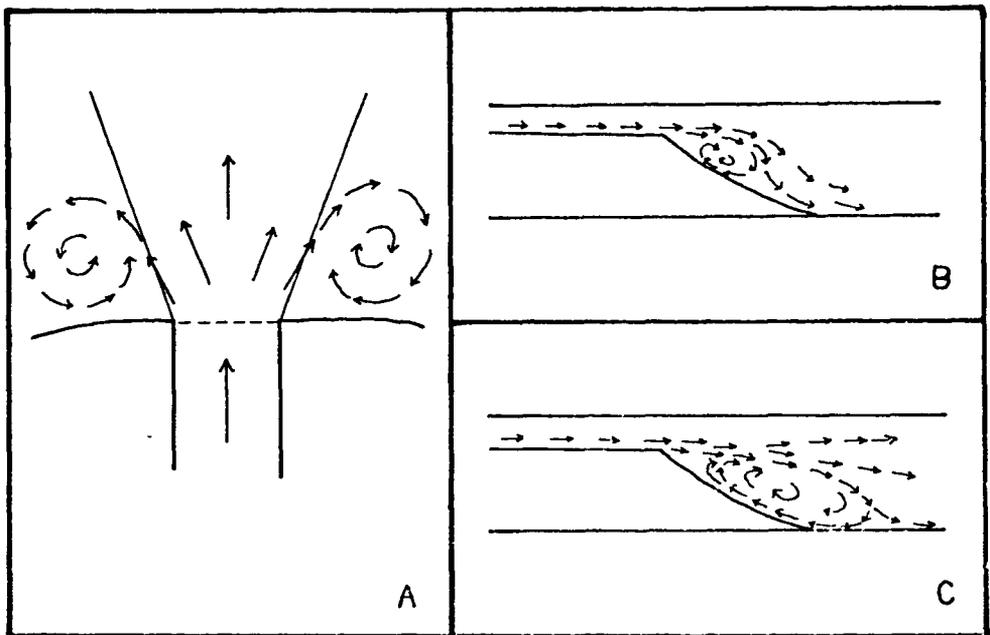


FIGURE 57:

Schematic diagrams of the separation vortices of eddies which may be developed in front of a channel flowing into a body of standing water when the density contrast between the inflowing water and the basinal water is very low. A. shows in plan view, eddies with vertical axes on either side of the mouth. B. shows the vertical section of eddies with horizontal axes with the locus of zero velocity impinging high on the slope. For a given density relationship, high influx velocity and low basinal water depth will tend to favour the development of the situation in C. Collinson (1968) does not give any quantitative figures for the phrase 'low basinal water'. (Figure 57 is from Collinson, 1968, p. 249.

orientation of the long-axis of fossil logs at the Foybrook area (see Figs. 48, 49 and 50) can be explained by the dominance of different types of eddy cells that existed in the delta-front zone at the time of deposition of the fossil logs.

Despite the lack of evidence for the presence of different coal facies on the delta-front slope, as predicted in Chapter 3, the similarity of the internal geometry of the Lower Arties Coal Seam (as defined by dirt bands; see Fig. 8) to the internal geometry of the large scale crossbeds of inorganic material, in dip-section, tends to suggest that the genesis of the two types of deposits (i.e. the inorganic and the organic) is very similar.

If there was any mobile differential compaction of the underlying coal seam and the overlying crossbed set then one would expect that the upright fossil tree stumps within the crossbed set to have undergone the same angle of rotation as the crossbeds themselves. The fact that one finds tree stumps vertical with respect to the crossbeds and the upper bounding surface of the underlying coal seam tends to suggest that there has been no secondary rotation or differential compaction of the enclosing strata and that the large scale inclined strata are indeed primary depositional crossbeds.

C H A P T E R 10

AN ENVIRONMENTAL MODEL FOR THE LARGE SCALE
HETEROLITHIC CROSSBEDS

If one envisages a forested coal-forming environment (producing an autochthonous coal) with all the surface irregularities that one finds on the forest floor, then the presence of very extensive lateral and uniform thinly bedded dirt bands (observed to be no greater than 20 cm thick) presents an intriguing problem. These dirt bands seem likely to be the deposits from volcanic activity that was prevalent during the Permian coal-forming time (Leitch, 1969). Because of the manner of aerial fall-out of ash, a blanket of deposits would cover the entire surface. Consequently one would expect to see at least an irregular lower bounding surface between the dirt band and the underlying peat. But this is not what one sees in the field. One sees, as already mentioned (Table 3), uniformly thin and laterally continuous (in the order of 100 metres) dirt bands that rarely develop great thicknesses with upper and lower straight and abrupt bounding surfaces (Figs. 22, 24 and 25). It is most likely that these dirt bands represent a moment in geological time. The volcanic detritus most likely fell in a standing body of water that was accumulating exclusively organic debris. Duff (1967) discussing a floating peat island environment suggests that "Growth of peat from decaying vegetation takes place with the base of the peat sinking downwards owing to the weight of waterlogged material above." This would account for the lack of seat-earths (Duff, 1967) and would also account for the geometry and shape of the dirt bands, because if the accumulation of peat is essentially a suspension fallout of organic fragments and particles (as suggested by Duff, 1967) then the resultant depositional surface for the dirt bands will be quite regular and planar. As the ash fall represents but a moment in geological time "banded" deposition of organic/inorganic material is not incompatible. The ash fall would merely record a volcanic eruption without unduly interrupting

the deposition of peat-forming organic detritus.

The fact that one sees no evidence of any deformation in the coal or its associated dirt bands tends to suggest that the peat compacted under its own weight, creating a regular planar surface for subsequent deposition of inorganic sediments or organic material forming peat (Fig. 58A). The introduction of clastic material would inhibit peat formation and its weight tend to cause slight compaction of the already accumulated peat. It is suggested that the 3 to 5 m thick bed of siltstone which is found to directly overlie the coal seam and underlie the crossbed-set (Figs. 22 and 24) is a prodelta deposit of fine sediment that was laid down largely from suspension (Figs. 58B and 59). The siltstone deposit just mentioned probably represents the hiatus between peat accumulation and the deposition of clastic deltaic sediment in the form of large scale crossbeds, which were deposited into a totally subaqueous environment. (The author suggests a totally subaqueous environment because no evidence of subaerial or aerial reworking of the crossbed-set was found). The incoming crossbeds (shown in Fig. 8 at the junction of the coal seam-split) have affected little the geometry and shape of the underlying coal seam (Fig. 58C). If there had been a large amount of compaction of the coal due to the overlying clastic material then one would expect to see quite a change in the geometry of the coal in addition to obvious differential compaction at the very point of the coal seam-split.

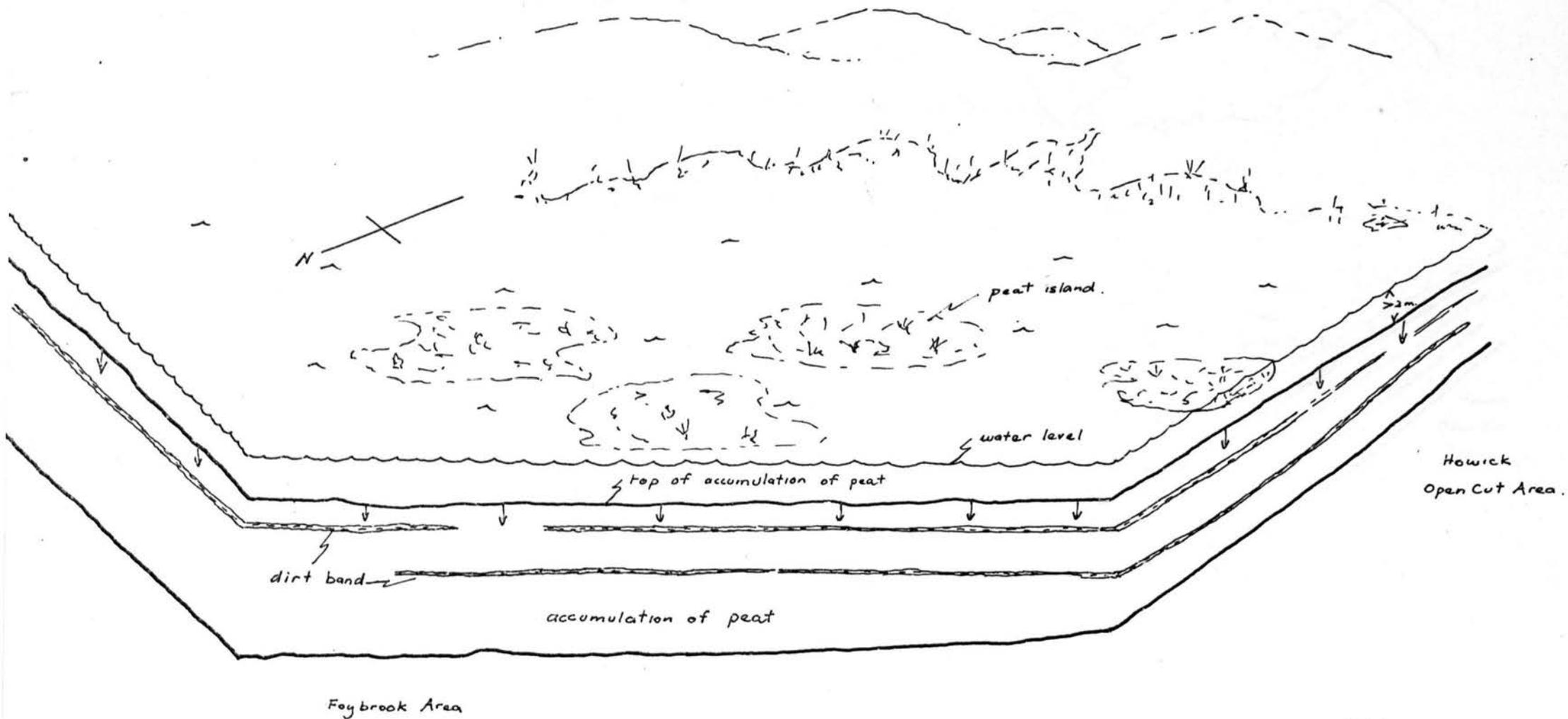
In situ fossil tree stumps vertical with respect to the master crossbeds and to the upper bounding surface of the main Liddell Coal Seam, together with the prevalence of flat-lying logs within the siltstone unit (Figs. 43, 44 and 45) indicate that there was in the Howick Open Cut area a localised phase of plant growth before the deposition of the

crossbeds (Fig. 58B). It is suggested by the author that this phase of tree growth took place in the hiatus between the final accumulation of plant material forming the thick peat deposits (largely allochthonous) and the rise in water level (which would have killed the trees) accompanying the influx of clastic material (Fig. 58C).

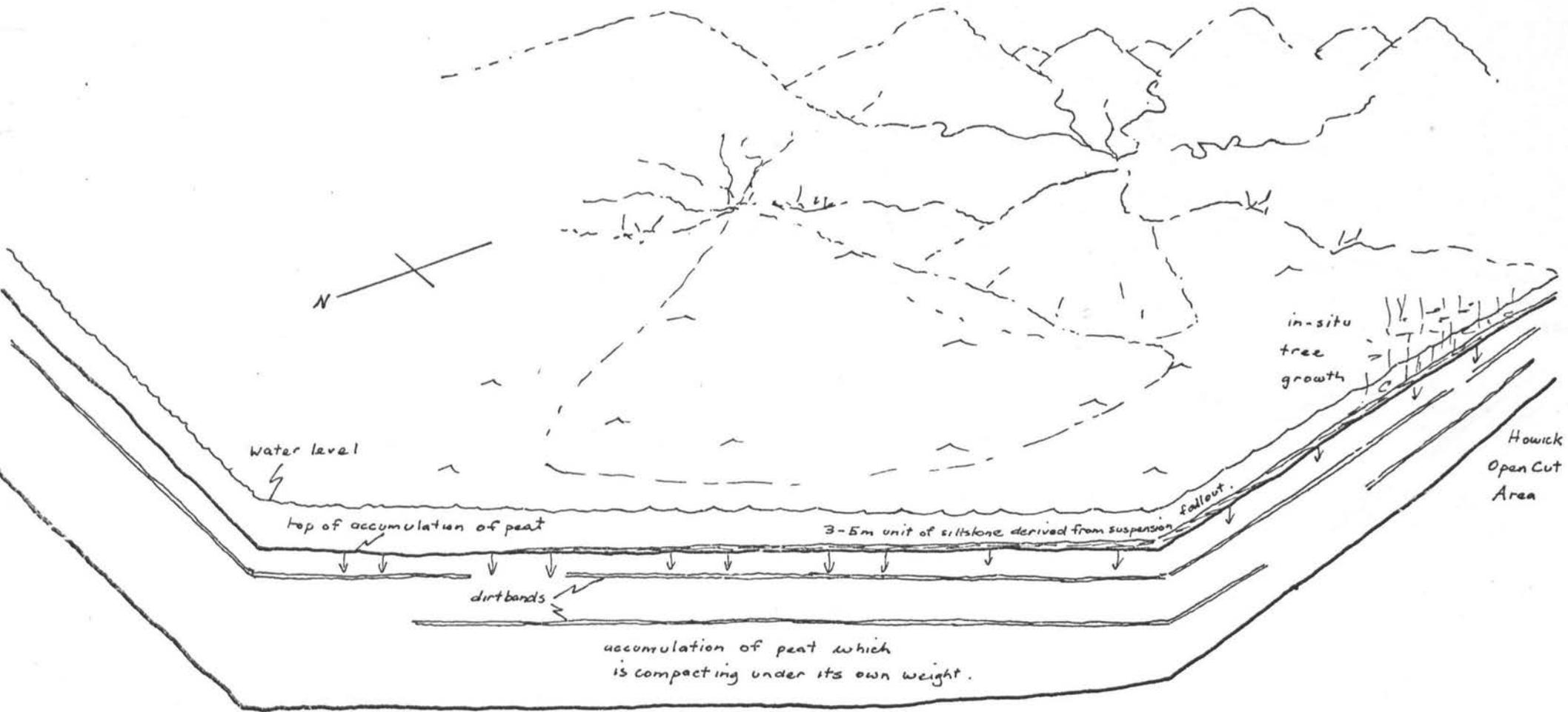
The Arties Coal Seam forming the upper bracketing unit of the crossbed-set represents a cessation of clastic influx and a regeneration of a peat-forming environment. The presence of upright and in situ fossil logs just below the Arties Coal Seam (at Foybrook-Main (South); Fig. 42) indicates that the deltaic deposits in the form of large scale crossbeds are no longer as dominant as the time when they were actively prograding into the depositional basin. The Arties Coal Seam represents the final accumulation in the delta of this region - it is taken to be the delta-plain facies (Figs. 58D and 59). The overlying pebbly sandstone unit is interpreted as a fluvial facies that prograded over the last stages of the delta-top facies (Figs. 58F and 59). The delta conditions in this area may then have ceased to exist at all or it may have switched into another unknown but subsiding area.

The Arties Coal Seam was deposited on top of the deltaic crossbeds and hence the seam reflects the different types of primary depositional slopes found in the delta crossbed complex. In areas where the topset geometry of the crossbeds had developed the peat (which was to form the Lower Arties Coal Seam) will have accumulated on essentially horizontal - or at least very low angle surfaces. But where the relic surface of the delta is steeply inclined as at the foreset (and less steeply inclined at the toset) of the delta, then the peat will have accumulated in conformity with this relic surface: - in fact, the geometry of the internal bands of coal within the Lower Arties Seam (con-

verging onto the main Liddell Coal Seam at Foybrook-Main (North) Open Cut) is in no way significantly different from the geometry of the underlying clastic material (Fig. 8). The internal geometry of the inclined coal ply suggests to the author that the ply is a primary depositional feature.



58A
not to scale



Water level

top of accumulation of peat

dirtbands

accumulation of peat which
is compacting under its own weight.

3-5m unit of siltstone derived from suspension

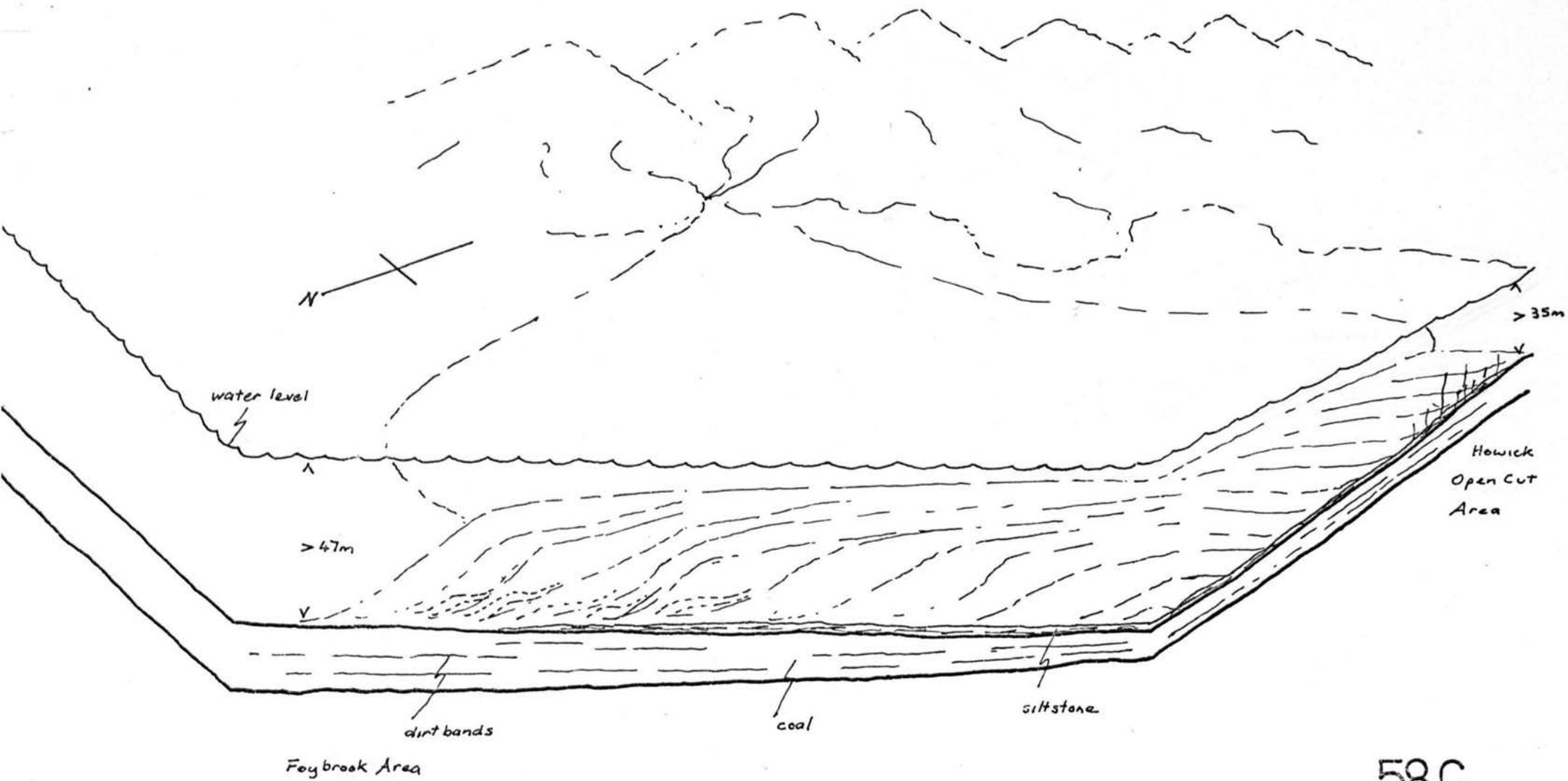
fallout.

in-situ
tree
growth

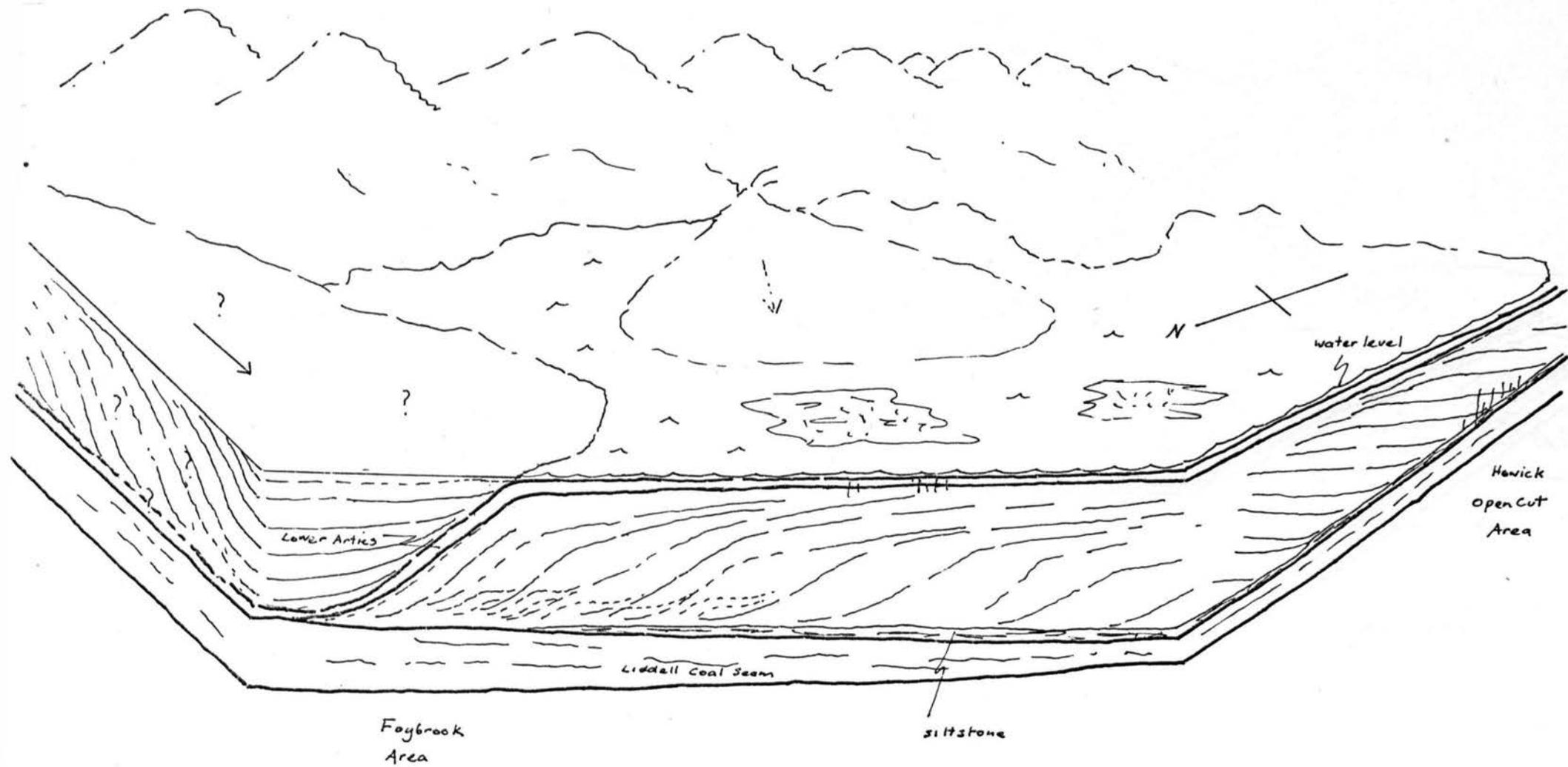
Howick
Open Cut
Area

Foybrook Area.

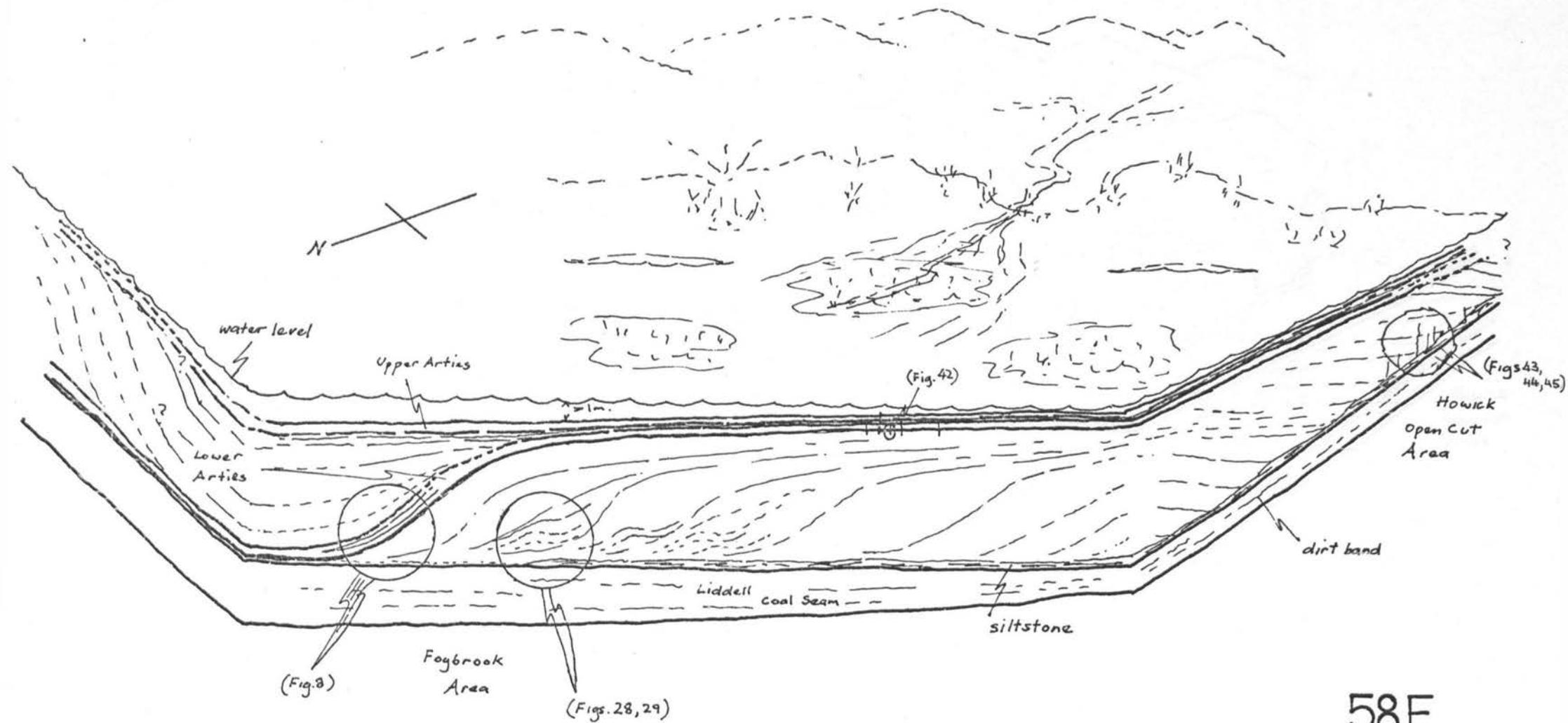
58B
not to scale.



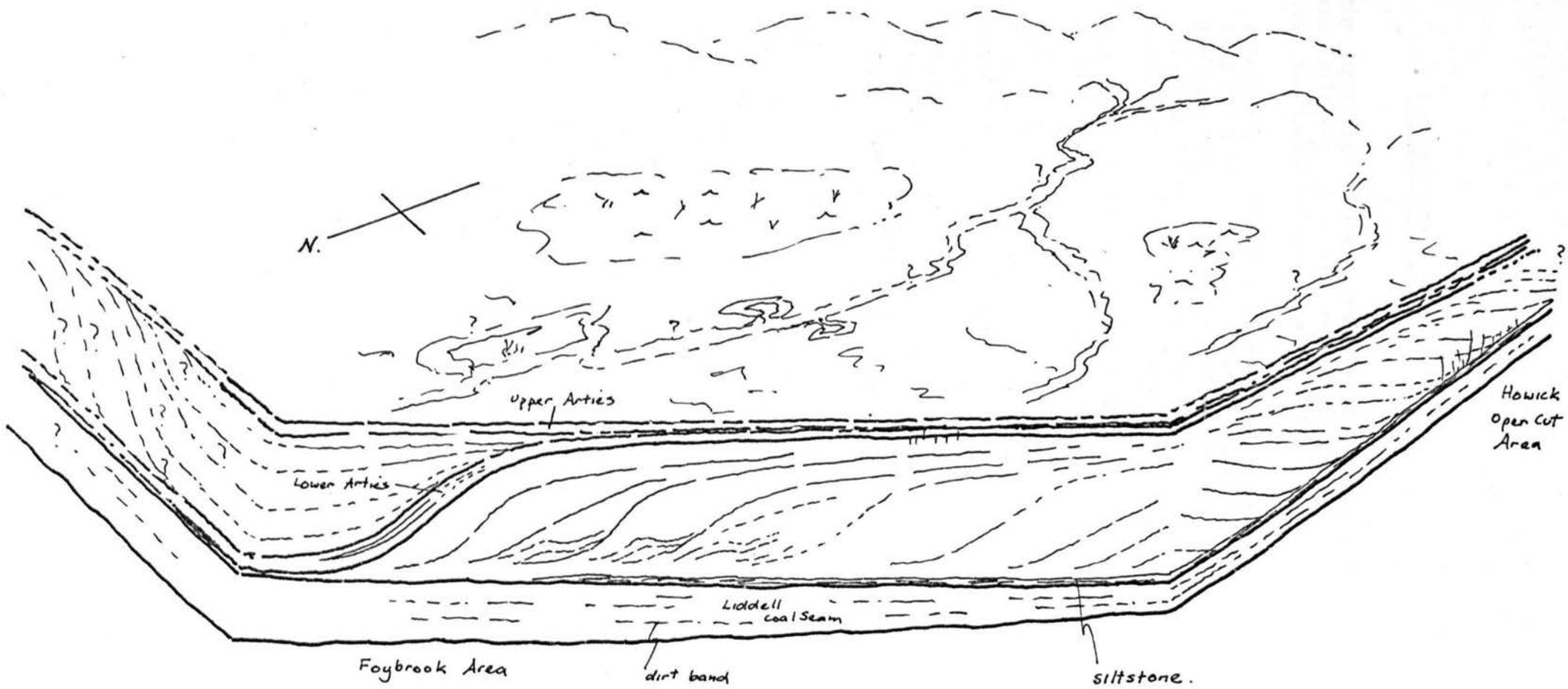
58C
not to scale.



58D
not to scale



58E
 not to scale.



58 F
not to scale.

FIGURES 58A TO 58F:

A model for the deposition of the deltaic large scale crossbeds is depicted in the following set of figures. (Note that the distance between Foybrook and Howick is approximately 8 km.)

- 58A: Deposition of peat (suggested to be largely allochthonous) in a relatively shallow lacustrine environment. Within the coal there are deposits of laterally extensive but thin beds of dirt bands (or volcanic ash bands; see Chapter 10). The peat compacts under its own weight.
- 58B: The coal forming environment has ceased with the introduction of siltstone and shale which was most likely deposited out of suspension from the standing body of water. The area to the northeast and east is uplifted in response to movement along the Hebden Thrust or the Hunter Thrust. This movement could account for subsidence of the depositional basin and/or a rise in water level. Before the movement along and adjacent to these fault systems had affected the surrounding areas too greatly, a localised environment around Howick Open Cut was able to support the growth of trees. The rising water level or sinking peat accumulation subsequently caused any further growth to cease. Note that, in response to the activity of structural elements to the north and northeast the proximal part of the depositional basin (i.e. to the north) probably underwent more active subsidence than the southwestern area; this would help account for the grossly thinning nature of the crossbed set to the southwest (Fig. 18).
- 58C: Deltaic deposits in the form of bottomsets, foresets and topsets are deposited into the subsiding basin (the subsidence is probably due more to tectonic activity than differential compaction of the peat; see Chapter 10). These deposits are laid down in an instant in geological time: - they have engulfed the upright trees at Howick Open Cut. The most likely sediment source for these deposits is the newly risen land to the northeast and north - along the Hebden and Hunter Thrusts.
- 58D: The Lower Arties Seam represents a cessation of active progradation of this particular delta. It is quite possible that a delta lobe from another direction (suggested, in this Figure, to come from a more northerly direction than the previous one) created an embayment which was to another peat forming environment. Before the second delta had reached the Foybrook area, the peat generated in the embayment had draped the first delta-front deposits. The peat is then overlain by the second delta which soon ceases to exist as that part of the basin has been infilled.

FIGURES 58A TO 58F (Continued)

- 58E: The environment then once again became a more stable one - the high land forms to the north have probably been eroded to such an extent as to allow more peat-forming conditions to exist. The Upper Arties Seam is then deposited blanketing both delta lobes.
- 58F: Deposition of a coarse pebbly sand from a fluvial system with overbank and swamp silts then covers the Upper Arties Seam in both the Foybrook and Howick Open Cut areas. The palaeocurrent trend of this system is questionable.

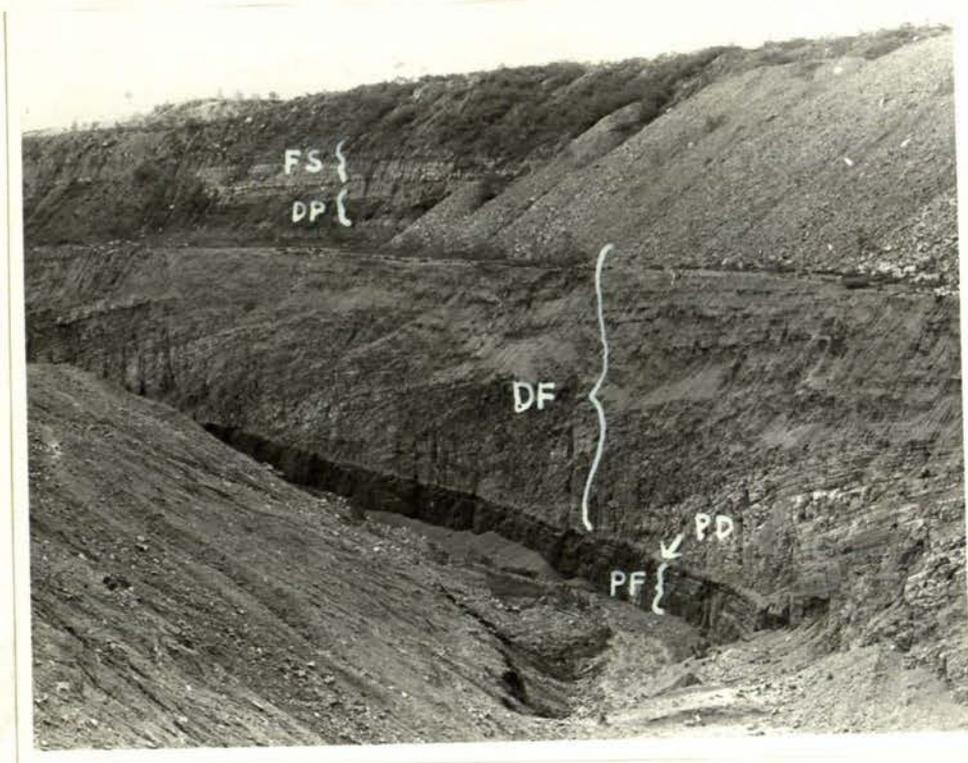


FIGURE 59: Simplified interpretation of different facies within the non-marine deltaic system based on the exposure at Foybrook-Main (South) Open Cut.

- Unit representing:
- a) The peat-forming conditions in lacustrine environment are indicated by the letters P.F.
 - b) The pro-delta deposit is indicated by the letters P.D.
 - c) The delta-front deposits (topset, foreset and bottomset) are indicated by the letters D.F.
 - d) The delta-plain deposits are indicated by the letters D.P.
 - e) The prograding fluvial system over the delta-plain deposits is indicated by the letters F.S.

A P P E N D I X 1

CHARACTERISTICS OF LARGE SCALE CROSS STRATA
ORIGINATING FROM THE INFERRED DEPOSITION OF
DELTA FRONT FACIES

Table A1.1

	G.K. Gilbert (1890) Lake Bonneville; Pleistocene, Utah, U.S.A.	J.D. Collinson (1968) Kinderscout Grit; Namurian	J.D. Collinson (1969) Kinderscout Grit; Namurian, England	P. Dodson (1971) Oldman Formation Upper Cretaceous, Alberta, Canada	Shepherd & Hills (1970) Bearpaw Formation-Horseshoe Canyon Formation, Transition Zone, Upper Cretaceous, Alberta, Canada	J.G. Van Eden (1970) Montañana Formation, Eocene, Pyrenees, Spain	E. Cutter (1975) Ferron Sandstone, Upper Cretaceous, Utah, U.S.A.	C.F.R. Perbury (1976) Foybrook Formation, Singleton Coal Measures, Sydney Basin, Upper Permian, N.S.W. Australia
Grouping (in vertical section) Solitary or grouped	Solitary (except locally adjacent to lake margin where major water-level fluctuations have led to the superposition of up to 3 delta sequences)	Solitary (see also rows 3 and 11)	'Isolated'	Solitary	Solitary	Solitary	Solitary	Solitary
Set thickness metres range	Approximately 16 metres max. (Range not given but Gilbert's Fig. shows thinner set-development in delta lobes deposited during periods of declining water level -)	Between 4 to 40 m	4 to 40 m thick	3 - 5 m thick	1.5 - 2.5 m thick	2 - 5 metres	Generally 12 to 24 metres although min. of 6 m and max. of 30 m recorded	20 m - 48 m
Gross 3-D Geometry of the large scale cross-stratified set (with areal dimensions where known)	Sheet-like or tabular (grossly lobate in plan view); areal extent of 20,000 acres	Extensive sheets. Collinson's Fig. (1968) suggests that each sheet is structurally composite comprising separate geometrically distinct lobate and laterally grouped sets	Sheet	Sheet	Sheet	Sheet-like	Sheet	Sheet-like but having a semi-wedge shape as the crossbed set thins to the southwest; see Fig. 18
Gross relationship between lower bounding surface of set and stratification in underlying sediment 1) Gradational 2) Sharply defined - Grossly concordant Grossly discordant Indeterminate	Sharply defined Asymptotic to grossly discordant	Sharply defined Asymptotic - concordant	Sharply defined	Sharply defined discordant - asymptotic	Sharply defined concordant to asymptotic erosional	Sharply defined Concordant to asymptotic	Sharply defined Grossly concordant	Sharply defined Asymptotic to grossly concordant
Gross configuration of lower bounding surface of set (planar, irregular, cylindrical/scoop shaped/trough-shaped)	Regularly undulose; see Fig. 56	Planar	Planar	Planar	Planar	Planar	Planar	Planar, but with small local irregularities (relief of about .5 m)
Contact Relationship between cross strata and lower bounding surface of set (as seen in dip section) (concordant, discordant; asymptotic)	Asymptotic to discordant	Concordant - asymptotic	Discordant if set < 15 m Asymptotic if set > 12 m	Discordant - asymptotic	Concordant - asymptotic	Asymptotic	Concordant - asymptotic	Asymptotic - discordant
Gross configuration of upper bounding surface of set (planar, irregular etc.)	Essentially planar	Planar to irregular	Planar	Planar	Planar	Planar	Planar	Planar
Contact Relationships between cross strata and upper bounding surface of set (concordant, discordant, asymptotic)	Discordant (but relationship exposed only in one place; see Fig. 56)	Discordant erosional	Discordant	Discordant	Discordant	Discordant	Discordant	Concordant to asymptotic
Gross configuration of cross strata in vertical section - parallel to dip (straight, flexed sigmoidal, curvilinear concave-up, curvilinear convex-up)	Curvilinear, concave-up	In tabular sets foresets are 'straight'; in the largest sets foresets are curvilinear concave-up	Straight if set < 15 m Curvilinear concave-up if set > 12 m	Straight to curvilinear concave-up	Curvilinear concave-up	Curvilinear concave-up	Flexed concave-up	Straight, sigmoidal Curvilinear concave-up
Angle (and range of angle) of maximum inclination of cross strata	15 to 20°	Predominantly low (20°) Maximum of 27°	17° - 25°	'Low angle foreset beds'	'Inclined'	Maximum of 20°	Steeply inclined delta front foresets no exact angle of inclination is given but up to 15°	40° - 25° - the dip of the crossbeds tends to get less higher up in the vertical section
Gross configuration of cross strata traces in plan view (continuous, discontinuous, regular, irregular, straight, regularly curved and concave (or convex) in direction of foreset dip sinuous) with observed lateral dimensions	No data given, but apparently grossly concordant with (i.e., parallel to) the almost wholly preserved lobate delta front	Convex in direction of dip; individual sets may be traced for some tens of metres. There may be some development of concave-discontinuous pattern in plan geometry. Perpendicular to dip direction of foresets, the sets up to 30 m thick are apparently 1 km wide	Convex in direction of dip				No data	Convex in direction of dip
Degree of lithological uniformity of cross strata and predominant lithologies (including textural characteristics where cross strata are lithologically homogenous)	Relatively uniform Rounded gravel with some intermingled fine sand	Foresets extremely coarse pebbly sandstone with bands or beds of fine silty sandstone. The bands reach thicknesses of up to 4 m	Mainly coarse to pebbly sandstone with occasional siltstone and fine sandstone units	Sandstone beds alternating with mudstone beds. Thickness of individual beds not stated	Fine laminated sandstone, silty sandstone thinly bedded siltstone	Heterogeneously composed of medium or fine sandstone - dip section shows lateral development of individual beds up to 100 m	Siltstone and fine sandstone (> 10% argillaceous matrix subangular grains poor to moderate sorting)	Siltstone, fine sandstone to coarse sandstone, shaly facies and sandstone facies. Sandstone is lithic quartz, quartz lithic arenite; siltstone has high carbonaceous content
Presence and nature of sedimentary structures within large-scale cross strata and palaeocurrent significance of these (if any) relative to attitude of the large scale cross strata	No data	Medium scale trough-shaped intrasets, trough axes indicate currents predominantly obliquely down the foreset face, but wide variation is present including some travel directions up slope; dunes and ripples generating these intrasets considered to reflect local currents of diverse origins including large reverse eddies generated by fluvial discharge initiated by flow separation at distributary mouths	As for Collinson (1968)	No data			Major sedimentary structure is even parallel lamination subordinate amounts of trough and planar cross lamination, ripple lamination, ripple drift cross lamination	Parallel-wavy lamination trending down-dip of foresets. Micro cross laminations defined by carbonaceous concentrations trend up, oblique-down, dip of foreset
Characteristics of underlying bed-set and directional relationship of palaeocurrents (if any) relative to attitude of overlying large scale cross strata	Delta foresets rest upon a very gently sloping floor of lacustrine sand and clay; no palaeocurrent data available for these underlying sediments but they are fine grained flat laminated sediments presumably originating from suspension - rather than from traction loads	No data	No data				1.5 - 3 metre thick transitional zone below steeply inclined beds - pro-delta beds are horizontal bottomset tails to the inclined delta front foreset beds. Sandstone to shale ratio approximately 1:1	10 m bright coal with thin dirt bands - drilling at the boundary between coal and foresets
Characteristics of overlying bed-set and directional relationship of palaeocurrents (if any) relative to attitude of large scale cross strata	Horizontal beds	20 cm to 2 m thick tabular or trough cross sets occur in cosets up to 5 m thick. Dip directions of the foresets of medium-scale tabular sets and the axial directions of the medium-scale trough sets are always extremely close to the dip direction of the underlying large-scale foresets	As for Collinson (1968)				Horizontal strata of sandstone, siltstone and some coal	Overlying bedset also another coal seam
Inferred or observed relationship between direction of inclination of large scale cross strata and direction of generative palaeocurrents	Dip direction of 'oblique lamination' is the same as the direction of generative palaeocurrents	Dip direction of large scale cross strata is almost the same direction as generative palaeocurrents	As for Collinson (1968)	Similar or almost so	Inferred by myself similar or almost so		Similar or almost so	Similar or almost so
Associated fossils or other palaeo-environmental indicators (either restricted to cross stratified units or to bracketing bed-sets etc.)	Freshwater molluscs; terrestrial vertebrates	No data	No data			No marine fossils	Biogenic structures are uncommon but <i>Ophiomorpha</i> and <i>Thalassinoides</i> were found. Finely comminuted plant material is present in most beds	Silicified logs, whole plant stems and leaves, fragmented plant material
Cyclic vertical pattern (if any)	Stacking of deltas occur as a consequence of major fluctuations in water level	The two facies deltaic and fluvial, are vertically associated with each other in a definite order of superposition; former underlying the latter facies	No data		No data		Pro-delta facies overlain by Delta front overlain by Delta plain overlain by	Little data but the vertical succession would seem to indicate the pattern: coal, large scale foresets, coal
Origin inferred by original workers for the large scale cross stratified units and	Large scale cross strata originate from the progradation of a delta front facies into a body of standing lake water under conditions of high sediment influx	Large scale cross strata originate from delta front facies	No data		Authors interpreted these structures as being formed by the migration downstream of large scale ripples or sand waves in a deltaic complex with migrating distributaries	Van Eden suggests the homogenous sediment, constant direction of foresets, even thickness of units and their isolated position provides enough evidence to assume a deltaic mechanism of deposition	Large scale cross strata originate from delta front facies developing into a water body whose salinity has been significantly reduced	Large scale cross strata originate from delta front facies (this report); mobile compaction structures (Dritzen, 1972, with others, 1975), levee crevasse splays (Bunny, 1969)
Names applied to structure	'Delta' with internal foresets described as 'oblique lamination'	Gilbert-type delta	No data	No formal name given, yet he distinguishes the crossbeds as <u>not</u> being alpha or epsilon			Cutter likens the crossbeds with Gilbert-type delta with delta front deposits that are steeply inclined	
Lateral extent of large scale cross stratified units seen in outcrop parallel to the dip section, or (in Quaternary deposits) inferred from preserved 'foreset' morphology	1.5 km	2.4 km	No data			100 metres	Tens of kilometres	1.8 to 3.0 km

A P P E N D I X 2

METHODS

All the highwalls in the abandoned open cut mines at Foybrook and segments of the open cut at Howick were photographed in such a way as to obtain stereo-coverage. From this photographic coverage, panoramic sketches of the highwall structures were drawn, drawing directly from the compilation of individual tracings made from each successive set of stereo-pair photographs. Because the camera-to-highwall distance changed progressively during the photography in some open cuts, the Panoramas incorporate a small amount of unavoidable photographic distortion. However this was compensated by the inclusion within many of the photographs of an internal scale consisting of a canvas banner with metre subdivisions hung from the top of the highwall (see Panorama enclosures in back pocket).

With the aid of special rockclimbing equipment, several stratigraphic sections were logged in each open cut highwall exposure by ascending a fixed rope (Table A2.1). The log was plotted directly on to a continuous scroll in the field as the field data was collected. This operation was performed on the cliff face while ascending the fixed rope in all open cuts except for Foybrook-Main (South) Open Cut where the data were communicated from the cliff face via walkie-talkie to an assistant on the ground who then plotted the data on the scroll (see Frontispiece). Each section was logged in fair detail using a metric tape measure; a record was made of lithology, bed thickness, dip and dip azimuth of beds, nature of the sedimentary structures, fossil content and relative grain size. Rock samples were collected during the stratigraphic logging and subsequently thin-sectioned for petrographic analysis. Because the majority of the highwalls trend approximately north-south the sections have been numbered progressively north to south; and for the only east-west trending highwall (Foybrook-S.E. southwall), the sections are

numbered from east to west (Table A2.1). Similar data collection was undertaken in road and rail cuttings that occurred within the outcrop zone of the stratigraphic interval between the main Liddell and Arties Coal Seams.

All the localities were plotted on a base map prepared from 1:1600 scale enlarged aerial photographs of the Muswellbrook and Camberwell vertical air-photo series (Table A2.2).

Data were also collected on the locality and orientation of silicified fossil logs throughout all the cuts (but mainly from Howick). From these and the recorded measurements of dip and dip-azimuth of the large scale (master) crossbeds stereoplots were plotted on the equal-angle stereonet. To restore the original primary dips of the master crossbeds the regional tectonic dip (which ranged from 2° to 8°) was rotated out on the Wulff stereonet for each different section or data-recording locality on the basis of a dip and dip-azimuth measurement on the top of the Liddell Coal Seam at that locality.

TABLE A2.1:

LOCATIONS AND NAMES OF OPEN CUT MINES IN THE FOYBROOK-LIDDELL-HOWICK AREA, AND INDEX TO LOGGED STRATIGRAPHIC SECTIONS AND HIGHWALL PANORAMAS ACCOMPANYING THIS REPORT

GENERAL AREA	OPEN CUT MINES (SEE MAP 2)	LOCALITY NUMBER (SEE MAP 2)	PRESENT CONDITION OF MINE	QUALITY OF HIGHWALL EXPOSURE	CODE INDEX TO PANORAMAS HOUSED IN BACK POCKET	CODE INDEX TO STRATIGRAPHIC SECTIONS HOUSED IN BACK POCKET (SEE MAP 2 FOR LOCATION OF SECTIONS)
FOYBROOK AREA	Foybrook-Main (North)	1	Abandoned, partially flooded and infilled with spoil	Fair; large scale inclined bedding structures are developed throughout length of highwall. Liddell Coal Seam exposed	P1	S1A, S1B, S1C, S1D
	Foybrook-Main (South)	2	ditto	Excellent; large scale inclined bedding structures are conspicuously developed throughout length of highwall. Liddell Coal Seam exposed	P2	S2A, S2B
	Foybrook-Box		Used as portal to Liddell No. 1 Underground Mine	Excellent; large scale inclined bedding structures exposed across extent of highwall. Liddell Coal Seam exposed		
	Foybrook-S.E.	3 3a	Abandoned and partially flooded	Excellent; large scale inclined bedding structures are conspicuously developed throughout length of highwalls. Liddell Coal Seam exposed	P3 (east wall) P3a (south wall)	S3A, S3B S3aC, S3aD, S3aE
	Foybrook-S.W.	4	Abandoned and flooded; presently undergoing refilling with spoil	Excellent; large scale inclined bedding structures conspicuously developed throughout extent of highwalls. Liddell Coal Seam exposed	P4	S4A, S4B, S4C
LIDDELL AREA	Durham		Abandoned and almost completely refilled with spoil	Excellent, but only a few feet of the top of the former highwall remain exposed. Liddell Coal Seam now buried. Large scale inclined bedding structures apparently developed but only a few feet remain exposed		
	Liddell-Portal		Abandoned and partly flooded	This is a box-shaped open cut similar in size and shape to the Foybrook-Box Open Cut. Exposure is good and the Liddell Coal Seam is exposed at the base of the highwalls but inclined bedding structures are not clearly evident.		
HOWICK AREA	Howick	5	Actively worked	Generally good, but affected by blasting of overburden and burial under veneers of mine dust. Large scale inclined bedding structures conspicuously developed throughout length of highwalls; Liddell Coal Seam exposed and actively mined.	P5	S5A, S5B, S5C, S5D

TABLE A2.2

GIVING SERIES RUN AND NUMBER OF AERIAL PHOTOGRAPHS
USED IN COMPILATION OF BASE MAP

	RUN	NO.
Muswellbrook Series	3M	NSW 2242 45
	3M	NSW 2242 46
	2M	NSW 2242 88
	2M	NSW 2242 89
Camberwell Series	3C	NSW 2259 95
	3C	NSW 2259 96
	2C	NSW 2259 77
	2C	NSW 2259 78

REFERENCES

- Allen, J.R.L., 1963. The Classification of Cross-stratified Units with Notes on Their Origin, Sedimentology, V.2, pp. 93-114.
- Allen, J.R.L., 1965. Late Quaternary Niger Delta and Adjacent Areas: Sedimentary Environments and Lithofacies, Bull. of Am. Assoc. Pet. Geologists, V.49, pp. 547-600.
- Axelsson, V., 1967. The Laitaure Delta - A Study of Deltaic Morphology and Processes, Geografiska Annaler, V.49A, pp. 1-127.
- Bates, C.C., 1953. Rational Theory of Delta Formation, Bull. of Am. Assoc. Pet. Geologists, V.37, pp. 2119-2162.
- Booker, F.W., Bursill, C. and McElroy, C.T., 1953. Sedimentation of the Tomago Coal Measures in the Singleton-Muswellbrook Coalfield: An Introduction Study, Jour. of the Royal Soc. of N.S.W., V.87, pp. 137-151.
- Booker, F.W. and Adamson, C.L., 1955. Correlation of Coal Seams at Ravensworth and Liddell, Ann. Rep. Dept. of Mines, N.S.W. for 1951.
- Booker, F.W. and McKenzie, P.J., 1956. The Ravensworth State Coal Mine Reserve, Tech. Rep. Dept. Mines, N.S.W. for 1953, V.1, pp. 13-19.
- Born, S.M., 1972. Late Quaternary History, Deltaic Sedimentation and Mudlump Formation at Pyramid Lake, Nevada, Centre for Water Resources Research, Desert Research Institute, University of Nevada, Reno.
- Britten, R.A., 1972. A Review of the Stratigraphy of the Singleton Coal Measures and its Significance to Coal Geology and Mining in the Hunter Valley Region of N.S.W., A.I.M.M. Newcastle Conference, pp. 11-22.
- Britten, R.A. and Smyth, M., 1973. The Bayswater Coal Member of the Singleton Coal Measures of N.S.W., A.I.M.M. Proc. No. 248, pp. 37-49.
- Britten, R.A., Smyth, M., Bennett, A.J.R. and Shibaoka, M., 1975. Environmental Interpretations of Gondwana Coal Measure Sequences in the Sydney Basin of N.S.W., Third Gondwana Symposium, Canberra, Australia in 1973, A.N.U. Press, pp. 233-247.
- Bunny, M.R., 1967. Geology and Coal Reserves of the Liddell State Coal Mine Holding, Hunter Valley, N.S.W., Rec. geol. Surv. N.S.W., V.12, pp. 81-123.
- Burgis, W.A., 1975. Environmental Significance of Folds in the Rangal Coal Measures at Blackwater, Queensland, Bur. Min. Res. Report 171, pp. 1-64.

- Carrigy, M.A., 1970. Experiments on the Angles of Repose of Granular Materials, Sedimentology, V.14, pp. 147-158.
- Church, M. and Gilbert, R., 1975. Proglacial Fluvial and Lacustrine Environments in A.V. Jopling and B.C. McDonald (eds.), Glaciofluvial and Glaciolacustrine Sedimentation, Soc. Econ. Pet. Min. spec. publ. No. 23, pp. 22-100.
- Coleman, J.M., Gagliano, S.M. and Webb, J.E., 1964. Minor Sedimentary Structures in a Prograding Distributary, Marine Geology, v.1, pp. 240-258.
- Collinson, J.D., 1968. Deltaic Sedimentation Units in the Upper Carboniferous of Northern England, Sedimentology, V.10, pp. 233-254.
- Collinson, J.D., 1969. The Sedimentology of the Grindslow Shales and the Kinderscout Grit - A Deltaic Complex in the Namurian of Northern England, Jour. Sed. Petrology, V. 39, pp. 194-221.
- Cotter, E., 1975. Deltaic Deposits in the Upper Cretaceous Ferron Sandstone, Utah in M.L. Broussard (ed.), Deltas Houston Geological Society, pp. 471-484.
- David, T.W.E., 1907. The Geology of the Hunter River Coal Measures, New South Wales, Mem. of the geol. Surv. of N.S.W., Dept. of Mines and Agriculture, No. 4.
- Dodson, P., 1971. Sedimentology and Taphonomy of the Oldman Formation (Campanian), Dinosaur Provincial Park, Alberta, Canada. Palaeogeography Palaeoclimatology Palaeoecology, V.10, pp. 21-74.
- Dott, R.H., 1966. Eocene Deltaic Sedimentation at Coos Bay, Oregon, Jour. of Geology, V.74, pp. 373-420.
- Duff, P. McL., 1967. Cyclic Sedimentation in the Permian Coal Measures of New South Wales, Jour. geol. Soc. Australia, V.14, pp. 293-307.
- Fisher, W.L., Brown, Jr. L.F., Scott, A.J. and McGowen, J.H., 1969. Delta Systems in the Exploration for Oil and Gas - A Research Colloquium, Bur. of Econ. geol. Univ. of Texas at Austin.
- Gilbert, G.K., 1885. The Topographic Features of Lake Shores, U.S. geol. Surv. J.W. Powell (Director) 5th Ann. Rep.
- Gilbert, G.K., 1890. Lake Bonneville, U.S. geol. Surv. J.W. Powell (Director), Monographs, V.1.
- Gray, D.R., 1971. The Geology of the Hebden Region, N.S.W. unpublished B.Sc.Hons. Univ. of Newcastle.
- Gray, D.R., 1974. Sedimentology of Permian Rocks Near Ravensworth, N.S.W., Northern Sydney Basin, Jour. and Proc. of Roy. Soc. N.S.W., V.107, pp.17-30.

- Gray, D.R., 1975. Structure and Jointing in Permian Rocks Near Ravensworth, N.S.W., Northern Sydney Basin, Jour. and Proc. of Roy. Soc. N.S.W., V.108, pp. 16-28.
- Greensmith, J.T., 1956. Sedimentary Structures in the Upper Carboniferous of North and Central Derbyshire, England, Jour. Sed. Petrology, V.26, pp. 343-355.
- Jopling, A.V., 1963. Hydraulic Studies on the Origin of Bedding, Sedimentology, V.2, pp. 115-121.
- Jopling, A.V., 1964. Laboratory Study of Sorting Processes Related to Flow Separation, Jour. of Geophys. Research, V.69, pp. 3403-3418.
- Jopling, A.V., 1965. Hydraulic Factors Controlling the Shape of Laminal in Laboratory Deltas, Jour. Sed. Petrology, V.35.
- Jopling, A.V. and Walker, R.C., 1968. Morphology and Origin of Ripple-drift Cross-lamination, With Examples from the Pleistocene of Massachusetts, Jour. Sed. Petrology, V.38, pp. 971-984.
- Labutis, V., 1973. A Report on South Avalon Area (unpublished report) Macquarie University, Sydney.
- Laury, R.L., 1968. Sedimentology of the Pleasant View Sandstone, Southern Iowa and Western Illinois, Jour. Sed. Petrology, V.38, pp. 568-599.
- Le Blanc, R.J., 1975. Significant Studies of Modern and Ancient Deltaic Sediments in M.L. Broussard (ed.), Deltas Houston Geological Society, pp. 13-85.
- Leitch, E.C., 1969. Igneous Activity and Diastrophism in the Permian of New South Wales, Jour. geol. Soc. Australia Spec. Publs. No. 2, pp. 21-37.
- Miall, A.D., 1976. Facies Model 4 Deltas, Geoscience Canada, V.3, pp. 215-227.
- Nevin, C.M. and Trainer, Jr. D.W., 1927. Laboratory Studies in Delta Building, Bull. geol. Soc. America, V.38, pp. 451-458.
- Packham, G.H. (ed.), 1969. The Geology of New South Wales, Jour. geol. Soc. Australia, V.16, Part I.
- Packham, G.H., 1976. Narrabeen-Palm Beach Triassic Sedimentation, Excursion 16B 25th J.G.C. Sydney, Australia.
- Raggatt, H.G., 1930. Singleton-Muswellbrook Coalfield. Ann. Rep. Dept. Mines, N.S.W. for 1929, pp. 100-104.

- Raistrick, A. and Marshall, C.E., 1939. The Nature and Origin of Coal and Coal Seams, English Universities Press Ltd.
- Retallack, G.J., 1973. Stratigraphy, Palaeobotany and Environmental Analysis of an Area Around Pittwater, North of Sydney, N.S.W. (Unpublished thesis, Hons.) University of New England, Armidale.
- Retallack, G.J., 1974. The Interpretation of Epsilon Cross-stratification (unpublished report, Macquarie University).
- Selley, R.C., 1970. Ancient Sedimentary Environments - A Brief Summary, Chapman and Hall Ltd.
- Shepherd, W.W. and Hills, L.V., 1970. Depositional Environments of Bearpaw-Horseshoe Canyon (Upper Cretaceous) Transition Zone, Drumheller 'Badlands', Alberta, Bull. Can. Pet. Geol., V.18, pp. 166-215.
- Taylor, J.H., 1963. Sedimentary Features of an Ancient Deltaic Complex - The Wealden Rocks of South Eastern England, Sedimentology, V.2, pp. 2-28.
- Tompkins, D.K., 1961. Studies of the Liddell Coal Seam (unpublished Ph.D Thesis) Sydney University.
- Traves, D.M. and King, D., (eds.), 1975. Economic Geology of Australia and Papua New Guinea 2 Coal, A.I.M.M. Monograph Series No. 6.
- Van Eden, J.G., 1970. A Reconnaissance of Deltaic Environment in the Middle Eocene of the South-Central Pyrenees, Spain, Geol. en Mijnbouw, V.49, pp. 145-157.
- Veevers, J.J., 1953. Howick Area Report, Bur. Min. Resour. Geol. and Geophys. Aust. Records 1953/47 (unpublished).
- Veevers, J.J., 1960. Geology of the Howick Area, Singleton-Muswellbrook District, New South Wales, Bur. Min. Resour. Geol. and Geophys. Aust. Rep. 53.
- Williams, R.J., 1976. Hunter Valley: Permian Coal Measures Geology, Excursion 11B 25 I.G.C. Sydney, Australia, pp. 1-13.