



FRONTISPIECE

Logging Section S2B at Foybrook-Main Open Cut (South). Note the massively bedded fine sandstone which forms the middle part of the large scale inclined strata. Above the thickly bedded fine sandstone are thinner interbeds of siltstone and fine sandstone. The siltstone and shale then predominates to the top of the highwall. Below the thick bedded sandstone is a unit of siltstone, finely bedded which overlies the Liddell Coal Seam (not seen in this photograph; see also Fig. 22).

CHAPTER 1

INTRODUCTION

This report documents a spectacular tabular development of large scale inclined bedding in the Upper Permian Singleton Coal Measures of the northern Sydney Basin and examines its likely origin. Unless otherwise stated, the term "crossbeds" will be used synonymously for "inclined bedding", and the word "crossbeds" (or "crossbedding", "cross-strata", "cross-stratification" etc.), will be used strictly as a descriptive, geometric term as defined by the American Geological Institute (1962, p. 144): "the arrangement of laminations [or beds] of strata transverse or oblique to the main planes of stratification of the strata concerned; inclined, often lenticular beds between the main bedding planes". No genetic connotations are implied by the use of these terms unless otherwise indicated.*

The crossbeds considered here are exceptional in two respects: firstly, their imposing scale - maximum set thickness is almost 50 m;

* A further terminological problem arises later in this report with regard to the verbal scale designation of crossbedding and cross-lamination structures developed on the more common scale of centimetres to decimetres as opposed to the metres to tens-of-metres scale which characterizes the giant crossbed structures considered throughout this work. In his classification of crossbedding Allen (1963) distinguishes two scale categories which he designates "small scale" and "large scale" and which he separates at a set-thickness of 5 cm. This subdivision is based on the rationale that there is a natural separation of size-populations of crossbeds produced by traction-transport phenomena at about this set-thickness, and that this natural size-frequency reflects, in turn, natural populations of traction-induced bedforms known respectively as ripples (at the lower end of the scale) and dunes (at the higher end of the scale - though other bedform terms have been used for generative bedforms which are known to produce crossbedding on scales of more than a few decimetres or so). Because the term "large scale" is used herein for inclined bedding structures of extraordinary set-thickness it is desirable to employ an alternative scale terminology for Allen's two categories of crossbeds. Hence the terms "centimetre-scale" and "decimetre-scale" will be used instead of Allen's "small scale" and "large scale" respectively, for qualifying crossbedding structures with set-thicknesses of less than about 0.3 m (which is the approximate upper limit of set-thickness encountered in 'normal' crossbeds in the present study area).

secondly, their heterolithic character (typically there is variation in lithology between adjacent crossbeds and on a still larger scale the bulk lithology shows lateral variation from one part of the crossbed set to another). Reports of structures with these or similar characteristics are rare in the geological literature and of those recorded very few have received detailed investigation (see Appendix 1). As a consequence, no doubt, the structure is unrecognized in current classification schemes of crossbedding such as that of Allen (1963) and its genetic significance accordingly remains obscure.

In Australia structures of the type considered here were first reported by Sir Edgeworth David (1907) from coastal exposures of the Newcastle Coal Measures and additional examples from the coal measure sequences have been encountered more recently in open cut mines in both the northern Sydney Basin (Bunny 1967, p. 87; Britten 1972; Britten and others 1975; Booker and others 1953, p. 146) and the Bowen Basin region of Queensland (Burgis, 1975). Examples are also known from coastal exposures of the Triassic Newport Formation (Narrabeen Group) of the Sydney Basin at Avalon, near Sydney (Fig. 1) where they have been studied by Labutis (1973), Retallack (1973, 1974) and Packham (1976). Table 1 highlights the gross characteristics of some of these Australian examples mentioned above.

Of the two varieties of large scale heterolithic crossbedding recognized in the elaborate classification scheme of Allen (1963), each differs in genetically important characteristics from the variety considered in this study (Fig. 2). In both of Allen's categories, that is Eta and Epsilon crossbedding, the lower bounding surface of the crossbed set is grossly irregular and erosional, and the crossbed sets are respectively trough shaped and tabular. Though the gross shape of the



FIGURE 1:

Large scale, grouped, heterolithic crossbeds with non-erosional bases, Bilgola Head, South Avalon, Sydney (Triassic Newport Formation, Narrabeen Group). The thickness of the crossbed sets is 8 m - 10 m. See Table 1 for additional details of these Avalon structures.

TABLE 1:

GROSS CHARACTERISTICS OF SOME AUSTRALIAN EXAMPLES OF THE LARGE SCALE, TABULAR, HETEROLITHIC CROSSBEDS*

Locality, Stratigraphic Occurrence, and Data Sources	Avalon (Sydney Area), Triassic Newport FM. (Labutis 1973; Retallack 1973, 1974; plus Personal Observations)	Coastal Exposures South of Newcastle. Permian Newcastle Coal Measures (David 1907, plus Personal Observations & Conaghan Personal Communication)	Open Cut Exposures at Foybrook and Howick, near Singleton. Permian Singleton Coal Measures (Present Report)	Open Cut Exposures at Blackwater, Bowen Basin, Queensland. Permian Bungal Coal Measures (Burgis 1975)
Vertical Scale	10 m	Max. set thickness approx. 30 m.	Set thickness varies regionally from 25 to 48 m	Ranges between 19.5 m to 41 m
Lateral Scale	300 m	Km's to tens of Km's	7 kms minimum	Minimum of 4.6 kms
Vertical Grouping	Grouped	Mostly solitary, possibly some grouping	Solitary	Mostly solitary, possibly some grouping
Lithology	Sandstone, siltstone, mudstone, intraformational mudstone breccia	Conglomerates, pebbly sandstones, and sandstones	Medium to fine sandstone, mudstone, siltstone, coal	Mudstone, siltstone, carbonaceous shale and sandstone
Gross Set Geometry	Tabular	Tabular	Tabular	Tabular
Maximum Inclination of Foresets	15°	Maximum of 25° - 30° (estimate at Redhead)	Maximum of 29° in foresets; minimum of 4° in topsets	No data
Gross Geometry of Crossbeds Viewed in Vertical Section Normal to Foreset Strike (cf. Terminology in Allen 1968, p. 99).	Sigmoidal	Tangential, and angular	Mostly sigmoidal	Variable, including tangential, angular, curvilinear-convex-up, and sigmoidal
Nature of Lower and Upper Bounding Surfaces of Sets	Planar and non-erosional. Contacts between sets are gradational because of strong development of topsets and bottomsets	Planar and non-erosional, always sharply defined	Planar and non-erosional, bottom contact sharply defined, top contact commonly more gradational because of strong development of topset.	Lower contact planar, non-erosional and sharply defined; Upper contact gradational because of strongly asymptotic relationship of inclined beds to the contact.
Geometry of Foreset Traces in Plan-View	No data available to resolve larger-scale configuration. Wave-cut platform exposures show configuration to be straight to concave (towards foreset dip direction) over scale of M's to tens of M's	No data available to resolve larger-scale configuration. Wave-cut platform exposures show traces to be essentially straight over distances of many tens of metres locally	Regional swing in strike of foresets suggests a regionally lobate configuration (that is convex towards direction of foreset dip)	No data
Associated Fossils	Plant fossils	Plant fossils	Plant fossils	Plant and fish fossils
Association of Crossbed Set With Coal Seams	None	Crossbed set usually overlies coal seam	Crossbed set overlies coal seam	Crossbed sets overlie coal seams

* This compilation does not include the epsilon crossbedding category of Allen (1963).

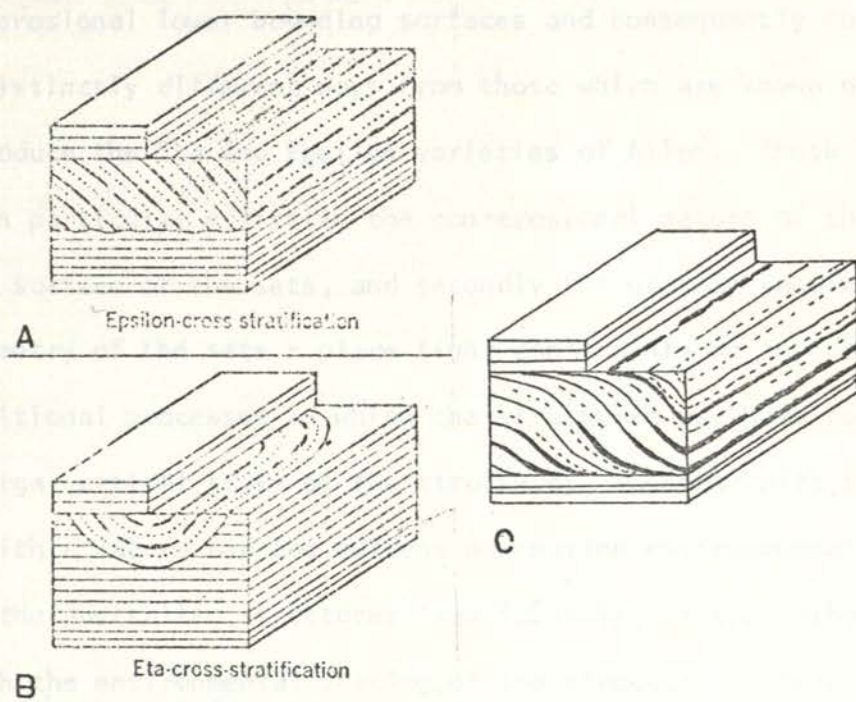


FIGURE 2:

- A and B:** Gross characteristics of the two varieties of large scale heterolithic crossbedding featured in the crossbed classification scheme of Allen (1963);
- C:** Gross characteristics of the variety of tabular, large scale heterolithic crossbedding concerned with in the present report. Note superficial similarity of Epsilon crossbedding and the variety illustrated at C but presence of an erosional lower bounding surface of the Epsilon crossbed set and absence of such an erosional surface in C.

crossbed sets of this report is tabular (see Table 1) they are bounded by planar non-erosional lower bounding surfaces and consequently must originate in distinctly different ways from those which are known or believed to produce the Eta and Epsilon varieties of Allen. These two restrictions in particular - firstly the non-erosional nature of the lower bounding surface of the sets, and secondly the grossly tabular or sheet-like geometry of the sets - place tight constraints on the possible types of depositional processes by which the structures may have formed. The overall large vertical scale of the structures, together with their varied heterolithic nature and the evident non-marine environmental affinities of the Australian structures (see Table 1), provide other constraints though the environmental setting of the structure is more varied when examples in other countries are considered (Appendix 1).

In the coal measure examples mentioned above the crossbed sets are almost invariably developed immediately above coal seams (Table 1) and this association has caused some authors to infer a secondary compactional origin for the crossbed structures (e.g. Britten 1972, 1975; Britten and others 1975; Burgis 1975). Nevertheless in situations where the structure (crossbed set or sets) is not associated with coal (as in the Triassic Newport Formation, Fig. 1, Table 1) its geometry is in no way markedly different from before, suggesting perhaps that a special compactional origin linked to the presence of underlying peat deposits is not wholly necessary in the general case.

Where a primary depositional origin has been proposed for the Australian examples, the suggested process has involved lateral progradation of levée banks within a fluvial or fluvio-deltaic system. This has been suggested, for example, by Labutis (1973), Retallack (1973, 1974) and Packham (1976) for the Triassic structures at Avalon and by Bunny

(1967) for the Permian structure at Foybrook in the Singleton Coal Measures. Where the structure has been investigated in other countries it has usually been interpreted to have formed through the progradation of a classical deltaic system involving the generation of prominent topset, foreset and bottomset beds in delta-top, delta-front and pro-delta environments respectively (see Appendix 1).

The present study was undertaken to document the nature of these structures at one or more localities in the Sydney Basin and to examine their likely origin in view of the diverse processes, both primary and secondary, to which they have been variously attributed. A reconnaissance of the crossbed structures in the Hunter Valley coal fields quickly established that the large scale crossbed set which is developed there immediately above the main Liddell Coal Seam in the Liddell-Foybrook-Howick area, offered major advantages for study and this structure was consequently selected for particular emphasis. Time constraints precluded detailed work on the large scale crossbed structures that were known to occur outside this area, though most of the known examples exposed in coastal exposures between Sydney and Newcastle have been examined at reconnaissance level in order to compare their major characteristics (Table 1).

The choice of the particular structure at Liddell for major study was influenced by the following considerations:

- (1) Large lateral extent of the structure: the crossbed set was observed to overlie the main Liddell Coal Seam wherever this seam was exposed in the open cuts. The inferred minimum lateral extent of the structure was therefore equivalent to the distance of separation of the two most distant open cut mines - approximately 7 kms.

(2) Large vertical scale: ranging from 23 m to 48 m in thickness the crossbed set was by far the most imposing of all examples encountered. However, this attraction was offset by the added difficulty of access to the highwall exposures necessitating resort to extensive use of rockclimbing equipment and ladders.

(3) Quality of the exposure: spectacular highwall exposure was available in a number of open cuts, one actively worked (at Howick), the others abandoned (various cuts at Foybrook). The quality of the exposure was generally good but ranged from excellent in the older abandoned open cuts to moderately good in the actively worked cuts where the highwalls are affected by blasting and concealment under coatings of mine dust (Appendix 2, Table A2.1).

(4) Need for urgency: the most impressive and useful exposures of the crossbed structure at Foybrook occur in the highwalls of the abandoned open cuts and these cuts are presently undergoing progressive fill as part of a mandatory land-restoration programme under the current mining act. The imminent loss of these spectacular and possibly unique exposures therefore seems certain unless some can be preserved. Similarly no record is routinely kept of the highwall structures continuously being exposed in the active open cut at Howick. Documentation and study of the crossbed structure in this area is therefore timely.

Methods used throughout this study are treated in Appendix 2,

together with relevant background concerning the present nature of the

open cut mines, and the types of graphic documentation represented in the enclosures housed in the back pocket of this report.

CHAPTER 2

LOCATION AND GEOLOGICAL SETTING OF THE STUDY AREA

The area of study is situated approximately midway between Singleton and Muswellbrook in the Hunter Valley (Fig. 7) - an area which currently supports the largest scale open cut coal mining activity in N.S.W.

The physiography of the area is characterized typically by open, gently undulating countryside of low to moderate relief with gentle slopes and rounded hills. To the north the relief increases abruptly in the vicinity of the northwest-southeast trending Hunter Thrust, whereas to the south the open undulating topography continues beyond the Hunter River to the northern escarpment of the sandstone plateau country of the central Sydney Basin.

2.1 STRATIGRAPHIC SETTING

The stratigraphic interval within which this study is concentrated lies between the main Liddell Coal Seam and the Arties Coal Seam - an interval varying approximately between 23 - 48 m thick. These coal seams occur within the Vane Formation which constitutes the lower part of the Singleton Coal Measures (Fig. 3). The Vane Formation conformably overlies the Saltwater Creek Formation which is regarded by Britten (1972) as a transitional unit between the underlying marine Maitland Group and the overlying coal measures. The top of the Saltwater Creek Formation is defined by the bottom of the Barrett Seam (Gray, 1974; Robinson in Packham 1969, p. 351), although Britten (1972) defines the same boundary as being at the base of the Hebden Seam. Conformably overlying the Vane Formation (approximately equivalent to the Foybrook Formation of Britten, 1972) is the Goorangoola Formation (approximately equivalent to the Bulga Formation of Britten, 1972), the boundary of this unit is placed at the top of the Bayswater Seam (Gray, 1974; Robinson in Packham, 1969, p. 353).

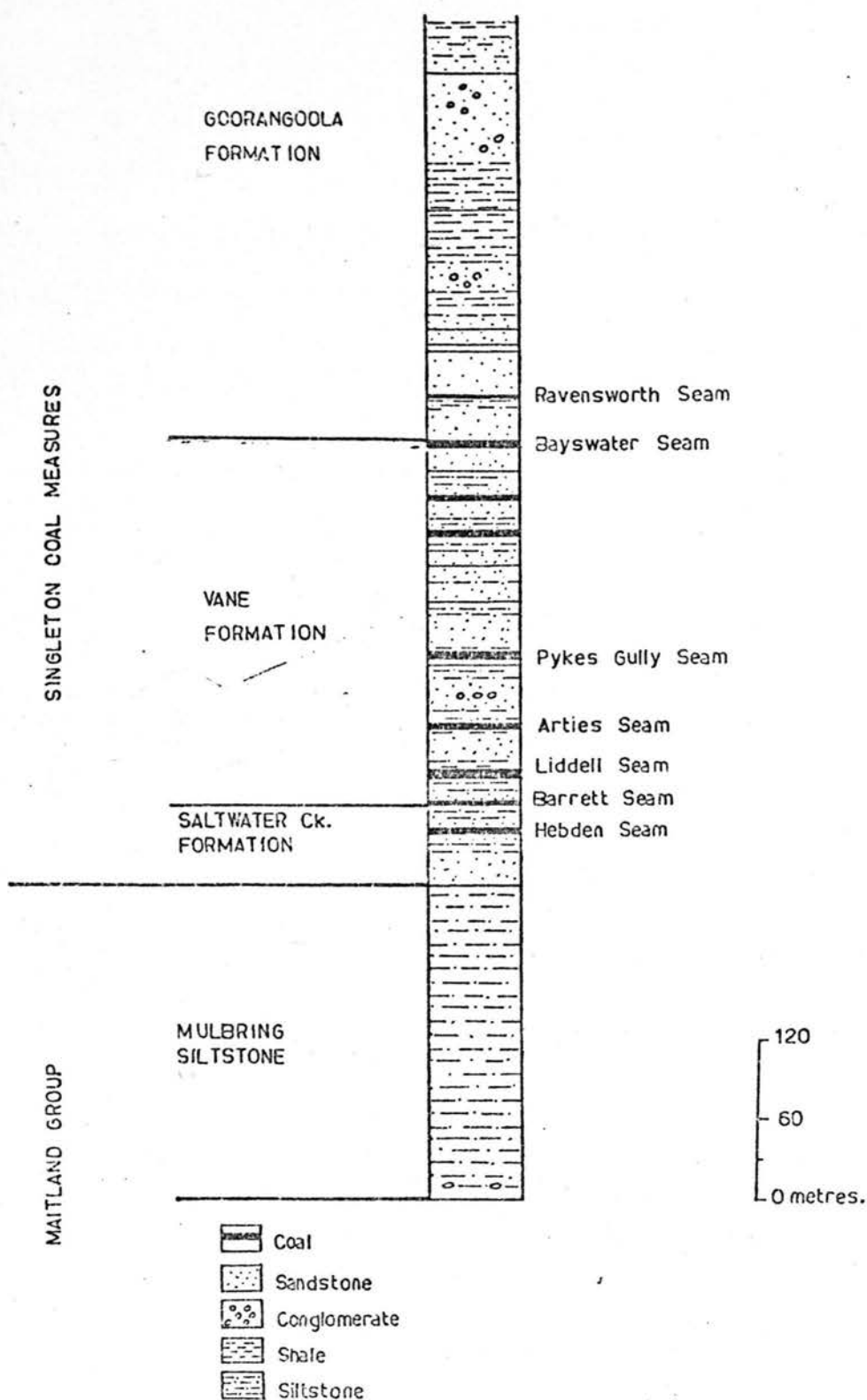


FIGURE 3: Stratigraphic column of Permian coal measure rocks in the Ravensworth-Liddell area (from Gray, 1974 fig. 2). Stratigraphic nomenclature is that of Robinson (in Packham 1969, pp. 350-354).

Britten interprets the Foybrook Formation as a terrestrial sequence with numerous coal seams and tentatively suggests that the Bulga Formation is a deposit of shallow marine or intertidal affinities. As mapped by Gray (1974) the palaeocurrent trends within the Vane Formation suggest a generally westerly flow direction but with divergent northerly and southerly flow patterns in the vicinity of Liddell (Fig. 4). Gray (1974, p. 25) suggests that this divergence possibly indicates the presence of a local palaeo-high.

The coal stratigraphy in the Foybrook-Liddell-Howick region is not as simple as depicted in the stratigraphic column of the Ravensworth-Liddell area (Fig. 3). Coal seam splits are numerous and render stratigraphic correlation over any great distance difficult. An example of such a cross-sectional correlation is shown in Figure 5. Terminology presently used in the area of the different coal seams based on detailed correlation studies of the various seams and seam splits is indicated in Figure 6.

For the purpose of this report, whenever there is a reference to the Liddell Coal Seam it will be prefixed by the word "main" to indicate local convergence into a single major coal seam of two or more of the major component plies or bundles of plies (see Figs. 5 and 6 for additional explanation). The main Liddell Coal Seam is the major seam mined by open cut operations and in the underground in the Foybrook-Liddell-Howick area. The Arties Seam also splits (Fig. 5) and the two known component seams are the Upper and Lower Arties. For the purpose of this report, whenever the two subsidiary seams coalesce to form one seam, that composite seam is termed the Arties Coal Seam.

Some further comments about the regional coal stratigraphy are given in Chapter 4.

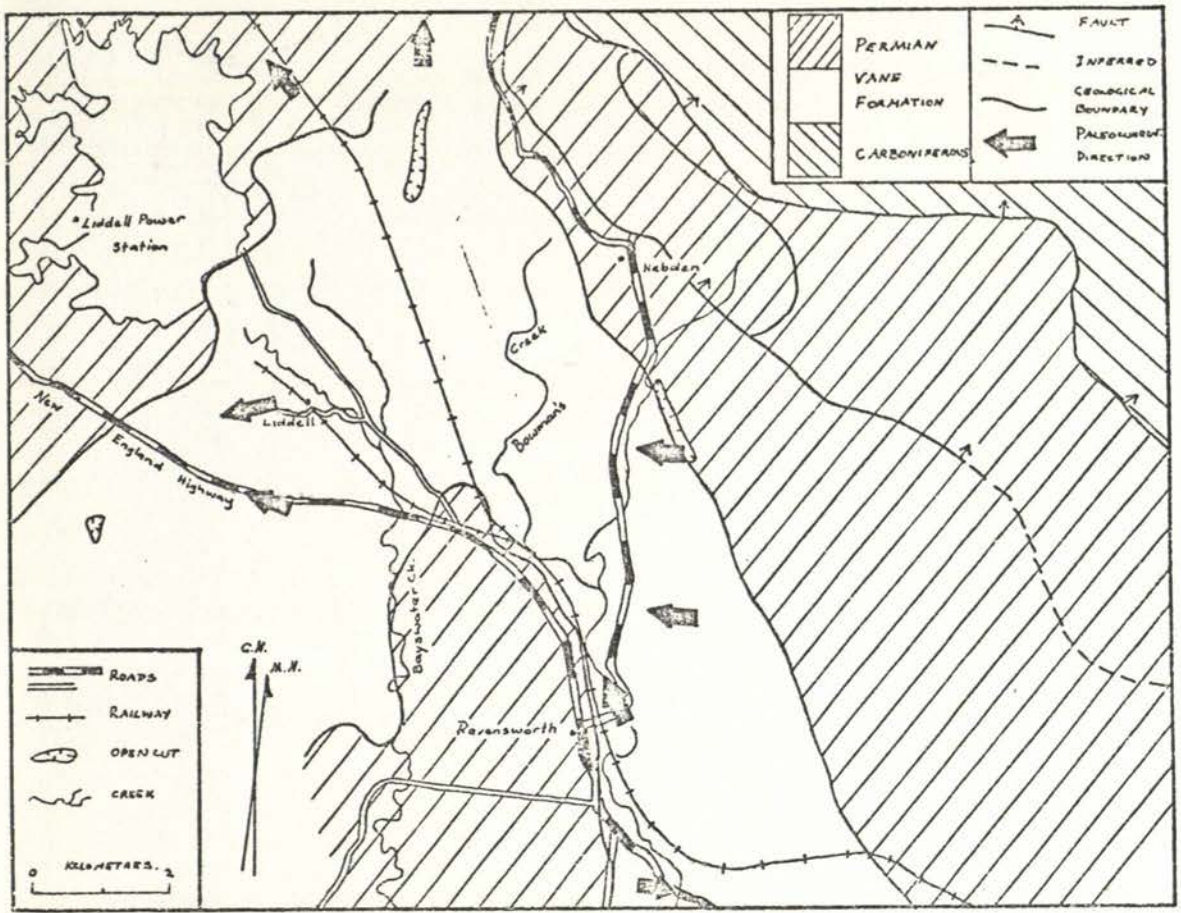


FIGURE 4: Inferred palaeocurrent directions in the Vane Formation as indicated by pebble imbrication and cross stratification (after Gray 1974, fig. 6).

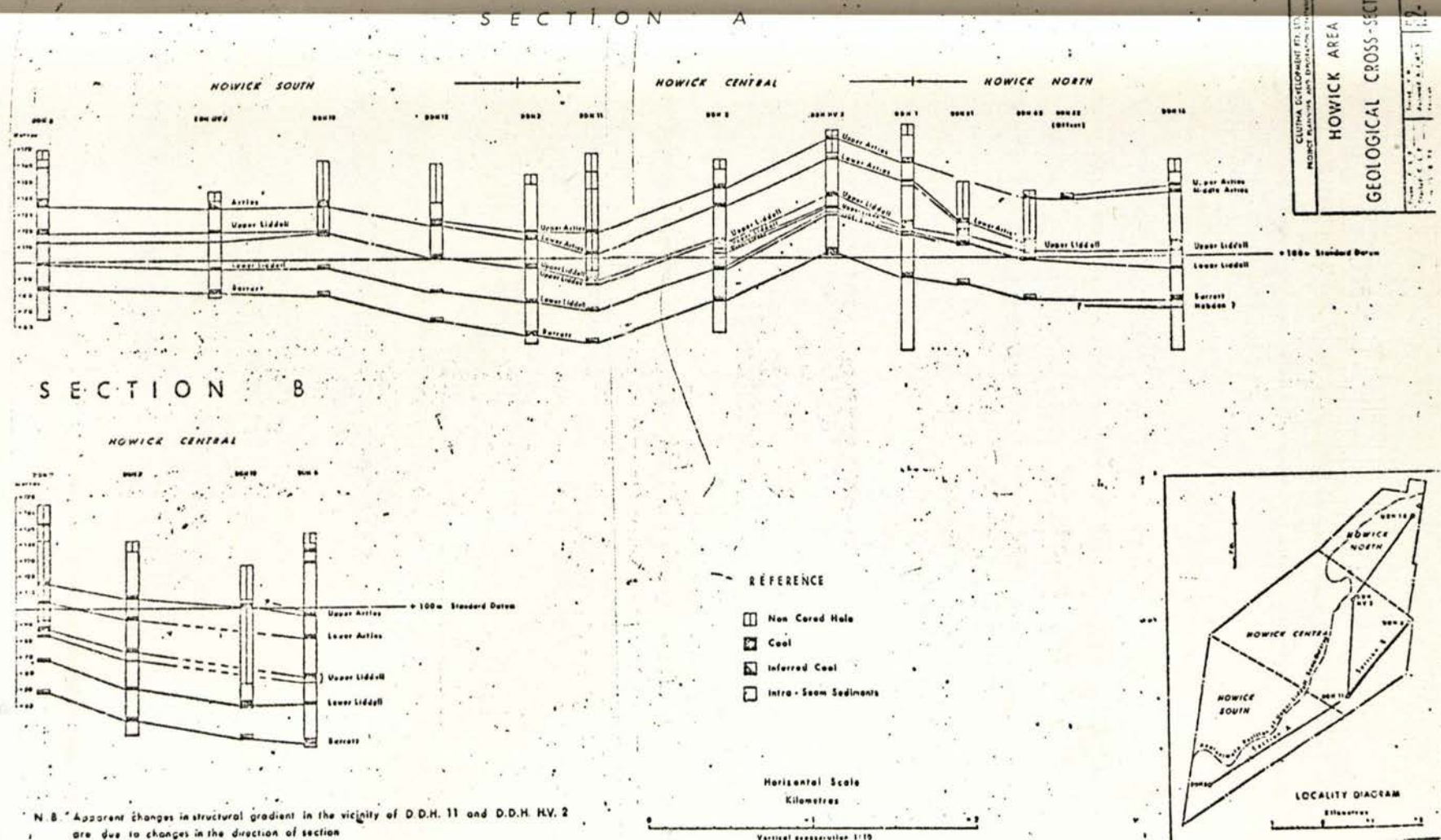


FIGURE 5: Geological cross-sections of the Howick Area showing the complex nature of stratigraphic correlation due to multiple progressive splitting of the Liddell and Arties Coal Seams. In the terminology employed in this report (see comments in text together with Fig. 6) the main Liddell Coal Seam in the Howick Area refers to the essentially unsplit or slightly split coal seam designated as "Upper Liddell" in the above diagram.

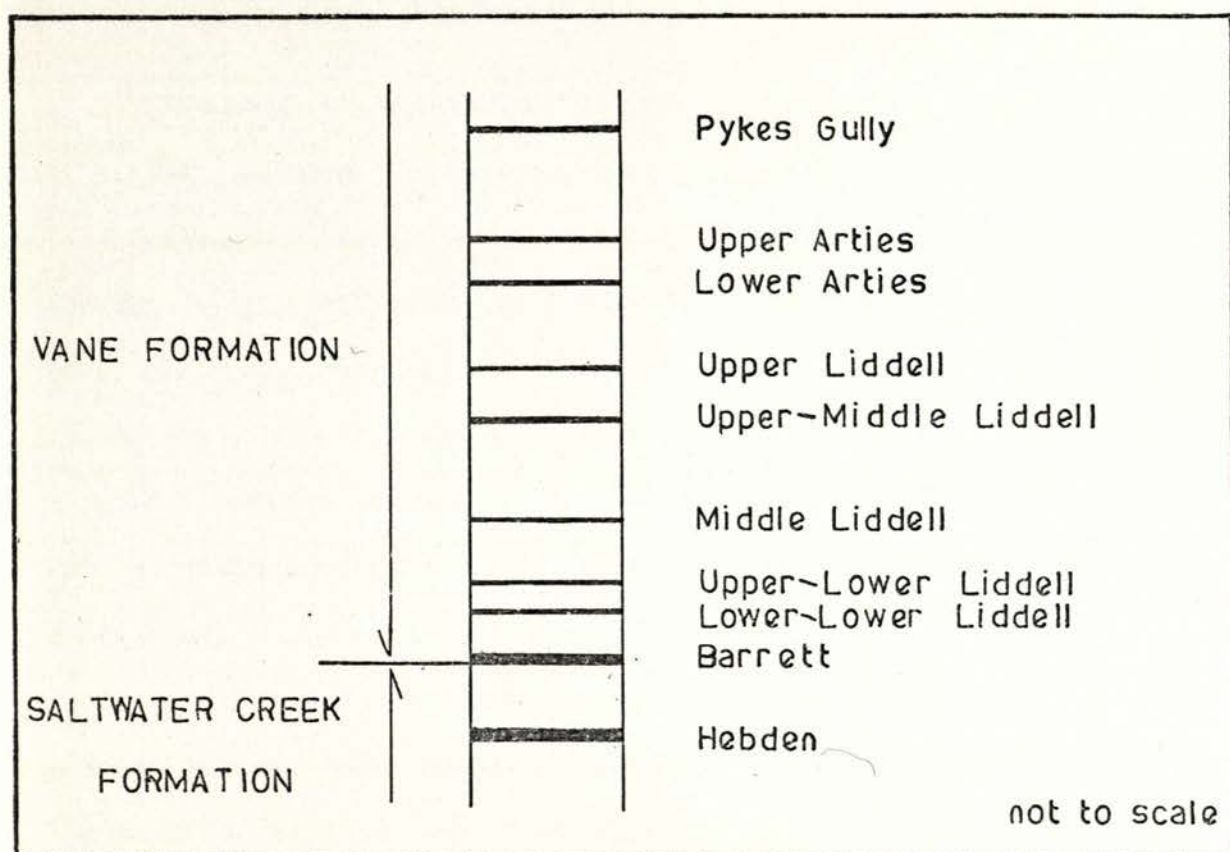


FIGURE 6:

Generalised stratigraphic column for the Liddell-Foybrook area showing terminology of both the major and minor coal seams (from personal communication with D. Marchoni, University of Newcastle, 1976). The term "main Liddell Coal Seam" refers to the thickest coal seam developed in the stratigraphic interval between the Barrett Coal Seam and the Arties Coal Seam (see Fig. 3) as a result of convergence of two or more plies. For example, in the Foybrook area the main Liddell Seam results from convergence of all of the ply-seams designated Liddell in the above diagram and locally incorporates through seam convergence the Lower Arties Seam as well (see Fig. 8). In the Howick area to the south (see Fig. 5) the main Liddell Seam includes fewer of these plies.

2.2 STRUCTURAL SETTING

The area lies within the "Dome Belt" of Voisey (in Packham 1969, p. 308), adjacent to the structural northern margin of the Sydney Basin - the Hunter Thrust. A subsidiary fault of the main Hunter Thrust, the Hebden Thrust, intersects the Sydney Basin succession just to the north of the study area and like the parent fault, locally trends approximately northwest-southeast (see Fig. 7). The "Dome Belt" of Permian rocks extends southwards for a width of approximately 24 kms normal to the Hunter Thrust before being obscured by the overlying Triassic rocks of the Narrabeen Group.

The structure of the study area is dominated by a series of open folds "... which are essentially minor warps on the eastern flank of the Muswellbrook Anticline" (Gray 1975, p. 16). The folds that intersect the area of present concern are the Camberwell Anticline and the Bayswater Syncline (Fig. 7). These folds trend in a north-south direction and are therefore discordant to the trend of the thrust faults to the north. The angle of dip of the limbs of these open folds varies, within the study area, between 5° and 20° (Gray 1972, map 2). The age of the north-south folds is inferred to be Early Permian, whereas the development of the Hunter and associated Hebden Thrusts is ascribed to the Late Permian (Gray, 1975). If this is so, the sedimentary accumulation of the Vane Formation took place during the active growth of the major thrust faults to the north and northeast. Gray (1971, p. 75) remarks that "The Singleton Coal Measures represent a clastic wedge association related to the rising New England Geosyncline and separated from it by the Hunter and Peel Thrusts. Within this association, Vane Formation sediments - generally mudstones, shales, sandstone, minor conglomerate and coal seams were deposited ... close to the basin margin."

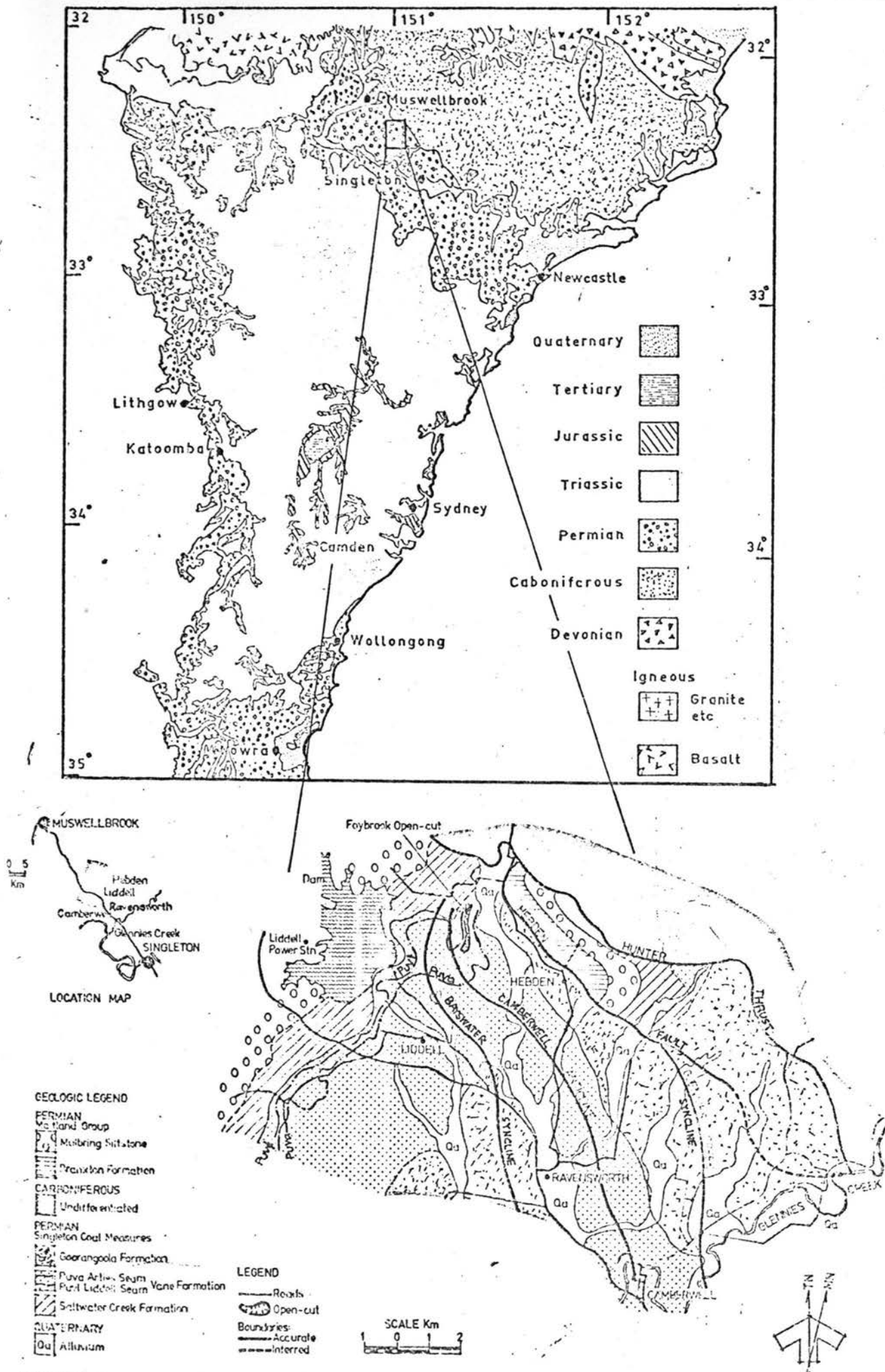


FIGURE 7: Regional structural elements and geology of the study area (after Bunny, 1969 and Gray, 1974).

CHAPTER 3

THE ANOMALOUS BEDDING STRUCTURES AT FOYBROOK: GENERATIVE MODELS AND THEIR EXPECTATIONS

3.1 GENERATIVE MODELS

The geology of this area has been studied by numerous authors: Raggatt (1930), Booker and Adamson (1951), Booker and others (1953), Booker and McKenzie (1956), Tompkins (1961), Duff (1967), Bunny (1967), Robinson (in Packham 1969, pp. 350-354), Gray (1971, 1974, 1975), Britten (1972), Britten and Smyth (1973) and Britten and others (1975) who have commented on the presence of the large scale inclined bedding structures and, more particularly in most cases, on the spectacular coal seam-split that occurs in the large Foybrook-Main (North) Open Cut (Appendix 2, Table A2.1) formed by a 3 m - thick ply of the main Liddell Coal Seam which rides up and conformably overlies the master crossbeds (see Fig. 8). Britten (1972; in Traves and King (eds.), 1975; and Britten with others 1975) in particular, has published accounts of the stratigraphy of the Foybrook area and has remarked especially about the presence of the coal seam-split at Foybrook within the stratigraphic interval studied in this report. Indeed Britten's work has been so wholly focussed on the seam-split at Foybrook as to have ignored the contiguous and laterally extensive development of geometrically similar structures associated with it throughout the 2 km - long highwall of the Foybrook-Main Open Cut and exposed within the same stratigraphic interval in other mines nearby (see Figs. 9, 10, 11, 12 and 13). Considering the widespread development of the crossbed set within the stratigraphic interval between the main Liddell and Arties Coal Seams, the seam-split at Foybrook-Main (North) Open Cut becomes a secondary, almost incidental, feature and geometrically can be considered simply as one of the many inclined beds that make up the cross-bed set (see Fig. 8). Britten has presented a model which is focussed solely on explaining the development of the seam-splits as secondary



FIGURE 8:

The spectacular coal seam-split in the eastern highwall of the Foybrook-Main (North) Open Cut. The lower horizontal seam is the main Liddell Coal Seam and the steeply inclined (up to 30°) ply is the Lower Arties Seam which further to the south coalesces with the Upper Arties Seam to form the Arties Seam (see Fig. 9). Note that the band of coal enclosed by the two dirt bands, arrowed, lenses out towards the split zone; this gives the coal band a geometric configuration (in dip-section) in no way dissimilar to the geometric configuration of the large scale crossbeds discussed in this report. The photograph was taken several years ago prior to abandonment of the open cut. Presently this particular section of the highwall is partly mantled by rock spoil dumped during subsequent mining operations above the highwall (photograph supplied by C. Herbert, Geological Survey of N.S.W.). For location of this seam split see Panorama P1.



FIGURE 9: Oblique view (looking south-southeast) of the highwall exposures in the Foybrook-Main Open Cut. The main Liddell Coal Seam is visible above the water level in the far end of the mine and at the base of the curved section of the highwall in the middle distance (arrows). Large scale inclined beds are conspicuous in the highwall above the Liddell Coal Seam and dip northerly towards the camera. The Arties Coal Seam is visible at the top of the highwall behind the road in the foreground (A.S.) Earth bridge divides the open cut into two sections designated North and South herein. Highwall averages 46 m above water level.



FIGURE 10:

Highwall exposure of the large scale crossbeds at Foybrook-S.E. Open Cut, east wall (see also Panorama P3). Main Liddell Coal Seam at bottom. The crossbed set extends high up the slope in the top right hand corner. In the middle and right of the photograph the inclined strata are exposed in dip-section, inclined approximately north, but due to an almost 90° change in orientation of the highwall the inclined strata in the distance are seen in strike-section. Scale division on draped banners is 1 m. Note progressive change in lithology from south to north in lower part of the highwall.



FIGURE 11: View (looking west-southwest) of the large scale inclined strata exposed in the south wall of the Foybrook-S.E. Open Cut (see also Panorama P3a). Liddell Coal Seam appears at base of highwall. Relative to the attitude of the inclined beds, highwall section is strike-parallel at the left end of the pit but changes progressively to an oblique section towards the far end. Note progressive change in lithology from near to far ends of the open cut. Banner scale divisions are 1 m.



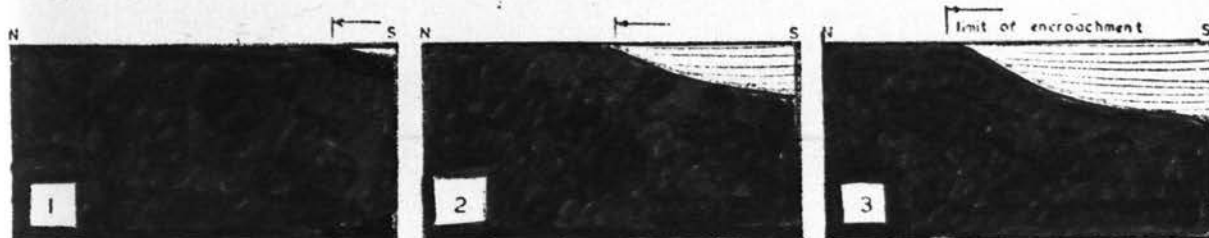
FIGURE 12: Highwall exposure at the Foybrook-S.W. Open Cut (west wall; see Panorama P4). Inclined strata overlie the main Liddell Coal Seam (covered by water in foreground) and dip towards the southwest. Banner scale divisions are 1 m.



FIGURE 13: View towards the northeast of the actively worked Howick Open Cut. The floor of the pit (where trucks are parked) forms the base of the main Liddell Coal Seam. Highwall section exposes the major part of inclined crossbed set but the topmost 2 - 5 m of the set has been removed by dragline operations in creating the working bench above and behind. The inclined strata dip from left to right in a direction towards the south-southwest (see Fig. 30). Crossbed lithology is dominated by sandstone. See also Panorama P5.

structures due to "mobile differential compaction" promoted by the laterally irregular loading of peat deposits by clastic sediments. The model assumes that the organic materials which generated the coal in the seam-splits were originally horizontally disposed. Thus Britten and others (1975, pp. 236-237) state: "... because of the necessity to accept that each peat bed is laid down horizontally in a coal swamp an unusual sequence of events has to be invoked to explain how the seams and splits have come to be so steeply inclined to each other." Britten (1972, in Traves and King (eds.), 1975) and Britten and others (1975) interpret the sedimentary rocks that form the inclined bedding structures as of fluvial origin with sediment accumulation taking place in horizontal to concave-up clastic wedges (Figs. 14 and 15). Then through mobile differential compaction Britten suggests the once sub-horizontal beds are subsequently bowed and rotated to form the inclined strata. This interpretation would seem to be based largely (if not solely) on his analysis of the geometrical configuration of the seam-split in the northern end of the Fcybrook-Main (North) Open Cut; certainly he fails to document the inclined beds in any of the other cuts, except for passing comment that the "... mobile compaction structure [between the Arties and main Liddell Coal Seams figured in Figure 14] is developed through a vertical interval of about 30 m and a lateral interval between 0.1 and 10 km" (Britten and others 1975, p. 237).

This idea most likely stems from a similar explanation proposed for British coal seam-splits by Raistrick and Marshall (1939; see Figs. 14 and 16 herein). Britten's model is clearly very elaborate but highly speculative and his diagrams (Figs. 14 and 15) bear little resemblance to the structures observed in the field (Fig. 9). Nevertheless, his suggestions that the coal seam-split and associated conformably inclined



DIAGRAMS 1-3 shows encroachment by sediment (assumed to be derived from NE. source) of Liddell Seam peat which compacts progressively.

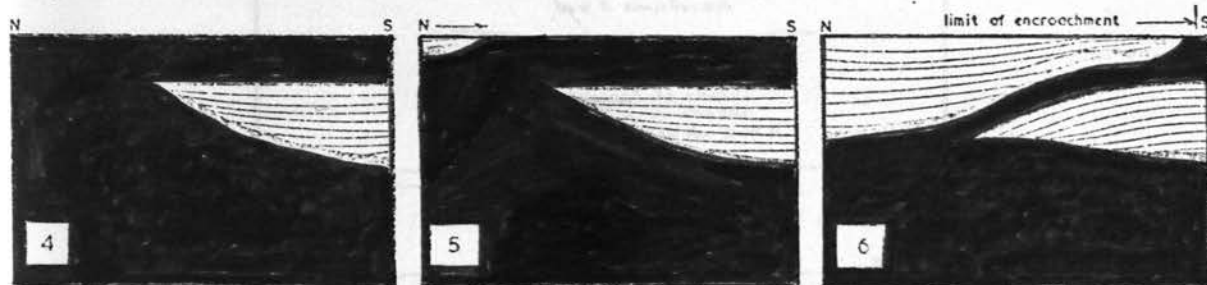
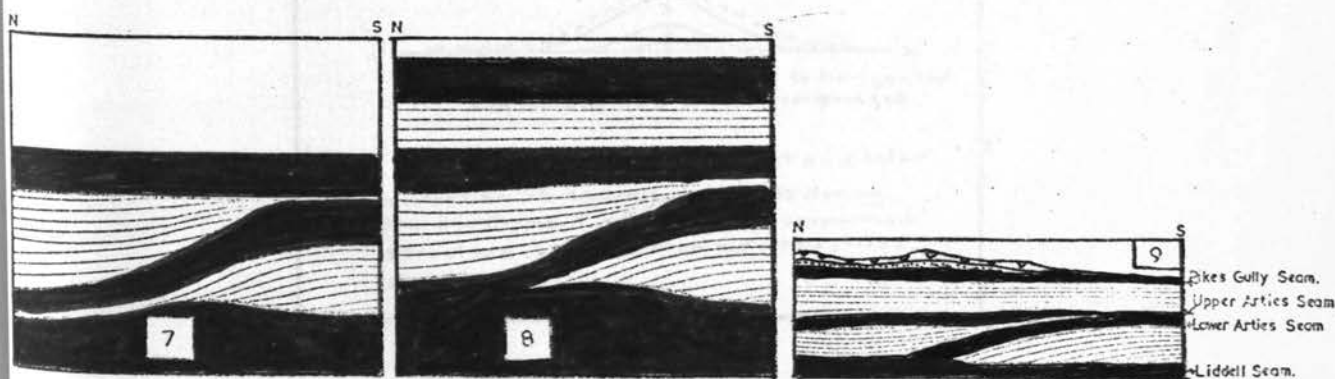


DIAGRAM 4 shows development of Lower Arties Peat.

DIAGRAMS 5& 6 shows encroachment by sediment (assumed to be derived from NE. source) of Lower Arties Seam peat. The underlying Liddell & Arties Seam peat compacts progressively in response to loading inter split sediment above Liddell peat is bent by loading as per diagram 6.



Arties Seam peat deposited.

DIAGRAM 8 shows situation with deposition of Upper Arties peat, Pikes Gully Seam & Inter Seam sediments.

Diagram 9 shows disposition of Seams after coalification with compaction of 10:1 from peat & 3:2 from inter seam sediments.

COAL OR PEAT
INTER SEAM STRATA

VERTICAL & HORIZONTAL SCALE IN FEET
200 100 0 100 200

FIGURE 14: Interpretation of the origin of coal seam-splits within the Singleton Coal Measures (from Britten 1972, figure 4).

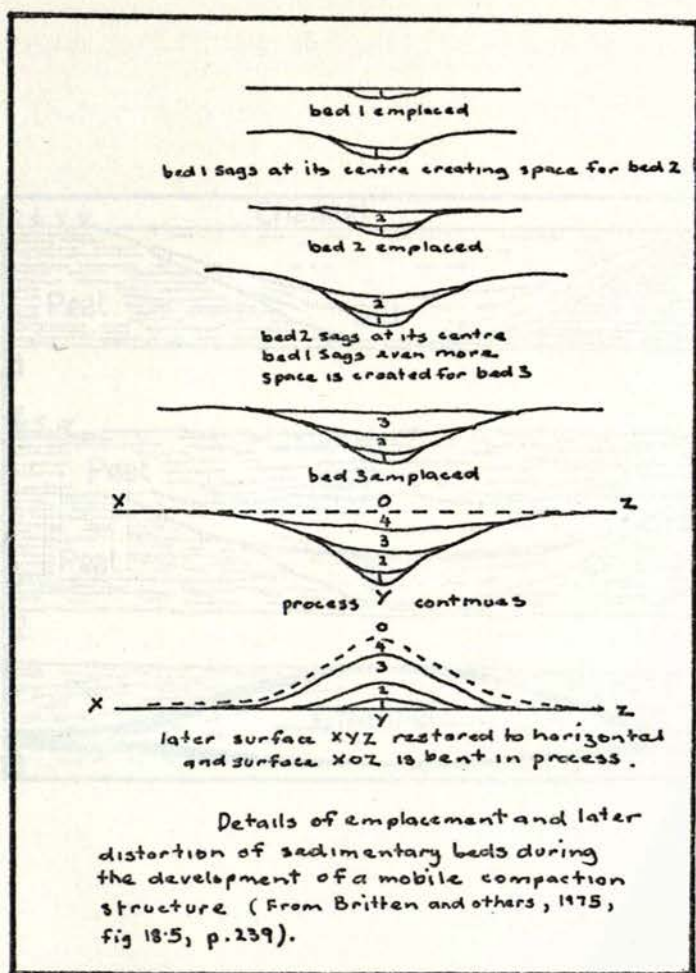


FIGURE 15: Inferred history of emplacement and subsequent distortion of sedimentary rocks during the development of mobile differential compaction structures (from Britten and others 1975, fig. 18.5, p. 239).

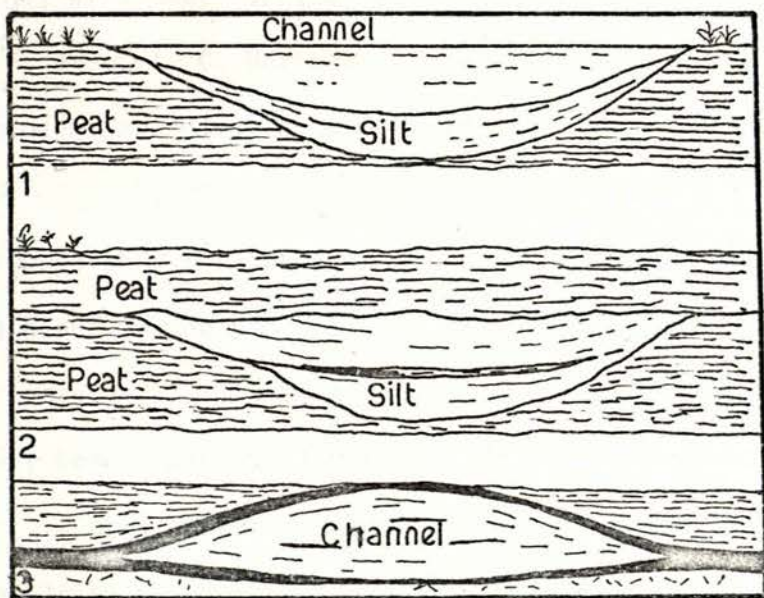


FIGURE 16: A conceptualized model for the origin of coal seam-splits as suggested by Raistrick and Marshall (from Raistrick and Marshall 1939, fig. 6, p. 75).

strata are of secondary origin and caused by processes of "mobile differential compaction" is the currently accepted view with many Australian coal geologists, judging by the support for the idea in the literature (e.g., Williams, 1976, p. 7; and personal communications (1976) with C.F. Diessel, C. Herbert, D. Marchoni and C. Ward) and its application to other examples in coal fields outside N.S.W. (e.g., Burgis, 1975).

I propose that the large scale crossbed structures are not of secondary origin and formed by "mobile differential compaction", but instead are primary and formed by normal depositional processes. This idea has already been mooted by Tompkins (1961) when he states: "Sedimentation ... does however suggest periods of great instability, with rapid deposition of clastic sediments showing inclined or foreset bedding, and periods of relative quiescence during the formation of coal seams. These sedimentary structures are clearly evident in the Liddell Sandstone, above the Liddell Seam, in open cut areas." A primary depositional origin for crossbeds was also suggested by Bunny (1967) in reference to the large scale crossbed structures of sandstone, siltstone and shale at Foybrook: "This body of water received no sediment until the sudden influx of sand which forms the foresets." Booker and others (1953) describe the crossbed structures as "... a series of interlocking lenses, of which the horizontal axes are not always parallel to true bedding, and there is frequently an angular difference of as much as 30 degrees between true bedding as represented by a shale bed or a coal seam and that of the greywacke lenses." In other parts of the same report (Booker and others 1953) and again in Booker and McKenzie (1956, p. 14) there are clear inferences that the structures are primary.

Further inferences as to the primary nature of the large scale inclined strata in the Hunter Valley Coal Measures are made by Rattigan and McKenzie (in Packham 1969, p. 434) when they state: "The commencement of this period ["Tomago-Newcastle"/"Singleton" Time] saw a gradual transition from obviously marine sedimentation to coal-forming conditions, and thick accumulations took place in troughs subsiding east and west of the Lochinvar Anticline. The relative stability of coal-forming conditions in Tomago time was in marked contrast to those in Newcastle time whereby arenites, with torrential cross-lamination developed on a grand scale, were deposited above and sometimes immediately on top of coal seams." Similar statements about the primary depositional origin of these same crossbeds were earlier made by David (1907) in reference to the examples exposed in coastal escarpments south of Newcastle.

To the extent that these large scale crossbed structures are unusual and, as yet, unknown in the more general geological literature, their presence in the coal measure sedimentary terrains of eastern Australia would seem to have been viewed by many local geologists as anomalous and enigmatic if only because of their imposing scale. However, notwithstanding the reference to and occasional illustration of the actual coal seam-split at Foybrook by earlier workers, it is not untrue to say that the seam-split and associated large scale crossbeds of this area have not been investigated or documented as yet in any detail. Hence, neither of the models outlined above to account for the origin of the large scale inclined bedding structures have been tested on the basis of detailed field studies in this area. The aim of the present project is therefore to fulfill this need.

3.2 EXPECTATIONS OF THE TWO MODELS

Both primary and secondary origins have been suggested to account for the large scale inclined bedding structures. Hence one might expect inherently different predictions to follow from each of these theoretical models. Several consequences might be expected if the large scale inclined beds formed as secondary structures due to mobile differential compaction:

- (1) One would expect to find abundant evidence of soft sediment disruption or deformation within those parts of the crossbeds that experienced wholesale rotation or collapse (Fig. 14, stages 5 and 6): e.g., folds of varying scale and geometrical style; faults (perhaps mainly antithetic faults); and clastic injection structures of various kinds.
- (2) One might also expect to find a coarse-to-fine/proximal-to-distal lateral facies change inherent in the generation of the clastic wedges in the Britten model.
- (3) Britten (1975, p. 237), in reference to a figure reproduced as Figure 16 herein, claims: "... it can be seen [from the figure] that the cross section of beds tends to be thicker at their centre."
- (4) Furthermore, another expectation arises from Britten's model when one speculates about the predicted final geometry of the contact between the underlying coal seam and the overlying inclined bedding structures (Fig. 14). Thus, one might expect to see evidence for a concave up contact between the

coal seam and the overlying clastic material due to the simultaneous vertical accretion of peat and clastic sediment side-by-side, ongoing with progressive but partial mobile compaction in response to the laterally expanding fluvial system (see Fig. 14, stages 2, 3, 4 and 5). If, alternatively, (as Britten and others, 1975; Britten, 1972, suggest), this concave-up contact is finally bowed up and flattened by later mobile differential compaction (again inferred from Fig. 14, stages 5, 6 and 7) then one would expect to see conspicuous evidence of large scale disruption and deformation in response to this later compaction in at least the top several metres of the underlying coal seam.

One would expect to find field evidence for some or all of the above predictions if the crossbed structures are actually of secondary origin.

Alternatively, if the crossbeds are primary structures, one might expect to find:

- (1) A systematic and perhaps constant relative geometric relationship between current-produced structures within the master crossbeds and the master crossbeds themselves.
- (2) Possibly a difference in coal types between that found in the seam-splits and that found in the main seams, should the organic materials that accumulated on the locally inclined surface have differed materially from that which accumulated on essentially horizontal surfaces to generate the main regionally-extensive seams.

(3) Geopetal evidence that bedding is primary; for example:

(a) in situ tree stumps within the inclined bedding structures that retain a right angle relationship to the lower bounding surface of the crossbed set;

(b) a systematic relationship between component mean grain size of the clastic sediment and angle of divergence of the crossbeds from the underlying coal seam.

CHAPTER 4

STRATIGRAPHIC CONTEXT OF THE LARGE
SCALE INCLINED BEDDING STRUCTURES
IN THE FOYBROOK-LIDDELL-HOWICK AREA

4.1 REGIONAL CONSIDERATIONS

As previously mentioned, the large scale inclined bedding structures studied in this report occupy the stratigraphic interval between the main Liddell and Arties Coal Seams in the lowest part of the Vane Formation (the basal formation in the Singleton Coal Measures). Like other formations in the Singleton Coal Measures and succession, the Vane Formation has been mapped in outcrop over a regionally extensive tract along the northern structural margin of the Sydney Basin in the area west of the Lochinvar Dome and has been followed into the subsurface in many areas by coal exploration drilling. The outcrop zone forms a V-like pattern around the southwestern and southeastern limbs of the Muswellbrook Anticline on the west but in approaching the Hunter Thrust, the north swings southeasterly along the crestline of the Camberwell Anticline (Fig. 17). The gentle easterly and southeasterly structural dip along the eastern flank of the Muswellbrook Anticline has led to a concentration of coal exploration and mining activities in this area and hence the most detailed stratigraphic information also comes from here, particularly so for the area immediately about Liddell. In his review of the Singleton Coal Measures, Robinson (in Packham, 1969, p. 351) remarks that: "The most reliable horizons in the measures are without doubt coal seams and because of the extreme lenticularity of the associated beds, ... the naming and correlation of members other than coal seams are most hazardous ..." Drilling programs, together with surface outcrop mapping, has permitted both local and semi-regional stratigraphic correlation of the lower part of the coal measures around the limbs of the Muswellbrook Anticline and indicates continuous areal development of all the major coal seams throughout the region, but

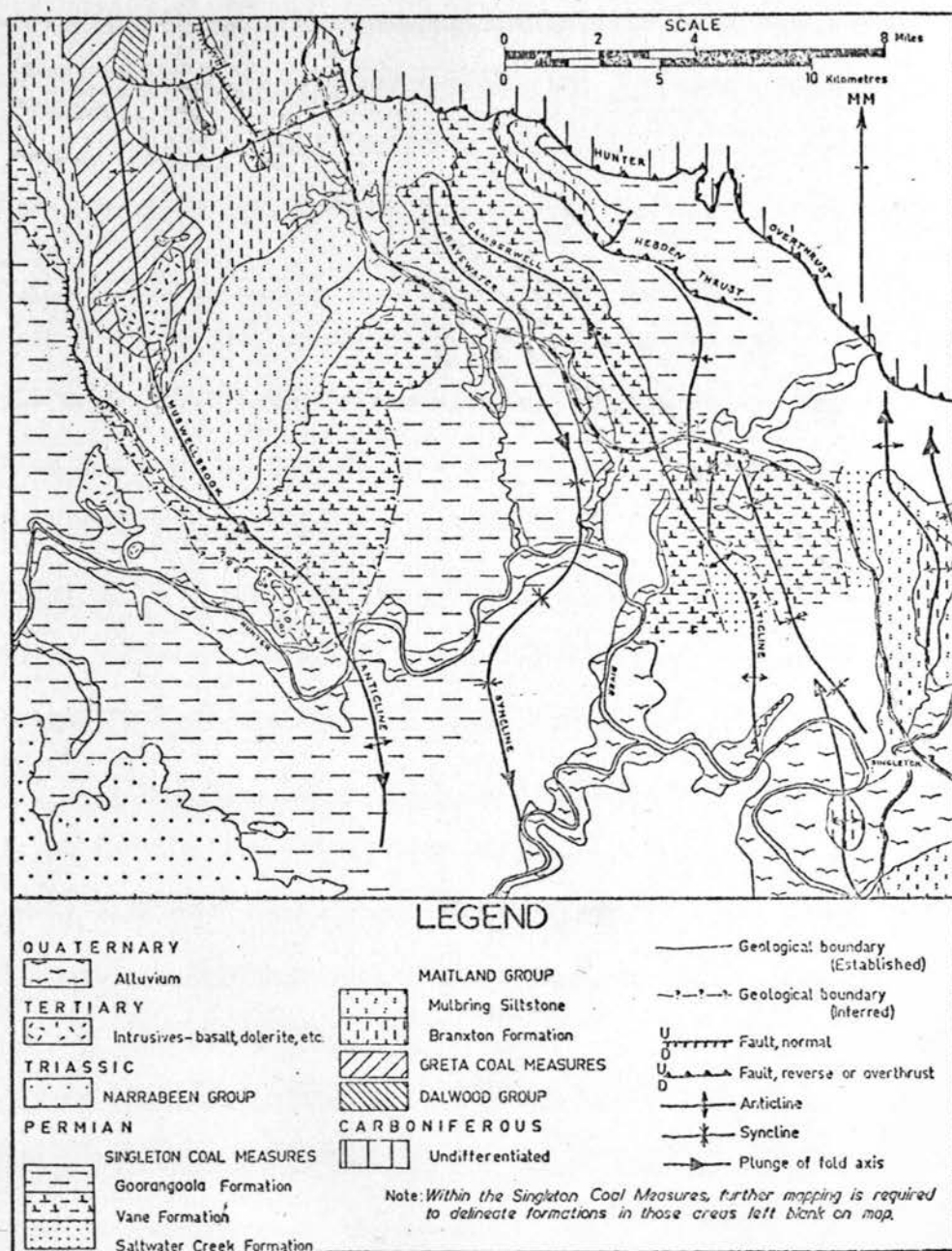


FIGURE 17: Geological map of the area northwest of Singleton. Note the V-shaped surface outcrop pattern of the Vane Formation about the southern nose of the Muswellbrook Anticline. To the northeast of the Muswellbrook Anticline the Vane Formation swings around to the southeast and south following the trace of the Camberwell Anticline (from Packham, 1969, p. 354).

accompanied nevertheless by numerous seam-splits (e.g. see reports by Veevers 1953, 1960; Bunny, 1967 and Britten in Traves and King (eds.), 1975). Similarly, Marchoni (personal communication, 1976) has established good correlations in the area to the east and northeast of Liddell and his work indicates extension of the major coal seams throughout the area but accompanied again by seam-splits. In summary, then, the major coal seams in the succession (including the Liddell and Arties seams of concern in this report) are laterally persistent and maintain an identity over a regional area (in the order of at least 100 sq. km) despite complication of stratigraphic correlation caused by seam-splits. Clastic intervals between the coal seams evidently show much greater lateral variation in lithological composition and thickness over much of the area. For example, the interseam intervals between the Barrett and Lower Liddell Coal Seams and the Upper Liddell and the Lower Arties Coal Seam have been termed the Barrett Sandstone Member and the Liddell Sandstone Member respectively (Veevers, 1960; Tompkins, 1961) in the areas studied by these two workers.

In the area around the southern nose of the Muswellbrook Anticline (Fig. 17) Veevers (1953, 1960) showed, from borehole data, that the various split components of the Liddell Seam (i.e., the Upper Liddell, the Middle Liddell and the Lower Liddell overlie the Barrett Sandstone Member (approximately 14 m above the Barrett Coal Seam) and the Arties Coal Seam overlies the Liddell Sandstone Member. In the area studied by Veevers the main Liddell Coal Seam has a thickness of 5.3 m and the Arties Coal Seam has a mean gross seam thickness of 5 m, though the latter seam has a very variable thickness, ranging between 1.8 m and 8.7 m.

In the study area of this report, northeast of the area studied by Veevers, the main Liddell Coal Seam attains an average thickness of

7 m at Howick but where the Lower Arties Seam has converged with the Liddell Seam it attains a maximum thickness of 14 m (Britten, in Traves and King (eds.), 1975). The Upper Arties Coal Seam has a thickness of about 2.8 m. To the north-northeast the surface outcrop traces of the Liddell and Arties Coal Seams abut the Hebden Thrust (Gray, 1971; Fig. 7). These two seams do not outcrop again in the east but subsurface data indicate that they occur in the area to the east and northeast of Liddell. No published information as yet is known of the possible continuation of the main Liddell and Arties Coal Seam to the south and southeast of the Liddell Area.

There is no palaeontological evidence to suggest anything other than non-marine environmental conditions throughout that part of the coal measures considered in this report.

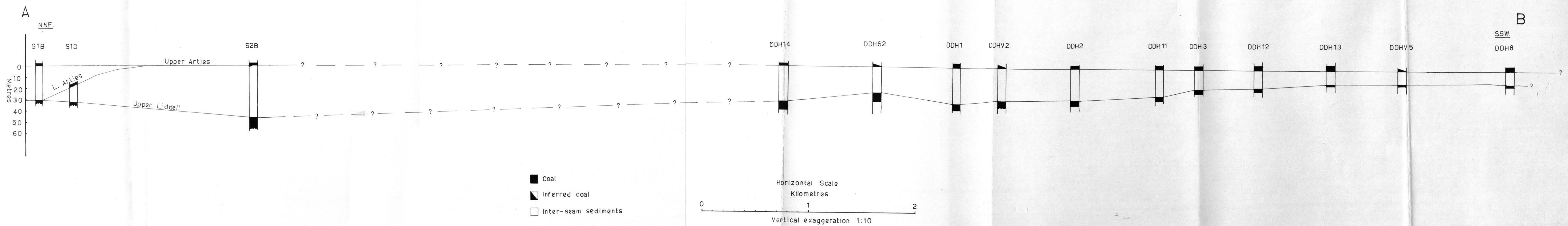
4.2 LOCAL ASPECTS

Compared to the known areal extent of the stratigraphic units of interest in this report (i.e., main Liddell Coal Seam, Arties Coal Seam, and the intervening clastic unit between these two seams - the "Liddell Sandstone Member" of Tompkins, 1961), the study area covered by field examination of this interval in the open cut exposures is not large. The stratigraphic interval is exposed in the north in the various Foybrook open cuts, in the Liddell area in the Liddell-Portal and Durham Open Cuts, and in the south in the Howick Open Cut (Table A2.1, Map 1) and is almost flat-lying throughout. Using the logged sections in these open cuts and drill hole data from the intervening areas a cross-section of this interval was constructed (Fig. 18). Between the southern area (Howick) and the northern area (Foybrook) drill hole data are sparse, but

FIGURE 18:

Cross section A - B of the interseam sedimentary unit between the top of the Upper Liddell (termed the main Liddell Coal Seam in this report) and the base of the Upper Arties Coal Seam (referred to as the Arties Coal Seam in the report). The locality of part of the section (A - A₁) is shown on Map 2; the rest of the section (A₁ - B: equivalent to DDH11 - DDH8) is located in locality diagram of Figure 5. In the construction of the cross-section, the Upper Arties Coal Seam has been restored to horizontality; from the figure one can see clearly that the interseam thickness gradually thins to the south-southwest, indicating a semi-wedge regional geometry.

FIG. 18



assuming that there are no lateral interruptions in the areal development of the structure it is evident that the inclined bedding structure most likely has a lateral extent of at least 7.0 km in a north-northeast-south-southwest direction. Within this distance the dip-azimuth of the inclined beds changes from being approximately northerly in the north to approximately southerly in the south (Map 2). A gross thinning of this stratigraphic interval occurs from north to south (Fig. 18; Table 2) with some local areas of thinning and thickening superimposed on this overall trend. Thus the regional geometry (or external form) of the set of inclined beds in this area would appear to be grossly tabular or semi-wedge-like with progressive thinning towards the south.

(a) Stratigraphic Units Immediately Below and Above
the Set of Inclined Beds

The general characteristics of the stratigraphic units which immediately underlie and overlie the set of inclined beds are tabulated in Table 3 (see also Sections S2A and S2B). Although the inclined beds are everywhere underlain by the Liddell Coal Seam in the open cut mines and good exposures of the latter unit are consequently common, the units which immediately overlie the set of inclined beds (i.e., the Arties Coal Seam and a superimposed pebbly sandstone unit; see Fig. 20 and Sections S2A and S2B) are rarely preserved in or adjacent to the open cuts because of open-cut mining of the Arties Coal Seam itself and because working benches have been cut down below this level in some open cuts (i.e., Howick) to allow continued open cut mining of the underlying Liddell Seam (see Figs. 9 and 13). Table 3 indicates where the outcrop of the

TABLE 2:

Thickness gradient of large scale crossbed-set with the lower bounding surface of the Upper Arties Coal Seam restored to horizontality. The vertical thickness of the interseam unit between the Upper Liddell and the Upper Arties (which coalesces with the Arties in some logs) was measured from the original draft of Figure 5; the horizontal distance between each of the drill holes was also measured. Using the simple trigonometric relationship

$$(\tan\theta = \frac{V}{H})$$

a dip-angle between two consecutive drill holes can be computed after restoring the Upper Arties to horizontality. This dip-angle indicates the gradient of the lower bounding surface of the crossbed-set, i.e., the top of the Upper Liddell Coal Seam. The tabled results indicate a gross thickening of the crossbed-set towards the north in the Howick area; this trend continues further northeast to the Foybrook area.

Drill Hole Nos.		$\frac{V}{H}$	Angle ^o	+ = increase - = decrease	in cross- bed thickness
NORTH	DDH 14				
	DDH 62	.008	- 30'		
	DDH 1	.011	+ 38'		
	DDH V2	.006	- 18'		
	DDH 2	.002	- 7'		
	DDH 11	.005	- 17'		
	DDH 3	.015	- 52'		
	DDH 12	.005	- 17'		
	DDH 13	.011	- 38'		
	DDH V5	0	0		
SOUTH	DDH 8	0	0		

TABLE 3:

GENERAL CHARACTERISTICS OF THE STRATIGRAPHIC UNITS WHICH STRATIGRAPHICALLY UNDERLIE AND OVERLIE INTERVAL OF LARGE SCALE INCLINED BEDDING IN THE FOYBROOK-LIDDELL-HOWICK AREA

Bracketing Unit	Locality of the Bracketing Unit	Geometry	Lithology	Fossils	Sedimentary Structures	Palaeo-current Trends
The pebbly sandstone above the Arties Coal Seam	Exposed at Foybrook Main Open Cut and at Howick Open Cut	Sheet-like tabular. Has a minimum thickness of 6 m	Pebbly sandstone - coarse to fine quartz rich sandstone. Clasts in pebbly sandstone are volcanogenic quartz, jasper, chert - well rounded to sub-rounded. At Foybrook the sandstone is pebbly - at Howick the sandstone is coarse and quartz rich	Coalified woody fragments in the form of stems and branches	Decimetre-scale cross-beds (up to 80 cm thick defined by pebble layers and subtle grain size differences	Northerly at Foybrook deduced from trough crossbedding
INTERVAL OF LARGE SCALE INCLINED BEDDING						
The Liddell Coal Seam	Exposed in all Open Cuts mentioned in this report	Sheet-like maximum thickness of coal seam 10 m at Foybrook Main Open Cut. Approximately 7 m thick coal seam at Howick Open Cut	Bright and dull coal. The seam contains dirt bands of clay rock and siltstone. These dirt bands are thin approximately 7 cm thick and are laterally very continuous - over tens of metres. The dirt bands have very sharply defined upper and lower bounding surfaces	Woody material, spores and leaf coatings and fragments in situ tree stumps have their base in contact with the upper bounding surface of the coal seam. Upright stumps in and above the coal only occur at Howick Open Cut.	Small scale 'fish tail' structures as seen in Raistrick and Marshall (1939) - these structures seen only at Howick. They occurred right at the contact between the coal and the overlying gross bed set	No definitive indicators found

Arties Coal Seam and overlying pebbly sandstone are located. Because the character and internal stratigraphy of the Liddell Coal Seam is relatively uniform throughout the study area (Table 3) the following discussion concentrates on the units which overlie the set of inclined beds.

(b) Lithology and Sedimentary Structures

The lithology above the Arties Coal Seam in both of the Sections (Sections S2A and S2B) is quite different from that which comprises the large scale inclined beds themselves (Fig. 19); it is the first occurrence of any very coarse to pebbly sandstone in that part of the stratigraphic succession studied in this report. This very coarse to pebbly sandstone has a regionally planar lower bounding surface (Fig. 20) which is sharply defined and locally discordant with the underlying shale (Fig. 19). The approximately 1 m - thick shale unit has a transitional boundary with the underlying Arties Coal Seam. The coarse-pebbly sandstone fines up into a siltstone over a vertical distance of about 3 m and this, in turn, is succeeded by another very coarse yellow sandstone with an erosional base. The clasts within the pebbly sandstone are well rounded to subrounded, attain a maximum size of 5 cm and consist of quartz, vein quartz fragments and red, grey and green chert-like fragments. The coarse sandstones above the Arties Coal Seam at the Foybrook-Main (South) and Howick Open Cuts are conspicuously cleaner and more quartz-rich than any of the sandstones within the large scale inclined bedding structure.



FIGURE 19: Very coarse decimetre-scale crossbedded sandstone overlying fine carbonaceous siltstone immediately above the Arties Coal Seam. The boundary between the sandstone and siltstone is regionally planar but locally quite irregular (see Fig. 20 and Section S2A). Locality of photograph 3 m above Arties Coal Seam, Section S2A; the fossil flat-lying log in middle right of photograph is $1\frac{1}{2}$ times the length of geological hammer. The travel direction indicated by the crossbedding is towards the north.

The dominant sedimentary structures in the pebbly sandstone unit above the Arties Coal Seam are decimetre-scale trough crossbeds (Fig. 19). These are usually found in cosets reaching a thickness of 2.0 m, with individual crossbed sets of up to 80 cm thick. The crossbedding is defined by the presence of pebble layers or by more subtle grain size changes in the very coarse sandstone (Fig. 19). Although only limited outcrop of the pebbly sandstone is available for study the predominant direction of foreset inclination in the decimetre-scale crossbeds is northerly in Foybrook-Main Open Cut. No palaeocurrent indicators were found in the very coarse sandstone at Howick Open Cut.

(c) Fossils

Macerated plant fragments occur in the siltstone units above the Arties Coal Seams (Sections S2A and S2B). They are obviously allochthonous and lie along bedding planes; they also define wavy and parallel laminations which occur in the siltstone units. Flat-lying fossil logs are found sporadically in the siltstone units (Fig. 20) and there are rare examples of fossil logs in the pebbly coarse-to-medium sandstone at Foybrook-Main Open Cut (South) (Fig. 19). No fossil logs were found in these units above the Arties Coal Seam at Howick Open Cut (Table 3).



FIGURE 20: Three silicified fossil logs (arrowed) lying along a bedding plane in a carbonaceous siltstone unit 8 m above the Arties Coal Seam. The top of the photograph shows the coarse sandstone with a locally erosional lower bounding surface. Locality: Section S2B, Foybrook-Main Open Cut (South).

CHAPTER 5

NATURE OF THE INCLINED BEDDING STRUCTURE IN THE STUDY AREA

5.1 EXTERNAL FORM

The external form of the inclined bedding structure has already been discussed in the previous chapter. The set of inclined beds is seen to be at its thickest in the north (at Foybrook-Main Open Cut) and then thins very gradually towards the southwest towards the Howick Open Cut area (Fig. 18). Measured over 10.0 km (the distance between the extreme ends of Foybrook-Main Open Cut to the north and Howick Open Cut to the southwest) there is a very gentle thinning to the southwest with a gradient at the base of the crossbed set of approximately 0.1° (restoring the bottom of the Arties (or Upper Coal Seam) to horizontality and using 48 m as the maximum interval thickness in the north and 18 m as the maximum in the south; Fig. 18).

5.2 LITHOLOGY

(a) Lateral Variation

Lateral changes in bulk lithology occur within the set of inclined beds on a regional scale and, in order to document these changes, sandstone and siltstone percentages were calculated from each of the stratigraphic Sections logged in the open cuts. The cumulative thickness of the sandstone beds was computed and expressed as a percentage of the total thickness of the crossbed-set; the same method produced the siltstone percentages for each of the Sections (Table 4). A mean percentage of sandstone and siltstone was also computed for each cut by combining together the data from the different logs at that mine (Table 4).

TABLE 4:

Cumulative amounts of sandstone and siltstone, expressed as a percentage, derived from the stratigraphic logs made in the open cuts (see Sections in back pocket). The figures in parentheses represent the mean sandstone and siltstone for the Foybrook-Main (North and South) Open Cut and the Foybrook-S.E. Open Cut (i.e., combined south and east-wall logs).

Open-Cut Mines	Sections	% Sandstone	% Siltstone	Mean % Sandstone	Mean % Siltstone
Foybrook-Main (North)	S1C	67	33	78	22
	S1D	92	8		
				(58)	(42)
Foybrook-Main (South)	S2A	40	60	38	62
	S2B	37	63		
Foybrook-S.E. (east-wall)	S3A	4	96	50	50
	S3B	94	6		
				(39)	(61)
Foybrook-S.E. (south-wall)	S3aC	40	60	29	71
	S3aD	24	76		
	S3aE	24	76		
Foybrook-S.W.	S4A	22	78	23	77
	S4B	31	69		
	S4C	16	84		
Howick	S5A	92	8	78	22
	S5B	85	15		
	S5C	72	28		
	S5D	63	37		
Foybrook-Box	None logged	No quantitative data; but field observation shows siltstone/shale to be the predominant lithology. General lithological aspect similar to that at Foybrook-S.E.			

In the northern area, within the Foybrook-Main Open Cut the lithology is quite heterogenous (Panoramas P1 and P2; Fig. 21) and the mean percentage of sandstone ranges from 37% to 92% in the four Sections logged there. Sandstone is mainly concentrated in the lower and middle parts of the inclined bed-set whereas siltstone is concentrated in the upper parts of the set (Figs. 21, 22; Panoramas P1, P2).

Siltstone is the predominant lithology in the Foybrook-S.W. Open Cut as it is also throughout all but the southeast corner of the Foybrook-S.E. Open Cut (Figs. 10, 11, 12; Table 4). Though no log was made there the predominant lithology at the Foybrook-Box Cut is also siltstone.

Within Foybrook-S.E. Open Cut there is a conspicuous progressive coarsening of bulk grain size and increase in the percentage of sandstone towards the southeast (Sections S3A, S3B, S3aC, S3aD, S3aE; Figs. 10, 11, 25). In the eastern wall of this mine sandstone beds dominate the section in the southern end of the cut (Fig. 25) but towards the north the predominant lithology is siltstone (sandstone percentages are 4% and 94% in the north and south of this wall respectively at Sections S3A and S3B respectively). The same coarse-to-fine relationship and progressive lateral change in the percentage of sandstone occur in the southwall of this same mine (Table 4; Panorama P3a, Fig. 11). Thus at the eastern end of this wall there are more sandstone beds which become less dominant and thinner towards the west.

At Howick Open Cut in the south of the study area the lithology is more homogenous throughout than at the other



FIGURE 21: An oblique panorama view of the inclined strata overlying the main Liddell Coal Seam in the eastern highwall of the Foybrook-Main Open Cut (South). The highwall section is essentially dip-parallel with respect to the attitude of the inclined beds, and the view looks towards the southeast. Sandstone (lighter coloured) is mainly concentrated in the lower and middle parts of the crossbed-set. Siltstone and shale (darker colours) predominate in the upper portion of the set though some siltstone also occurs in the lower and middle parts of the set. Note that the gross shape of the inclined beds in this dip-section is sigmoidal (i.e., strong asymptotic relationships of the inclined beds at the base and top of the set and steeper gradients in the central part of the set). The Liddell Coal Seam is just below the water level except in two places (arrows). Highwall (below level of the lower bench) is approximately 45 m high.

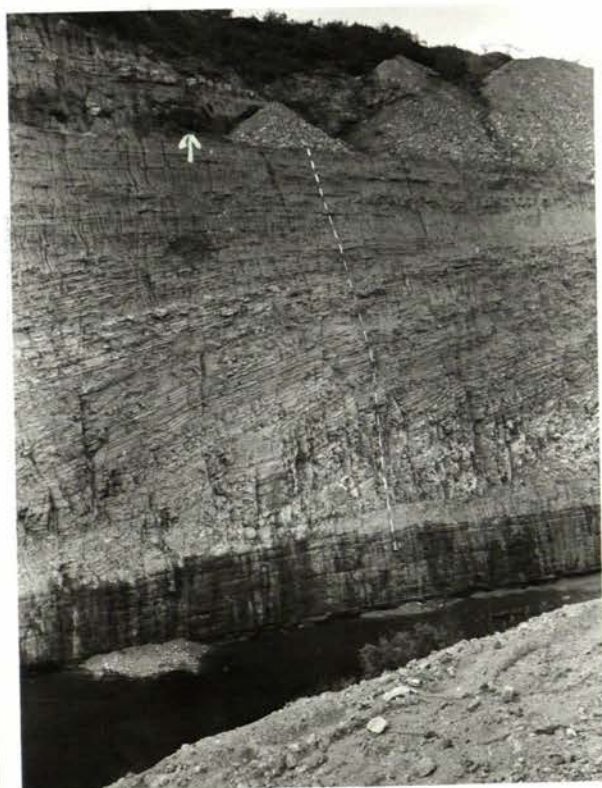


FIGURE 22: A close up of the eastern highwall in the southern part of the Foybrook-Main (South) Open Cut. Liddell Coal Seam at bottom of exposure. Section S2B was logged at the position of the metric banner scale. Sandstone is concentrated in the lower half of the inclined bed-set whereas siltstone dominates the upper half (see Fig. 21). The top of the inclined bed-set is defined by the base of the Arties Coal Seam (arrowed). The pebbly sandstone unit which overlies the Arties Coal Seam forms the conspicuous resistant zone in the topmost part of the cliff above the bench. The canvas banner has 1 m subdivisions. Note that an approximately 2 m - thick unit of siltstone overlies the coal and underlies the inclined strata.

mines, both laterally and vertically, and comprises greater amounts of fine-to-medium sandstone in massive beds (Figs. 13, 23; Panorama P5; Sections S5A, S5B, S5C and S5D).

(b) Vertical Variation in Lithology

Because of areal variations of bulk facies and areal variation of the internal geometry and shape of the inclined strata (discussed later) the vertical distribution of lithology as seen in the various stratigraphic Sections also varies but does exhibit some definite overall vertical patterns (see Sections). Four such patterns are recognizable:

(1) Only incomplete sections at the seam-split of the Liddell and the Lower Arties Coal Seams (Foybrook-Main Open Cut (North)) were possible because of the difficulty of locating suitable anchors for the fixed ropes. Consequently the vertical extent to which each section was logged at this locality was restricted by the limits of safety when climbing up the cliff face and high-angled loose scree slopes. Section S1D was the only one to extend above the Upper Arties Coal Seam in this mine because of these restrictions. The Sections (S1A, S1B, S1C, S1D) show that between the Lower Arties and the Liddell Coal Seams, the percentage of sandstone is high to very high (67% to 92%). It is in this area also where the inclination of the strata are very high - up to 33° with some beds up to 44° (Sections S1C, S1D).

At Foybrook-Main Open Cut (North) in most of the Sections there is a thin (0.5 m - 2 m - thick) unit of



FIGURE 23:

Typical view of inclined bedding structure at Howick Open Cut. View looks towards the east and southeast. Massively bedded, dominantly fine-to-medium sandstone comprises the inclined beds (Table 4). Scree and debris totally obscure the topmost beds and partially obscure the main Liddell Coal Seam which has its top boundary with the overlying inclined strata at the level of the man's head. Topmost part of the inclined bed-set has been removed by dragline stripping. Note the fairly straight geometry of the inclined beds.

carbonaceous siltstone which directly overlies the main Liddell Coal Seam. The siltstone is then abruptly overlain by a fine-to-medium sandstone which dominates each section throughout the inclined crossbed-set up to a level of a couple of metres below the Upper Arties Coal Seam (Section S1A) or the Lower Arties Coal Seam (Sections S1B, S1C, S1D; Panorama P1). Below the two Arties Seams there is a unit of carbonaceous siltstone.

(2) At Foybrook-Main Open Cut (South) (Section S2A) a 1.5 m - thick carbonaceous siltstone containing coalified plant stem fragments concordantly overlies the Liddell Coal Seam (this same siltstone unit occurs in Section S2B and is pictured in Figure 22). Overlying this siltstone is a unit of fine-to-medium sandstone approximately 16.5 m thick. The inclination of the beds within the large scale inclined strata is at its steepest in the lower parts of the inclined bedding structure and becomes less steep in the upper parts of the interval. Above this sandstone there is a gradational change into a siltstone rich in carbonaceous material and several discrete beds having a carbonate cement. This unit of siltstone is 26 m thick and is overlain by the 3 m - thick Arties Coal Seam (the Lower Arties and Upper Arties Coal Seams have coalesced further to the north). The lower boundary surface of the Arties Coal Seam is transitional and planar whereas the top of the seam is planar and abrupt. A similar vertical pattern of lithological change occurs in Section S2B in the same mine

(Fig. 22; Panorama P2).

(3) At Foybrook-S.W. Open Cut a thin unit of carbonaceous siltstone (0.75 m to 1.5 m - thick) conformably overlies the Liddell Coal Seam. The rest of the section comprises siltstone with thin interbeds of fine sandstone (Fig. 12; Panorama P4; Sections S4A, S4B, S4C); these sandstone interbeds vary in thickness between 0.1 m to 1.2 m (Fig. 24). A similar vertical lithological pattern occurs at Foybrook-S.E. Open Cut, except in the southeast corner of the mine where the bulk of the sandstone is observed to occur (Section S3B) as a 9 m - thick unit of dominantly sandstone with very minor siltstone interbeds overlying a siltstone unit which, in turn, overlies the Liddell Coal Seam (Fig. 25; Panorama P3).

(4) At Howick immediately above the main Liddell Coal Seam, is a finely bedded siltstone unit which has a maximum thickness of 5.5 m and a minimum thickness of 2 m. This unit underlies the lower parts of the inclined beds which here comprise a fine-to-medium grained sandstone throughout most of the section. At the top of the section a fining-upward trend occurs and begins in the upper part of the crossbed set. This fining-upward trend is defined by a gradual transition of fine-to-medium sandstone into a carbonaceous siltstone (Sections S5A, S5B, S5C, S5D). The siltstone is then overlain by the Arties Coal Seam which has a gradational planar boundary with the underlying siltstone.



FIGURE 24:

View of inclined bedding structure in the western highwall of the Foybrook-S.W. Open Cut (view looks northwest). Liddell Coal Seam at base. Beds of siltstone (recessive) dominate but are associated with thin interbeds of fine sandstone (resistant beds). Note that the inclined beds extend up into the vegetated slope at the top of the photograph. The geometry of the beds tends to be straight with flexed lower parts (i.e., asymptotic contact with the underlying coal seam). Note also the progressive change in facies towards the left as reflected by change in the proportion of resistant sandstone beds. The inclined beds dip towards the west-southwest (see Fig. 30). The banner has 1 m subdivisions.



FIGURE 25:

Southern end of eastern highwall of Foybrook-S.E. Open Cut (looking east). The bulk of the lithology is fine-to-medium sandstone which overlies a thin siltstone unit which, in turn, overlies the main Liddell Coal Seam. An oblique view looking onto this wall in a northeasterly direction is shown in Figure 10. The inclined strata dip towards the north, highwall is approximately 25 m high.

5.3 INTERNAL ORGANIZATION OF THE CROSSBED SET

The highwall exposures afford views of the sedimentary rocks in sections which are both parallel to and normal to the strike of the inclined strata. In all but the south wall of the Foybrook-S.E. Open Cut and short highwall exposures at the southern end of the Foybrook-Main Open Cut and northern end of the east wall of the Foybrook-S.E. Open Cut, the highwalls are essentially dip- or near dip-sections. The southern wall at the Foybrook-S.E. Open Cut provides an oblique section of the inclined beds and because of a local swing in their strike here the exposed section changes progressively from being a strike-section in the east to sections which are oblique, and possibly strike-parallel again in the west (see Fig. 11 and Panorama P3a).

(a) Geometry of the Inclined Strata in Dip-Section

In vertical exposures viewed in dip-section the geometry of the inclined beds varies considerably and can be related directly to changes in gross lithology and grain size. Several distinctive geometrical patterns can be recognized (Figs. 26, 27).

(1) At Foybrook-Main Open Cut the inclined strata exhibit a grossly sigmoidal geometry (Fig. 21; Fig. 26, case C) and are developed in locally homogenous facies; i.e., the lower segments and middle segments of the inclined beds tend to be made up of fine-to-medium sandstone (Sections S2A and S2B; Panoramas P1, P2). Within the sigmoidal units, the sandstone beds tend to be massive, attaining thicknesses of 2 m. Individual sandstone and siltstone beds are

Figure 26

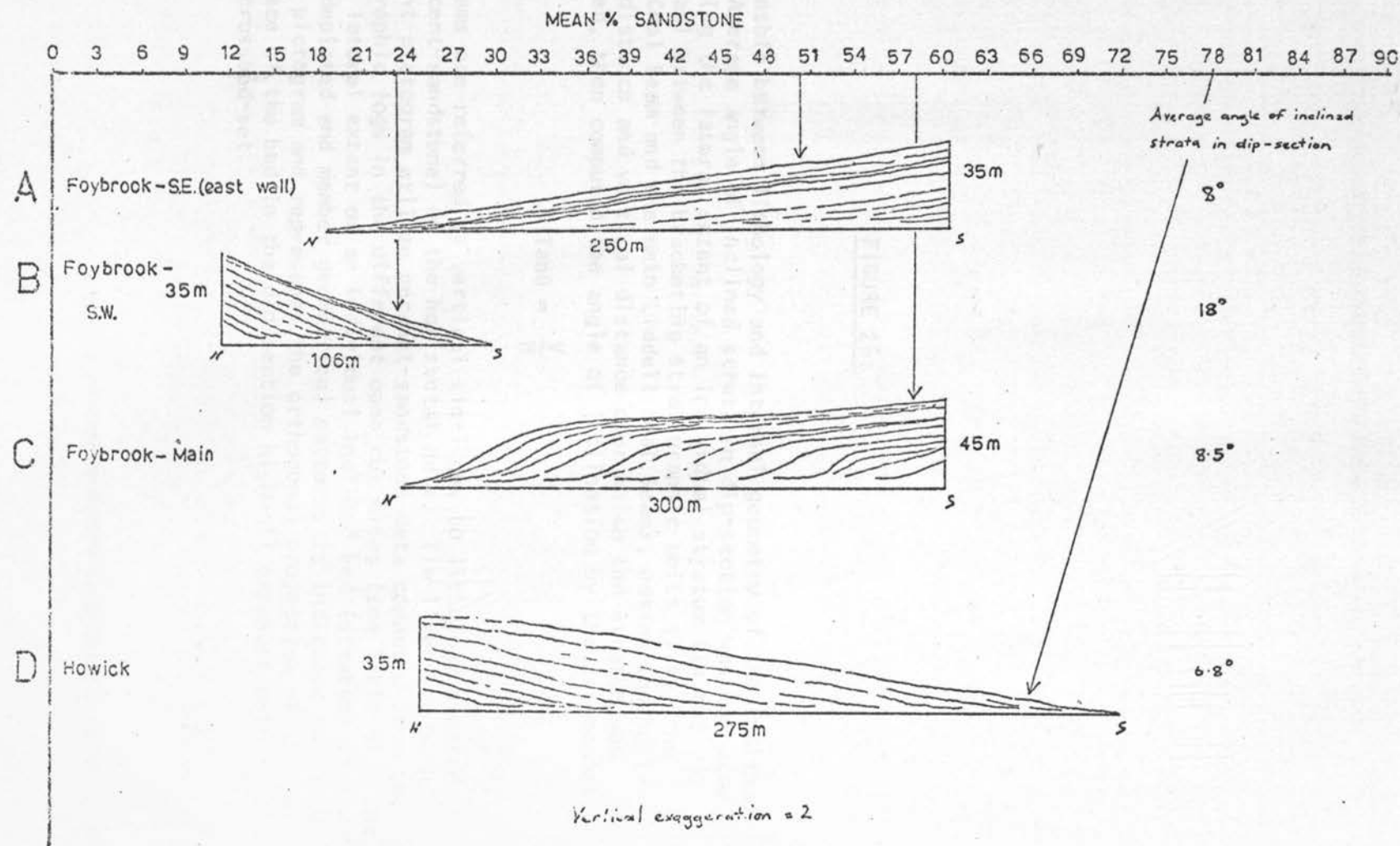


FIGURE 26:

Relationship between lithology and internal geometry of the inclined beds. Average angle of inclined strata in dip-section was computed by tracing the lateral extent of an individual stratum (in the Panoramas) between the bracketing stratigraphic units (i.e., the Arties Coal Seam and the main Liddell Coal Seam), noting the horizontal distance and vertical distance over which the stratum was developed, then computed the angle of inclination by the trigonometric ratio:

$$\text{Tan}\theta = \frac{V}{H}$$

Pictograms are referred by vertical tie-lines to lithology plotted (as percent-sandstone) on the horizontal axis. Tie-lines for each different pictogram utilize percent-sandstone data computed from the stratigraphic logs in the different open cut mines (see Table 4). The average lateral extent of an individual inclined bed (stratum) in each of the depicted end member geometrical patterns is indicated on the base of each pictogram and represents the orthogonal projection of the outcrop-trace of the bed in the dip section highwall exposure onto the base of the crossbed-set.

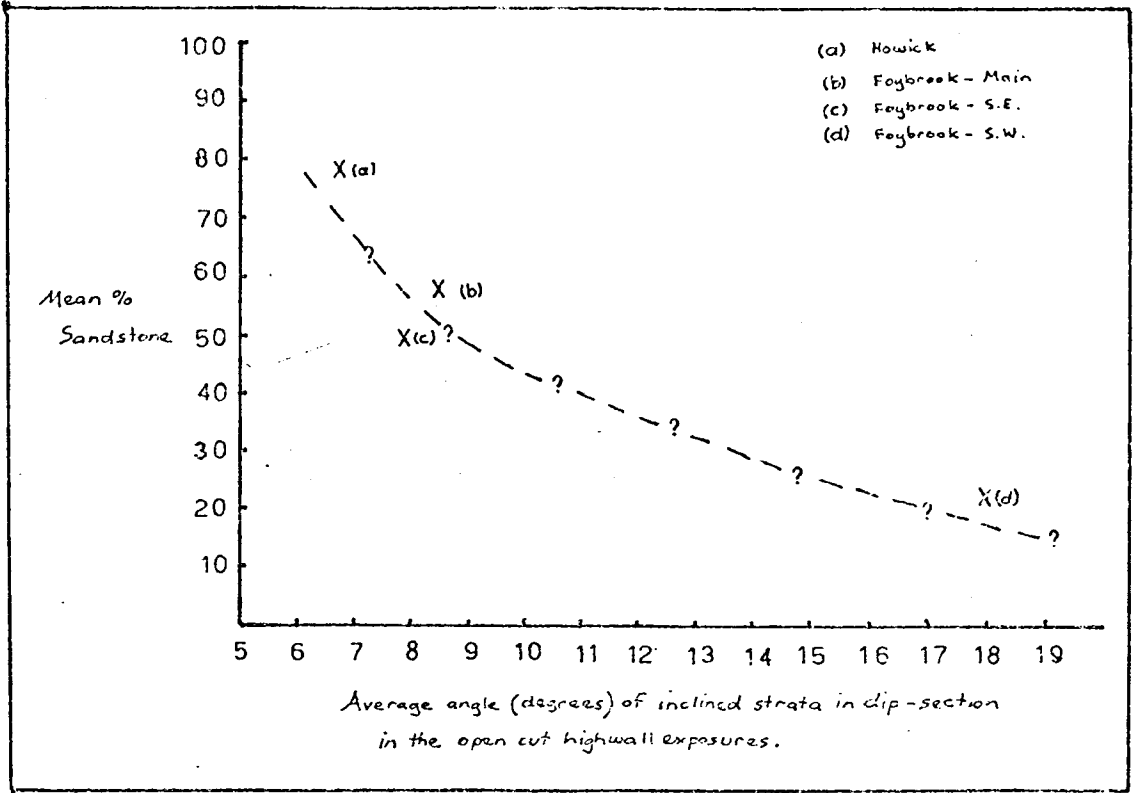


FIGURE 27:

The relationship of mean angle of dip of an individual inclined stratum and the mean percent of sandstone in the respective open cut (see Table 4). This angle was calculated by the same method as elaborated in Figure 26.

laterally very continuous in the Foybrook-Main Open Cut, e.g., the trace of an individual bed may be up to 300 m long in dip-section. The sigmoidal shape of the inclined beds is typically asymmetric about an imaginary plane drawn through the crossbed-set at about a mid-height position above its lower bounding surface and parallel to this surface: whereas the asymptotic relationship of the inclined beds to the lower bounding surface of the crossbed-set is relatively abrupt (because the concave-up segments are of relatively small lateral extent), the asymptotic geometry developed at the top of the crossbed-set is much more gradual (because the convex-up segments of the inclined beds have lateral extents here far greater than do the concave-up segments at the base - see Figs. 21, 22 and 26; Panoramas P1, P2). This geometrical asymmetry is accompanied by a lateral bed thickness asymmetry: beds are thicker in the vicinity of the lower-inflection point but become progressively thinner when followed upwards towards the top of the bed-set where up dip convergence of the inclined beds begins (Figs. 21, 20; Panoramas P1, P2).

(2) Although the lateral dip-section extent of the inclined strata is of a similar order of scale to that at Foybrook, the actual geometrical configuration of the inclined beds differs in the other open cut exposures (Fig. 26). In the dip-sections at the Foybrook-S.E. and Foybrook-S.W. Open Cuts the geometry of the strata tends to be straight with short, concave-up, flexed lower segments

giving a concordant asymptotic relationship with the underlying siltstone and main Liddell Coal Seam (Fig. 26, cases A and B). The upper segments of the inclined beds are also most likely asymptotic with the overlying stratigraphic unit (the Arties Coal Seam) but this relationship cannot be seen because of mining and stripping operations at the stratigraphic level in these open cuts. However, the inferred asymptotic relationship is indicated by a progressive decrease in the dip of the strata higher up in the highwall exposures (Sections S3A, S3B, S4A, S4B, S4C; Figs. 10 and 11). The sandstone beds in the Foybrook-S.E. and the Foybrook-S.W. Open Cuts are thin (generally less than 1 m thick and are laterally extensive but relatively straight throughout most of their exposed length within the crossbed-set (Panoramas P3, P4).

(3) At Howick the relationship of the inclined beds to the underlying main Liddell Coal Seam is generally asymptotic: - most beds are straight with relatively short asymptotic terminations in the lowermost and uppermost parts of the set (Fig. 23; Fig. 26, case D). The middle segments of the inclined strata consist here of massively bedded fine-to-medium sandstone which continues into the lowermost and uppermost parts of the crossbed-set where it is eventually replaced by siltstone (Panorama P5).

(4) Within the Foybrook-Main Open Cut (North and South) there are subsidiary large-scale crossbed-sets developed within the framework of the master crossbed-set (Figs. 28

and 29; Panorama P2). These secondary but still large-scale features are developed in the basal 6 - 8 m of the master crossbed-set and exhibit asymptotic relationships with the main Liddell Coal Seam and with the overlying master crossbeds which tend to drape the second-order set (Figs. 28 and 29). The secondary crossbeds have a set thickness of approximately 5 m and individual beds within the set have a dip-section development in the order of 26 m.

(b) Areal Variation in Dip-Azimuth of the Master Crossbeds

Within each open cut mine the spatial attitude of the large-scale inclined beds is unimodal (Fig. 30) but there is a progressive change in dip-azimuth from north to south: in the Foybrook-Main Open Cut the strata are inclined to the north; at Foybrook-S.E. they are inclined to the north-north-west; in the Foybrook-S.W. Open Cut they are inclined to the west-southwest and in the Howick Open Cut they are inclined to the southwest (see Fig. 30 A-E). This areal pattern of direction of inclination of the strata reflects an overall lobate structure defined by azimuths of inclined bedding which swing progressively counter-clockwise from the north (at Foybrook-Main Cut) through west (at Foybrook-S.W. Open Cut) to the southwest at Howick (Map 2). Measurements on the inclined strata taken in road and rail cuttings in intervening areas between the open cut mines contribute to the delineation of this grossly lobate pattern convex towards the west (Map 2).



FIGURE 28:

Large scale subsidiary crossbedding occurs within the first-order crossbed-set in Foybrook-Main Open Cut. The second-order crossbed-set is developed immediately above the main Liddell Coal Seam (which is just below the water). The lithology within the second-order set is essentially homogenous and predominantly fine-to-medium sandstone. The banner has 1 m divisions. Location: middle part of the eastern highwall of the Foybrook-Main Open Cut (South).



FIGURE 29:

Oblique view of the second-order crossbedding shown in Figure 28. Note also the lateral continuity and upward attenuation of individual beds within the primary crossbed set. The main Liddell Coal Seam is just below the water level. The banner has 1 m divisions. Location: see caption to Figure 28.

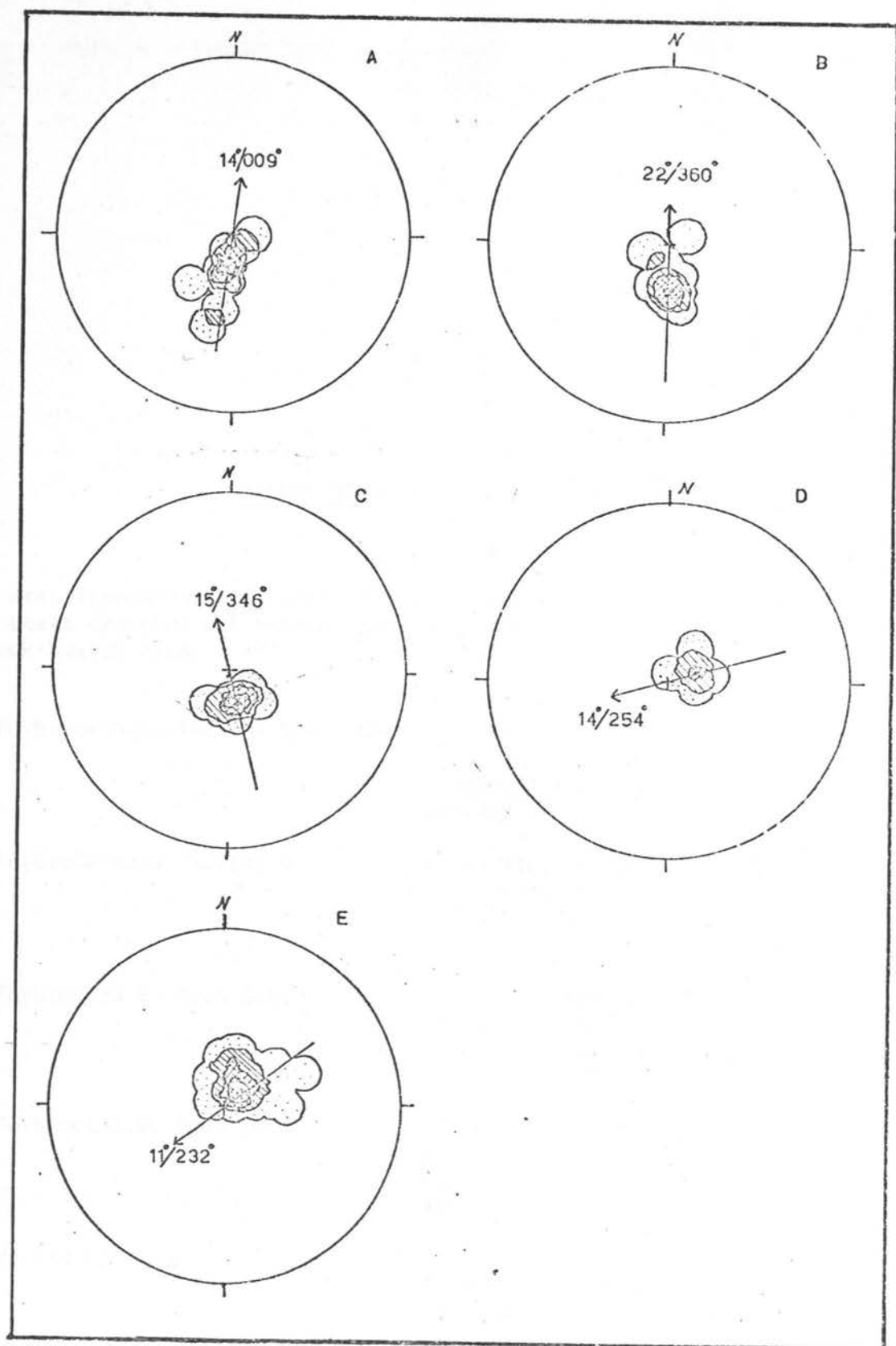


Figure 30

FIGURE 30:

Equal area stereograms of poles to master bedding planes within the large scale crossbed set exposed in the open cut highwalls in the Foybrook-Howick area.

- A: Foybrook-Main (North) Open Cut; 10 points, contoured at 1, 2, 3, 4, 5 percent contour levels; mean bedding dip/dip-azimuth = $14^{\circ}/009^{\circ}$.
- B: Foybrook-Main (South) Open Cut; 15 points, contoured at 1, 3, 6, 10 percent contour levels; mean bedding dip/dip-azimuth = $22^{\circ}/360^{\circ}$.
- C: Foybrook-S.E. Open Cut; 22 points, contoured at 1, 5, 9, 12, 15 percent contour levels; mean bedding dip/dip-azimuth = $15^{\circ}/346^{\circ}$.
- D: Foybrook-S.W. Open Cut; 14 points, contoured at 1, 5, 11, 12 percent contour levels; mean bedding dip/dip-azimuth = $14^{\circ}/254^{\circ}$.
- E: Howick Open Cut; 34 points, contoured at 1, 5, 9, 12, 14 percent level contours; mean bedding dip/dip-azimuth = $11^{\circ}/232^{\circ}$.

(c) Sedimentary Structures Within the Master
Crossbeds

Sedimentary structures within the master crossbeds are developed on a scale of millimetres and centimetres (rarely decimetres) in contrast to the tens-of-metres scale and metres scale which respectively characterize the first-order and second-order crossbed sets discussed above. The characteristics of these small-scale structures are outlined in Table 5.

Wavy and parallel laminations were by far the most common sedimentary structures within the master crossbeds. These sedimentary structures were found to be developed in both siltstone and sandstone beds in all the highwall exposures; they could be found in every part of the master crossbed set and were mostly defined by the concentration of carbonaceous material along distinct planes (Table 5). Ripple-drift cross lamination are relatively common and appeared to be mostly restricted to the middle and upper segments of the inclined beds. Only two examples of disturbed or contorted lamination were seen and these were centimetre-scale structures encountered in the Foybrook-Main Open Cut (North) precisely at the lower limits of the inclined master beds (Fig. 41) and half way up the crossbed-set in a siltstone bed found in Foybrook-Main (South) Section S2B. No other disturbed or contorted bedding was seen in the study area. Centimetre-scale trough cross lamination was abundant in all the open cuts; like wavy lamination and parallel lamination, cross-lamination was usually defined by concentrations of carbonaceous

TABLE 5: SEDIMENTARY STRUCTURES WITHIN THE LARGE SCALE MASTER CROSSBEDS

FORM	SCALE	EXAMPLES (FIGURE)	OVERALL ABUNDANCE	LOCALITY	CHARACTERISTIC SETTING (WITHIN PARENT CROSSBEDS)	DEFINED BY	GEOMETRICAL RELATIONSHIP TO PARENT CROSSBEDS	CHARACTERISTIC LITHOLOGY
Parallel lamination	< cm	31, 32, 35 36, 39	Very abundant	Howick Foybrook-S.W. Foybrook-S.E. Foybrook-Main	Topmost segments Middle segments Bottom-most segments	Carbonaceous material and subtle grain size changes	Developed along the bedding plane	Siltstone Fine sandstone
Wavy lamination	< cm	32, 33 40	Very abundant	Howick Foybrook-S.W. Foybrook-S.E. Foybrook-Main	Topmost segments Middle segments Bottom-most segments	Carbonaceous material and subtle grain size changes	Developed along the bedding plane	Siltstone Fine sandstone
Centimetre- scale ripple- drift cross- lamination								
Type* 1		34, 35, 39		Foybrook-S.E. Foybrook-Main (South)	Topmost segments Middle segments	Grain size difference & carbonaceous material	Oblique-to-dip Down-dip Up-dip	Fine sandstone
2	set thickness < 7 cm	34, 36, 40	Common	Howick Foybrook-Main (South)	Middle segments	Carbonaceous material	Down-dip Up-dip	Fine sandstone
3		36		Howick Foybrook-Main	Middle segments	Carbonaceous material	Down-dip Up-dip	Fine sandstone
Centimetre- scale trough cross- lamination	coset thickness < 15 cm < 7 cm set thickness	37 38	Abundant	Foybrook-Main Foybrook-S.E. Foybrook-S.W. Howick	Topmost segments Middle segments Bottom-most segments	Carbonaceous material and subtle grain size change	down-dip oblique-to- dip	Fine sandstone Siltstone
Disturbed or contorted lami- nation (small scale)	developed thickness < 5 cm	39	Rare	Foybrook-Main (South) Foybrook-Main (North)	Middle segments Bottom-most segments	Carbonaceous material	Developed essen- tially along bedding plane	Siltstone

* From Jopling and Walker (1968)



FIGURE 31: Parallel laminations defined by the concentration of carbonaceous material in a siltstone, Section S3aC (Foybrook-S.E. south wall); the carabiner is 11 cms long.



FIGURE 32: Wavy and parallel laminations defined by the concentration of carbonaceous material and by grain size changes. Location: 6 m above the main Liddell Coal Seam at Howick Open Cut; Section S5B. The rock type is fine-to-medium lithic sandstone and dip of the inclined strata is left to right.



FIGURE 33: Ripple-drift cross laminations (Type 1 - Jopling and Walker, 1968) and wavy laminations in a fine lithic sandstone at Howick, 6 m above the Liddell Coal Seam, Section S5A. The tape measure case is resting on an inclined master bedding plane. Direction of traction transport indicated by the cross lamination is up-slope with respect to the master bedding.



FIGURE 34:

Type 1 and type 2 ripple-drift cross lamination of Jopling and Walker (1968) located 15 m above the main Liddell Coal Seam in the southern end of the Foybrook-Main Open Cut (South). The structures are developed in fine sandstone and are defined by carbonaceous material. The master bedding dips from right to left and the direction of traction-transport indicated by the ripple-drift cross lamination is up-slope (i.e., left to right) with respect to the attitude of the master beds. Coin (20 cent piece) gives scale.



FIGURE 35: Parallel laminations and type 1 ripple drift cross lamination of Jopling and Walker (1968) in Section S3aC (Foybrook-S.E., south wall); the carabiner is 5 cms wide. Travel direction indicated by the ripple-drift cross lamination with respect to the attitude of the master crossbeds is oblique-to-dip.



FIGURE 36: Parallel laminations and type 2 and type 3 ripples of Jopling and Walker (1968) at Howick Open Cut in a fine sandstone in Section S5B 5 m above the Liddell Coal Seam. Direction of travel indicated by ripple-drift cross lamination is down-dip with respect to the attitude of the master crossbeds.



FIGURE 37: Trough cross laminations in a coarse carbonaceous siltstone located at Foybrook-S.E. (south wall), Section S3aD; the carabiner is 11 cms long. Travel direction indicated by trough cross laminations is oblique-to-dip (left to right) with respect to the attitude of the master crossbeds. The exposure of this photograph is strike parallel so the master crossbeds dip towards the reader.



FIGURE 38:

A coset of centimetre-scale trough cross lamination in a fine sandstone. Location: top of Section S3B (Foybrook-S.E., east wall). The sets of trough cross lamination indicate a direction of travel down-dip with respect to the attitude of the master crossbeds. The master crossbeds dip shallowly from right to left.



FIGURE 39:

Contorted and parallel laminations and ripple-drift cross laminations (Type 1) defined by the concentration of carbonaceous material in fine-to-medium sandstone 16 m above the Liddell Coal Seam, Foybrook-Main Open Cut, Section S2B. The master crossbeds dip from right to left. The travel direction indicated by the ripple-drift cross laminations is oblique-to-down-dip with respect to the attitude of the master crossbeds.



Figure 40:

Wavy laminations, ripple-drift cross lamination, (type 2 ripples of Jopling and Walker, 1968) and defined by concentrations of carbonaceous material. Location: 3 m north of the seam-split, Foybrook-Main (North) Open Cut; Section S1B. Travel direction indicated by ripple-drift cross lamination appears to be predominantly left to right, which means that it is up-dip with respect to the attitude of the master crossbeds.

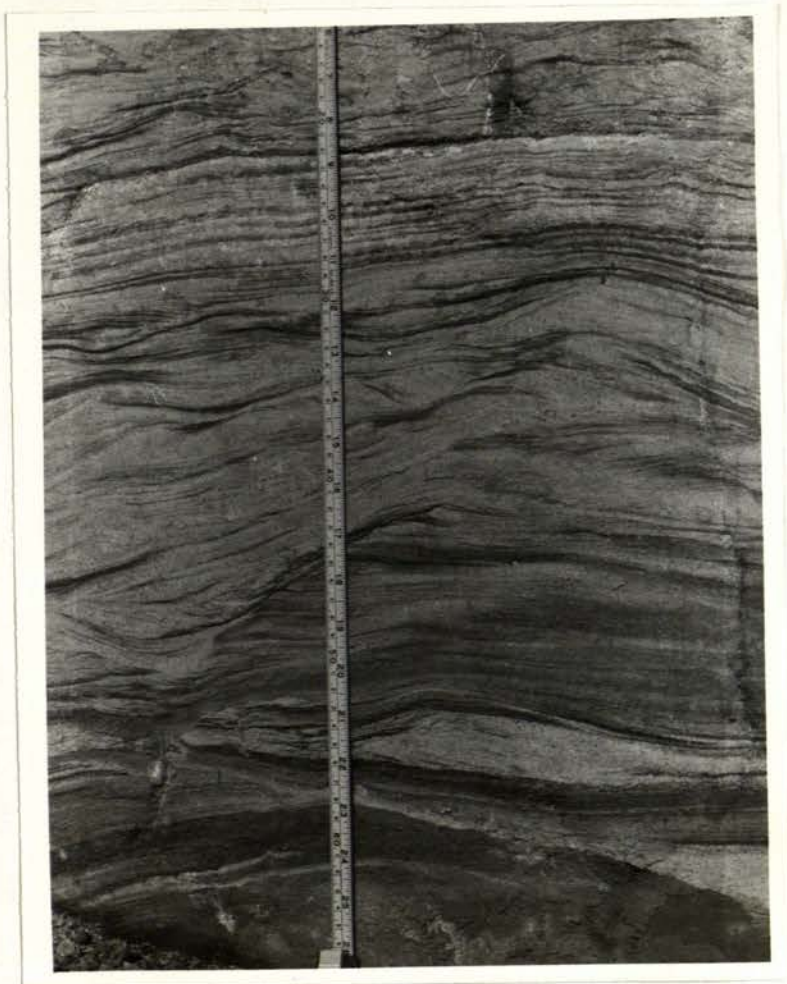


FIGURE 41: Close-up view of part of the exposure shown in Figure 38 just above the hammer. Note small scale scour structures and prevalence of traction-transport from left to right as indicated by the micro-cross lamination. Centimetre-scale sedimentary structures indicate a predominant travel direction up-dip with respect to the attitude of the master crossbeds.

material (Table 5), nonetheless some good examples of centimetre-scale trough cross laminations defined by grain size differences were found (Figs. 37 and 38).

(d) Fossils

The fossil material encountered was exclusively of vegetable origin and included leaf impressions, leaf fragments, tree trunks, stems and woody tissue that had been coalified. The state of preservation of the leaves within the beds is usually poor, mostly consisting of extremely macerated plant matter. Particular kinds of plant material were found in particular areas; for example, the larger fossil logs whose diameters reach 30 cm are found exclusively in the first 3 m of siltstone directly above the main Liddell Coal Seam; and smaller logs were encountered at Foybrook-Main Open Cut only within a 5 m - interval immediately below the Arties Coal Seam.

Throughout each of the sections logged in the Foybrook -Main Open Cut (North and South) coalified fragments of woody tissue are restricted lithologically to the medium to coarse sandstone of the master crossbeds. Upright fossil tree segments (some at least in-situ trunks) as well as flat-lying fossil logs are found at Howick only in the lower part of the crossbed-set immediately above the Liddell Coal Seam and at Foybrook-Main Open Cut only immediately above and below the Arties Coal Seam (Fig. 42). The fossil logs at Howick that are demonstrably in-situ or apparently in-situ are upright with respect to the upper bounding surface and internal bedding of the underlying Liddell Coal Seam and project upwards into the inclined strata



FIGURE 42:

In situ fossil log in carbonaceous siltstone just below the Arties Coal Seam; Foybrook-Main Cut (South), Section S2B.

from the upper surface of this seam (Figs. 43, 44 and 45). At least twelve such structures have been encountered. Their exposed height above the top of the Liddell Coal Seam ranges from 1 m to 7 m, but generally they are less than 3 m high. Unique to the Howick Open Cut are laterally restricted, seemingly lenticular concentrations of coalified fragmented plant material interbedded with the master cross-strata (Figs. 46 and 47). One such lens measured 0.3 m thick at its maximum development and was approximately 6 m long as exposed in section. Because of the limitations of the exposure no information about the plan-view geometry of these carbonaceous-rich beds is available. Thin sections HS51, HS52 of this rock revealed abundant organic material in a sandstone matrix: seeds, seed coatings, leaves, spores, leaf fragments and cuticle fragments intermixed with inorganic clastic detritus. Leaf fragments and poorly-preserved whole leaves could be found in most parts of the siltstone and sandstone beds in all the open cuts. The dominant leaf type is Glossopteris. A very minor amount of Equisitaleans (at Howick, Section S5E) and a questionable specimen of Phyllothea australis (at Foybrook-S.W. Open Cut) were also found.

Measurements of the bearing were taken on each of the flat-lying logs found at Howick Open Cut, Foybrook-Main Open Cut and Foybrook-S.E. Open Cut. Where the number of measurements was great enough (as at Howick Open Cut) a rose diagram was constructed (Fig. 48), for data of log bearings found at Foybrook-S.E. and at Foybrook-Main (South), the bearings were simply plotted on a 'compass' diagram together with the



FIGURE 43:

Upright, in situ carbonized fossil tree at Howick Open Cut. Digging revealed that the log continues down into the underlying Liddell Coal Seam. Bedding planes in the surrounding sandstone show abundant plant remains. The log is approximately 2 m high.



FIGURE 44:

Upright carbonized fossil log whose continuity into the top of the underlying Liddell Coal Seam (the floor in the photograph) was indeterminable. The enclosing strata dip left to right at a low angle and consist largely of fine-to-medium sandstone. Location: In the east wall of Howick Open Cut.



FIGURE 45:

View of part of the eastern highwall of the Howick Open Cut showing an upright fossil tree segment that has been intersected by the highwall exposure and so exposed at several places along its length (arrowed). The exposed parts of the fossil tree show that it is at least 7 m high above the top of the Liddell Coal Seam (which is exposed in the floor of the open cut at the bottom of the photograph). The fossil tree is vertical with respect to the left to right inclination of the master bedding planes of the enveloping sandstone as well as with respect to the top of the Liddell Coal Seam. As reconstructed here, this is the longest upright fossil tree encountered in the study area.

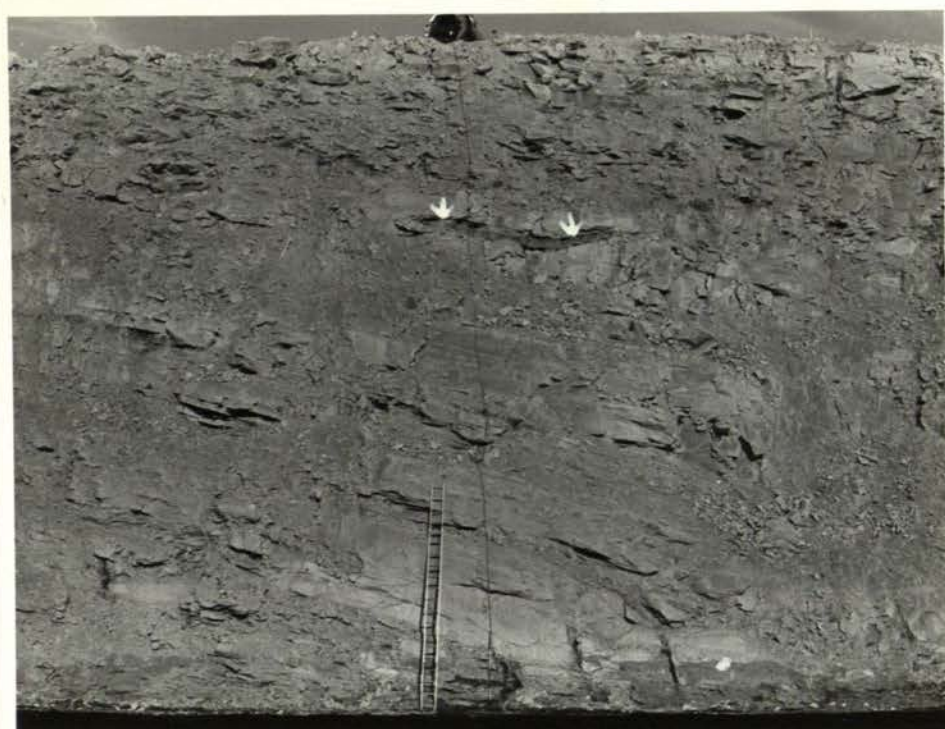


FIGURE 46:

View of part of the eastern highwall of the Howick Open Cut at the locality of Section S5B. Liddell Coal Seam forms floor of the mine and is overlain by inclined beds of sandstone which dip towards the southwest. At two-thirds the height of the highwall is a dark lenticular bed (arrowed) of coalified fragments concentrated within a sandstone host rock. Note discordant lower contact of this bed with underlying strata towards its right margin. See also Figure 47. Car provides an anchor for section logging up fixed rope.



FIGURE 47: Close-up view of the dark, carbonized-fragment rich sandstone bed illustrated in Figure 46, Howick east wall, Section S5B. Note lenticular shape of the bed and internal lamination defined by small tabular or platy carbonized plant fragments.

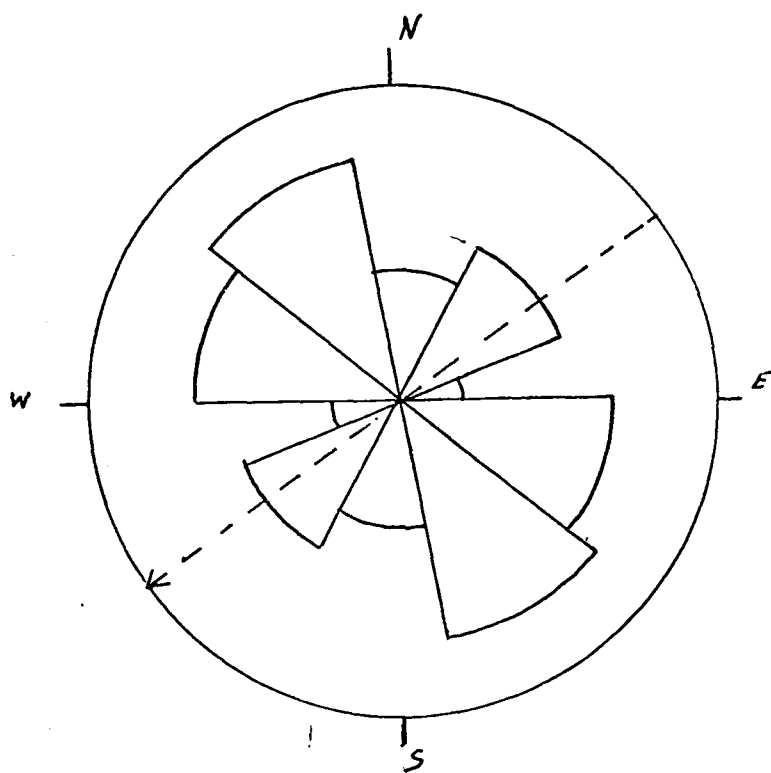


FIGURE 48:

Rose diagram of the long-axis orientation of flat-lying fossil logs at Howick Open Cut. All measurements were from within a 3 m - interval above the main Liddell Coal Seam. Sample number = 39; class interval = 35° . The average long-axis orientation of the fossil logs is approximately $150^{\circ} - 330^{\circ}$ which is nearly 90° to the average dip-azimuth of the master crossbeds at the Howick Open Cut (indicated by the dashed line with arrow).

measured trends of several decimetre-scale trough cross laminations (Figs. 49 and 50). It would seem that there is very definitely a relationship between the long-axis orientation of flat-lying fossil logs, the trend of sedimentary structures (discussed later) and the direction of inclination of the large scale cross-strata. In Foybrook-S.E. Open Cut and Foybrook-Main Open Cut (South) the average orientation of the flat-lying logs is aligned approximately parallel to the average dip-azimuth of the inclined strata. At Howick Open Cut the average long-axis orientation of the flat-lying fossil logs (150° - 330°) is approximately perpendicular to the average dip-azimuth of the inclined strata (232°).

(e) Palaeocurrent Trends as Evidenced by Small Scale Sedimentary Structures Within the Master Crossbeds

Because the master crossbeds are exposed predominantly in vertical section, plan-view exposures of sedimentary structures developed within these beds are rare or of very limited extent. The primary sedimentary structures that occur within the inclined master beds and reliably indicate local bottom current flow directions are restricted mainly to abundant traction-induced features such as cross lamination of various kinds (Table 5). Where plan view or three-dimensional exposures of these mostly centimetre-scale cross laminated structures were encountered, the flow direction could be inferred and accurately measured (Figs. 49 and 50). Elsewhere, where only two-dimensional vertical exposure was available, the sense of flow could still be confidently inferred. In

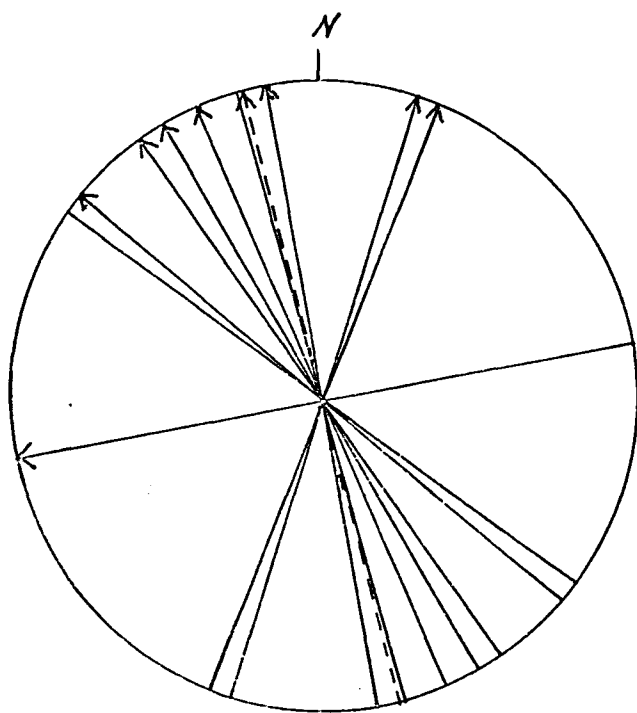


FIGURE 49: Compass diagram of fossil log long-axis orientation and trough cross lamination orientation in Foybrook-S.E. (east wall). The average trend of both these directions lies approximately parallel to the average dip-azimuth of the inclined strata at this locality, i.e., 15/346, indicated by dashed line with arrow). Trough cross lamination data refer to trough axis orientation measured towards the direction to which the cross laminae dip. Logs (unbroken lines without arrows) = 2. Trough cross laminae (unbroken lines with arrows) = 8. The fossil logs and trough cross laminae were found throughout the crossbed set lying generally along the bedding planes of the master beds. They were not found in a particular area or part of the crossbed set as at Howick (see Fig. 48).

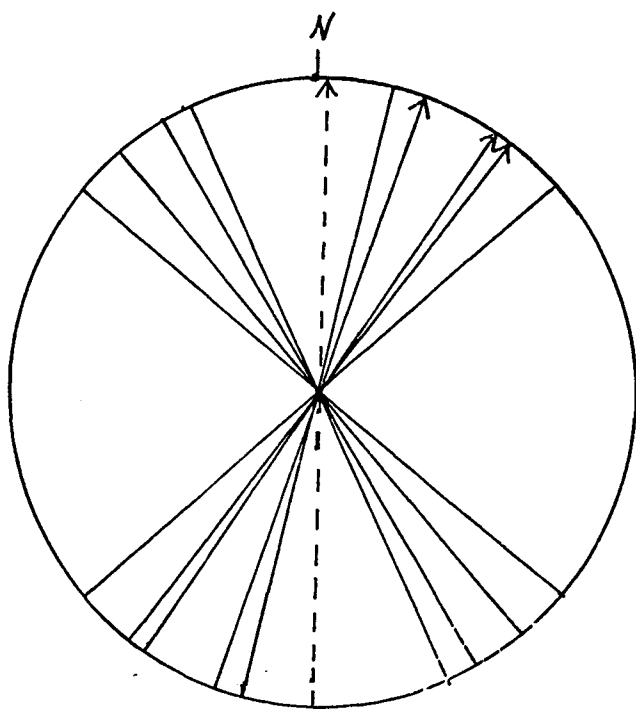


FIGURE 50:

Compass diagram of fossil log long-axis orientation (unbroken lines without arrows) and trends of trough cross laminations (unbroken lines with arrows). The average trend of both these directions lies almost parallel to the dip-azimuth of the inclined strata at Foybrook-Main Open Cut. The azimuth of the dip is the average of the azimuth of Foybrook-Main (North and South) and is towards 004° (indicated by broken line with arrow). The data on the cross lamination refers to dip-azimuth of the cross laminae; hence with respect to the inclination of the master crossbeds the direction of travel indicated by the cross laminae is down-dip. The fossil logs (6) and the trough cross laminations (3) were found throughout the crossbed set lying generally along the bedding planes of the master beds.

these cases the direction of flow observed in the vertical section was referred to the direction of inclination of the parent or master crossbeds and hence recorded as up-dip down-dip, or oblique-to-dip relative to this framework (Table 5). This information is represented in each of the Sections logged in the open cuts. The majority of the minor traction-induced sedimentary structures are found to indicate a travel direction down or oblique to the parent strata, but there are also numerous examples of up-dip ripple travel direction (Figs. 33, 34, 40 and 41).