Channel bodies of the lower Sydney Mines Formation (Carboniferous), Sydney Coalfield, Atlantic Canada

by

Paul A. Batson

Submitted in partial fufillment of the requirements
for the degree of Master of Science

at

Dalhousie University
Halifax, Nova Scotia
August 25, 1997.

Distribution License

DalSpace requires agreement to this non-exclusive distribution license before your item can appear on DalSpace.

NON-EXCLUSIVE DISTRIBUTION LICENSE

You (the author(s) or copyright owner) grant to Dalhousie University the non-exclusive right to reproduce and distribute your submission worldwide in any medium.

You agree that Dalhousie University may, without changing the content, reformat the submission for the purpose of preservation.

You also agree that Dalhousie University may keep more than one copy of this submission for purposes of security, back-up and preservation.

You agree that the submission is your original work, and that you have the right to grant the rights contained in this license. You also agree that your submission does not, to the best of your knowledge, infringe upon anyone's copyright.

If the submission contains material for which you do not hold copyright, you agree that you have obtained the unrestricted permission of the copyright owner to grant Dalhousie University the rights required by this license, and that such third-party owned material is clearly identified and acknowledged within the text or content of the submission.

If the submission is based upon work that has been sponsored or supported by an agency or organization other than Dalhousie University, you assert that you have fulfilled any right of review or other obligations required by such contract or agreement.

Dalhousie University will clearly identify your name(s) as the author(s) or owner(s) of the submission, and will not make any alteration to the content of the files that you have submitted.

If you have questions regarding this license please contact the repository manager at dalspace@dal.ca.

Grant the distribution license by signing and dating below.

___________________________________	____________________________________
Name of signatory	Date

DALHOUSIE UNIVERSITY

FACULTY OF GRADUATE STUDIES

The undersigned hereby certify that they have read and recommend to the Faculty of Graduate Studies for acceptance a thesis entitled "Channel Bodies of the Lower Sydney Mines Formation (Carboniferous), Sydney Coalfield, Atlantic Canada" by Paul A. Batson in partial fulfillment of the requirements for the degree of Master of Science.

Dated: September 8, 1997

External Examiner

Supervisor

Supervisory Committee

Departmental Reader

Departmental Chair

DALHOUSIE UNIVERSITY

DATE: September 15, 1997

AUTHOR: Paul A. Batson

TITLE: Channel bodies of the lower Sydney Mines Formation (Carboniferous), Sydney Coalfield, Atlantic Canada

DEPARTMENT OR SCHOOL: Earth Sciences

DEGREE: M.Sc. CONVOCATION: Fall YEAR: 1997

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ENCLOSURES

ABSTRACT

The Sydney Mines Formation (SMF) forms the upper unit of the Late Carboniferous, Westphalian D to Stephanian A, Morien Group - correlative regionally with the Cumberland Group. The lower Sydney Mines Formation was studied, and is intermittently exposed in the Sydney area over a distance of 45 km along depositional strike. It forms part of the onshore component and southern limit of the Sydney Basin. The lower SMF exhibits cyclothems bounded by coal seams. The SMF commences with the Emery seam cyclothem interval where it rests on the underlying South Bar Formation (SBF). The SMF thickens and, therefore, is expanded to include the underlying Gardiner and McRury seam cyclothem intervals, in the Glace Bay Syncline area, where the SMF rests on the Waddens Cove Formation (WCF). The highest interval studied is capped by the lower leaf of the Bouthillier seam. Twenty channel bodies, up to 18.6 m thick, were studied in sea cliffs using photomosaic tracings.

Seven channel body groups were recognised. Group A comprises multi-storey bodies that were deposited from large sandy bedload systems with low sinuosity (braided) channel planforms; some may be valley fills. Group B comprises planar sand sheets and within-channel bars formed in low sinuosity, sand-flat systems. Group C has lateral accretion surfaces and ridge-and-swale topography, and represents sinuous mixed-load (C_1) and suspended load (C_2) channels. Group D comprises narrow channel bodies that cut bayfill and mouthbar deposits, and represents distributary bedload (D_1) and mixed-load (D_2) channels. Group E represents thin, channel fills laid down during individual flood events. In a few cases, channel bodies comprise storeys that represent two or more groups.

Channel body group is closely linked to stratigraphic level within the cyclothems, especially those higher in the Sydney Mines Formation. The roof of the thick economic coal seams, in close association with black fossiliferous limestone and shale which represent condensed sections, indicate maximum flooding surfaces. A highstand systems tract that follows typically is represented by bayfill deposits that are cut by distributary channels (D_1, D_2). Both bayfill and distributary channel deposits are commonly incised by channel bodies of Group C, representing larger, sinuous rivers. Relative sea-level then progressively dropped to a lowstand sequence boundary, marked by nodular calcretes, suggesting arid climatic conditions. Coincidentally, deep channel incision occurred (typically below channel bodies of Groups A and B). Subsequent relative sea-level rise promoted channel body aggradation, localized subaerial exposure, formation of red beds, then eventual drowning and more bayfill deposition and peat formation. A return to more humid climatic conditions is inferred. This sequence of events defines a typical cyclothem.

The typical cyclothem is not visible in outcrop until the Stony to Phalen interval, in which thick coal seams are developed. This interval also marks a significant change in fluvial style. It transforms from a dominance of low sinuosity, braidplain and sheet sand (Group A and B respectively) channel systems, carried over from the older SBF and WCF, to a more sinuous but variable fluvial style, including Groups C, D and E. This pattern continues upward, reflecting the influence of base-level fluctuation and the relative position of the exposed sections to a paleocoastline.

Some channel bodies are amalgamated to form thick, multi-storey units, on the order of 18 m in composite thickness. An understanding of channel body geometry and fluvial style has important implications for underground coal mining operations. Economic seams are commonly overlain by Group D channel bodies, which are relatively narrow and inferred to be straight or sinuous in planform. Elsewhere, thicker and more extensive channel bodies of Groups A - C rest on the coals, locally amalgamating with or cutting through Group D bodies. Some channel bodies in the local collieries contain hydrocarbons, and superb outcrops provide excellent analogues for reservoirs elsewhere in the world.

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Dr. Martin Gibling, for his guidance, encouragement, patience and excellent support throughout this entire project. John Calder, Milton Graves, Peter Reynolds and Tom Martel reviewed the manuscript and provided excellent suggestions for improvements to the thesis. I would like to thank Ron Boyd, Basil Cooke, Robert Creed, Gary Freeman, Jack Harvey, the late Mike Keen, J. Ross Mackay, Clint Milligan, David Piper, the late Ruth and William Rothel, Paul Schenk and Marcos Zentilli for their inspiration.

Johannes Paul and Judy White were helpful to me during my first summer of field work. Paul (Red) Cormier of New Waterford, Fred King of Glace Bay, and Ken Wadden of Port Morien were very obliging in providing boat support for photographing the coastal cliff exposures.

Claudia Currie, at the Atlantic Geoscience Centre, Bedford Institute of Oceanography, was very helpful in assisting me with the digitizing process in AutoCAD of the tracings of outcrops from photomosaics. I would also like to thank Dr. Jacob Verhoef for the use of the computer facilities at the Atlantic Geoscience Centre. Andrew Henry exported the AutoCAD files into CorelDRAW and produced the final profiles included as enclosures. He also helped me generate slides for my thesis defence presentation. Audrey Isaacs was helpful in compiling the manuscript.

Financial assistance came from an NSERC operating grant to Dr. Martin Gibling.

I am eternally grateful to my wife, Joyclin and our special son, Trevor, for their unwaning love and understanding. I would also like to thank my parents for their moral support.

CHAPTER 1: INTRODUCTION

1.1 OVERVIEW

The Sydney Basin has had an historical tie to coal production since the early 1700's. Geologic investigation of the Sydney coalfield was not documented until the 1800's (Brown, 1871; Robb, 1876). Many workers have contributed to the knowledge of the Sydney Basin since. In recent years, much attention has been given to the application of the cyclothem model to facies analysis of the Sydney Mines Formation (Bird, 1987; White, 1992; Gibling and Bird, 1994; Tandon and Gibling, in press). The cyclothem model has also been integrated with the concepts of sequence stratigraphy (Saunders, 1995; Rehill, 1996; Tandon and Gibling, in press).

The application of the study of Channel bodies within the above cyclothems has significant economic importance. Understanding the geometry of channel bodies is applicable to solving complex problems related to underground coal mining operations (Forgeron, 1980). Presently, of particular interest is the Phalen to Backpit interval in the Phalen colliery offshore. Intersection of channel bodies in the roof of adits may reduce the mining operation efficiency by slowing down the cutting action at the rock face or generating a spark that can ignite methane. Rock outbursts created by the release of trapped gas in the channel body sandstone is a potential hazard. Roof rock stability related to differential compaction and joints is also a problem associated with exposing channel body sandstones.

Channel body geometry is also significant in hydrocarbon exploration. Isolated channel bodies are not economic, however, stacked multi-storey channel bodies similar to those studied in outcrop are potential reservoirs for economic hydrocarbon accumulation in the subsurface. The large channel body systems that cut down to the black organic rich fossiliferous limestones and shales are of particular interest because of the juxtaposition to this source rock. In addition, coalbed methane is a potential energy source.

The systematic approach to channel body geometry analysis introduced by Miall (1978), and subsequently refined, has been a significant contribution to the distillation and synthesis of copious amounts of stratigraphic data in siliciclastic sequences. This approach was used in this study. Outcrop exposures of variable quality and accessibility occur along the present coastline of the Sydney Basin. Seven representative localities were selected for this study.

The purpose of this study is to integrate channel body strata with adjacent facies and to show the relationships within and between respective cyclothems. The study also presents the channel body analysis in the context of sequence stratigraphy where possible. In doing so, it is hoped that the thesis will provide some insight to future applications related to underground coal mining operations and hydrocarbon exploration.

This chapter provides a general overview and regional setting of the Sydney Basin and the Sydney Mines Formation. Chapter 2 describes the methodology employed in the study of the channel bodies (field methods and analysis). Chapter 3 provides detailed descriptions of the channel bodies and includes first order interpretations (e.g. architectural elements and bounding surfaces). Higher order interpretations (e.g. flow style and sinuosity) are included under the subheading of INTERPRETATION for each channel body. Chapter 4 presents a classification scheme for the channel bodies derived from the detailed descriptions. This classification scheme is then applied to the interpretation of the stratigraphic relationships and depositional history within the context of the cyclothem model and sequence stratigraphy. This is followed by a discussion and finally, conclusions are presented in Chapter 5.

1.2 REGIONAL SETTING

The Sydney Basin (Fig. 1.1) is located onshore in northeastern Nova Scotia and extends offshore to the northeast for at least 450 km under the Laurentian Channel and Grand Banks (Bell and Howie, 1990). The basin is part of the larger Maritimes Basin of eastern Canada, a successor basin which developed on continental crust following the mid-Devonian Acadian Orogeny. It subsided episodically until latest Carboniferous or early Permian time. Late Carboniferous subsidence was probably thermal in origin (Bradley, 1982; Marillier *et al*., 1989; Durling and Marillier, 1990) and concurrent regional strike-slip faults were active elsewhere in the Maritimes Basin (Gibling *et al*., 1987; Stockmal *et al*., 1990).

This study focuses on the cyclothem strata of the Sydney Mines Formation, which is the main coal measures succession within the Sydney Basin (Fig. 1.2). Gibling and Bird (1994) discussed the stratigraphic setting of this formation. The Sydney Mines Formation (SMF) is the uppermost formation of the Morien Group (regional Cumberland Group). Deposition of the Morien Group spans the Westphalian B to Stephanian A ages of the Pennsylvanian Period. It marks the onset of renewed deposition following a 9.5 Ma hiatus above the underlying Horton, Windsor and Mabou Groups (Fig. 1.3) of Tournasian through Namurian age . The Sydney Mines Formation was deposited during the Westphalian D to Stephanian A ages, is approximately 500 m thick, and is composed of predominantly grey sandstone, grey and red mudstone, minor limestone and economic coal seams. The dominant depositional environments are alluvial and restricted marine (Rust *et al*., 1987). It overlies the braided-fluvial South Bar Formation (SBF) across the northeastern part of the basin and interfingers with the

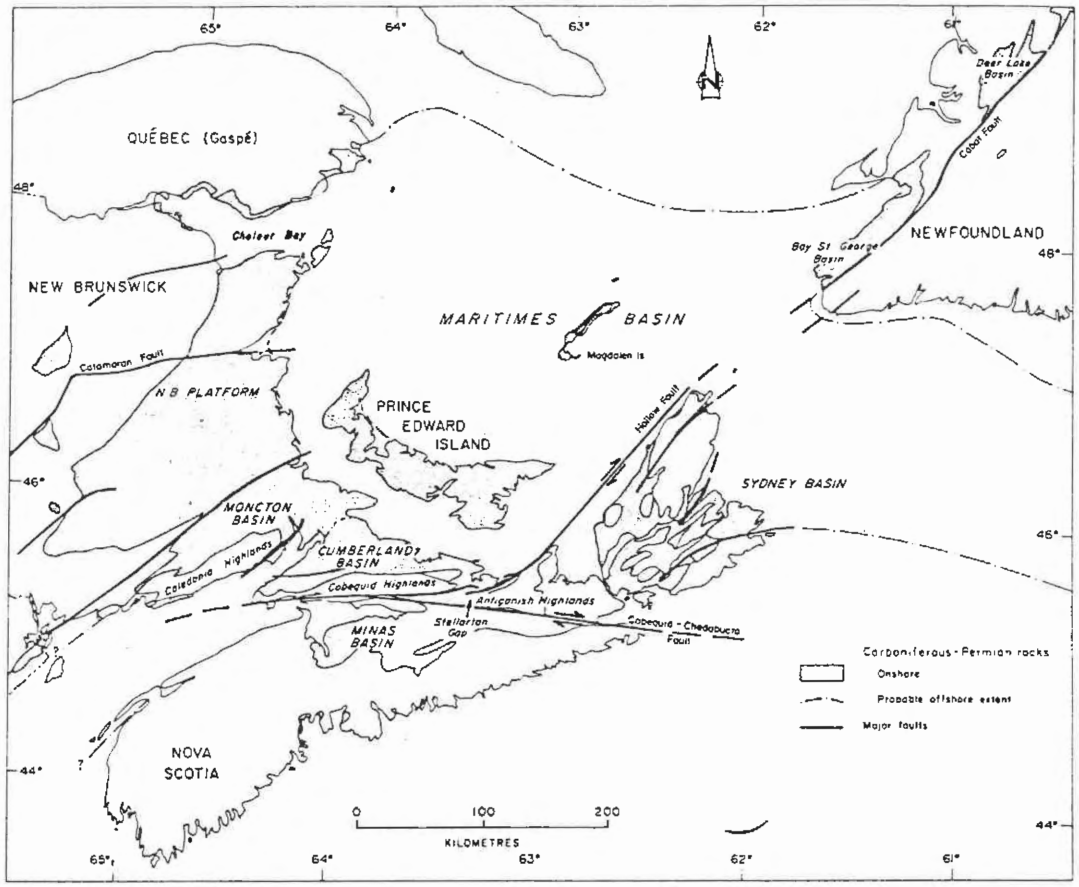

Figure 1.1

Regional map showing position of the Sydney Basin (shaded) within the greater Maritimes Basin (dotted outline). (From Gibling *et al.*, 1987).

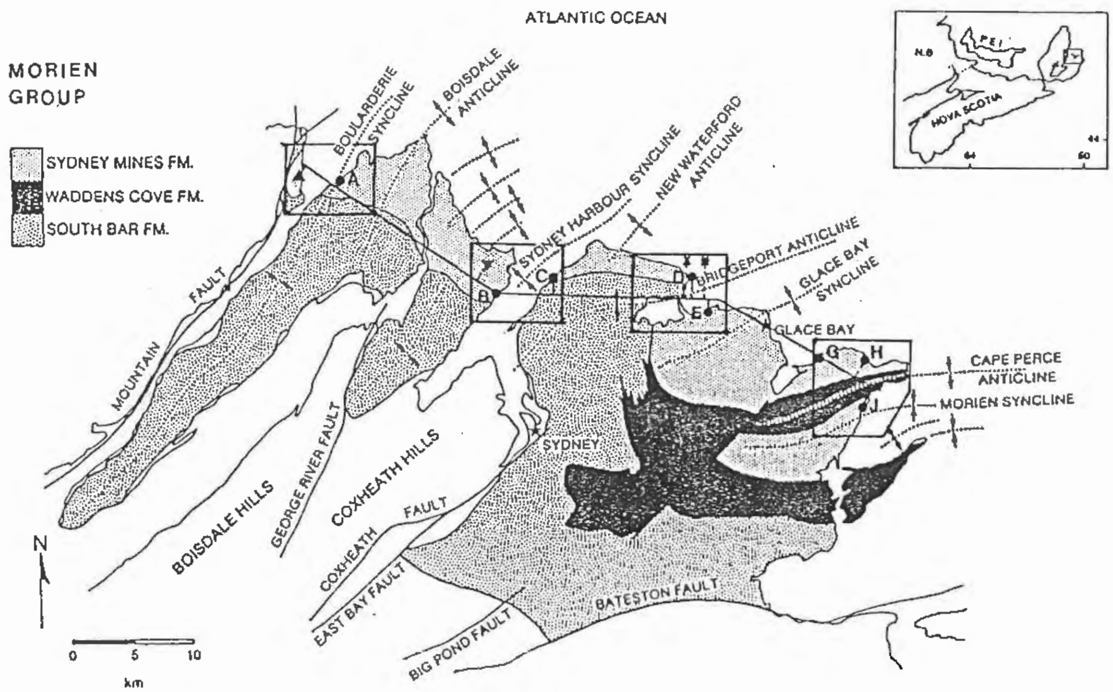

Figure 1.2

Onshore distribution of the Morien Group (Cumberland Group equivalent). Location of line of cross-sections (Figures 4.1 to 4.3) and expanded areas of sections (Figures 1.6 and 1.7) shown. Letters indicate coastal outcrop sites examined in study (except J). From west to east: A = Black Rock Point & Big Bras d'Or; B = Sydney Mines; C = Victoria Mines; D = Lingan; E = Dominion; G = Port Caledonia; H = Donkin; J = Longbeach. Symbols represent core locations (not looked at in this study) from west to east: ▲ = NC-87-1; ▼ = SMS-91-29-B; X = C-137; * = C-136. (Modified from White, 1992).

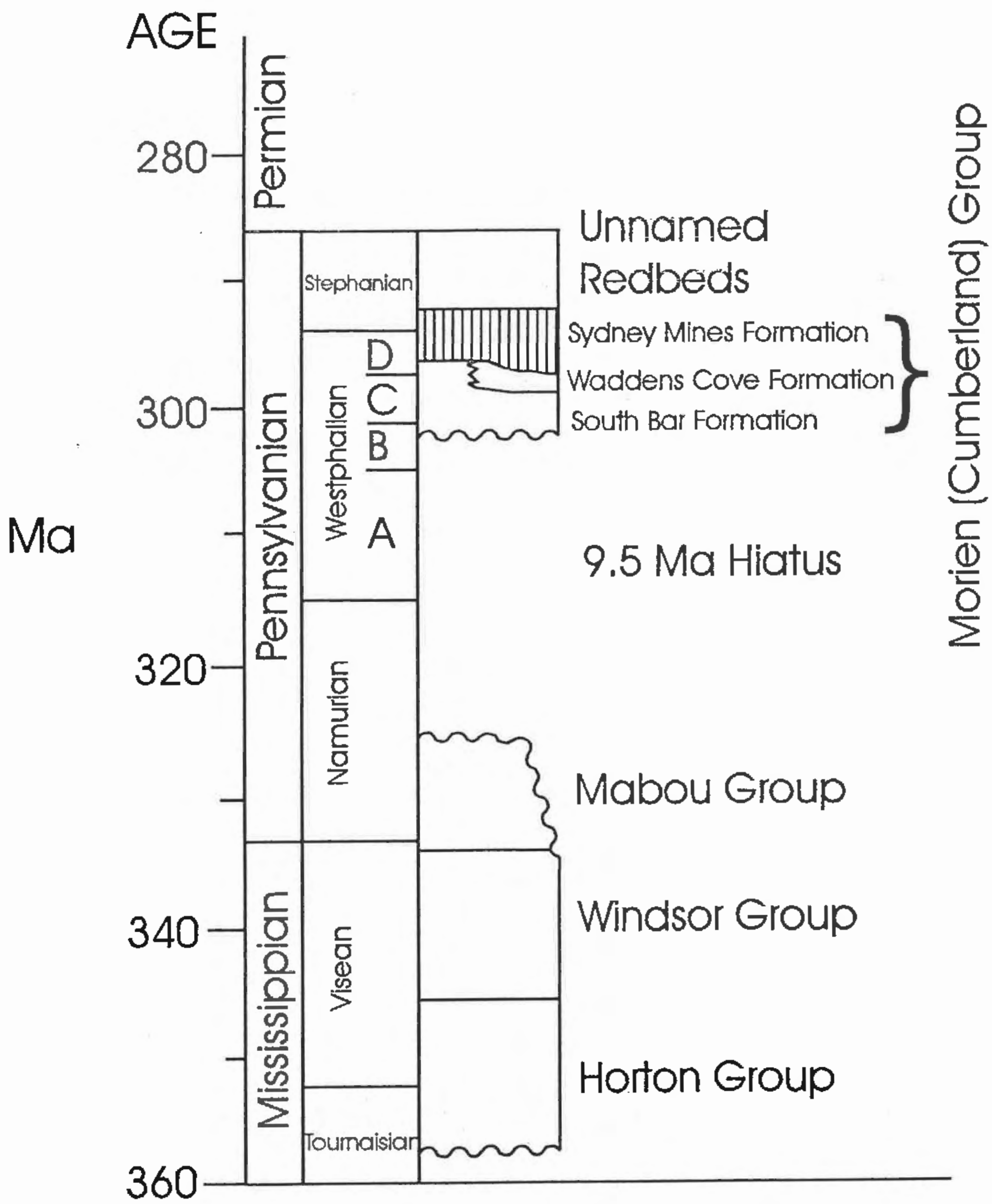

Figure 1.3.

Generalized stratigraphy of the onshore part of the Sydney Basin. (Modified from Gibling *et al*., 1987). Ages are based on the time scale of Lippolt and Hess (1985).

meandering- to braided-fluvial Waddens Cove Formation (WCF) in the Glace Bay Subbasin (Fig. 1.2) toward the southeast. Paleoflow data indicate that sediment transport was northeastward and eastward for all three formations. The headwaters of rivers that traversed the basin probably had their source in the rising orogenic belts of the northern and central Appalachians and drained eastward to marine basins in southern and western Europe (Gibling *et al.*, 1992a). The southeast-trending coast (Fig. 1.1) provides a traverse parallel to depositional strike. Although drill logs are available for the North Sydney P-05 well 50 km offshore, little is known about the presumed distal part of the basin offshore.

The Sydney Basin is bounded by faults that may have been active during the Late Carboniferous period. The Morien Group typically dips at a few degrees, is only gently folded, and faults that cut earlier strata cannot be traced across the unconformity at the base of the group. Development of local sub-basins during deposition of the Morien Group is attributed to differential subsidence over faulted basement blocks (Gibling and Rust, 1990).

The Sydney Mines Formation contains a series of major coal seams up to 4.3 m thick (Emery to Point Aconi Seams: Fig. 1.4) that extend for at least 45 km across the onshore part of the basin and were also identified in the P-05 well offshore (Hacquebard, 1983). Many coal seams are similarly extensive. Red mudstone units are widespread in most interseam strata but are thin or absent at lower levels in the Glace Bay Subbasin where the SMF thickens. In this area the cyclothems are expanded to include the McRury and Gardiner seams. Systematic intercalation of extensive coals and red mudstones form the principal basis for the cyclothems recognised by Gibling and Bird (1994), who identified 11 complete cyclothems from 12 to 72 m thick in the formation. They inferred that the cyclothems represent relative changes in sea-level. Based on the time scale of Hess and Lippolt (1986), each cyclothem has a mean duration of 200 ka (Tandon

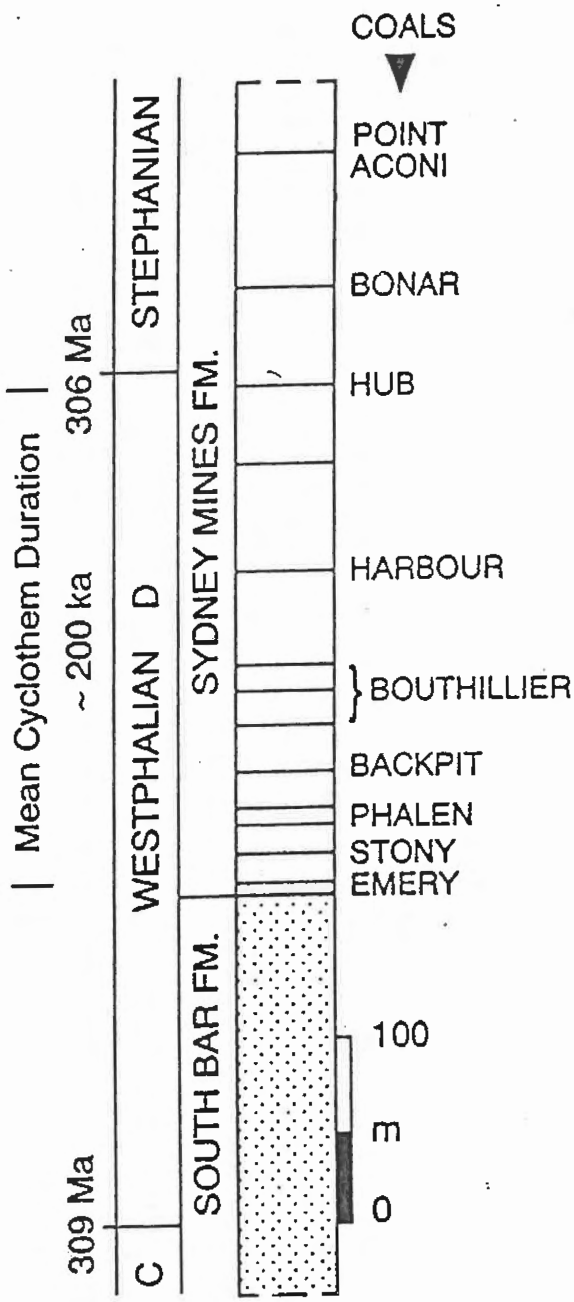

Figure 1.4.

Generalised stratigraphic column of the Sydney Mines Formation to show major coal seams, which lie near the tops of cyclothems. Estimation of mean cyclothem duration is based on stratal proportions and biostratigraphic analysis (see Gibling and Bird, 1994), and 3 Ma duration of the Westphalian D (Hess and Lippolt, 1986). From Tandon and Gibling, in press.

and Gibling, in press), (Fig. 1.4). Cyclothems above the Harbour Seam show more regular stratal alternation, and cyclothem boundaries are placed at the base of distinctive, carbonaceous limestones or shales that typically overlie the major coal seams. These commonly contain a restricted-marine biota, and represent the maximum flooding surface and a condensed section during cyclothem formation. Basinal conditions have been inferred in terms of sequence stratigraphic units by facies analysis within cyclothems (Tandon and Gibling, in press), (Fig. 1.5, Table 1.1). Many workers have indicated that the formation of cyclothems is related to regular changes in climate and sea-level which may be controlled by Milankovitch orbital cycles (Berger, 1977; Heckel, 1986; Leeder, 1988; Collier *et al.*, 1990; Gibling and Bird, 1994; Saunders, 1995). Paleogeographic setting may also have had some controlling influence on climate and sea-level changes contributing to cyclothem formation (Rowley *et al.*, 1985; Hatcher *et al.*, 1989; Calder and Gibling, 1994).

A key interval of the Sydney Mines Formation was selected for this study which includes the McRury to Bouthillier cyclothems (Fig. 1.4). The channel body study was designed to complement and be integrated with detailed measured sections by J. White (1992) and J. Paul (unpublished data). The locations of section sites are outlined on Figure 1.2 which correspond to enlarged map areas shown on Figures 1.6 and 1.7. The location of the line of cross-sections (Figs. 4.1 to 4.3) is also indicated on Figure 1.2.

Coalbeds comparable in age to the Sydney Basin coalbeds underlie much of the Maritimes Basin beneath the remainder of the Gulf of St. Lawrence to the west (Haites, 1952; Hacquebard, 1986; Rehill, 1996), (Fig. 1.1). Stratigraphic data are sparse but the Sydney cyclothems may have correlatives in this basin. The two basins have a combined area in excess of 80,000 km^2.

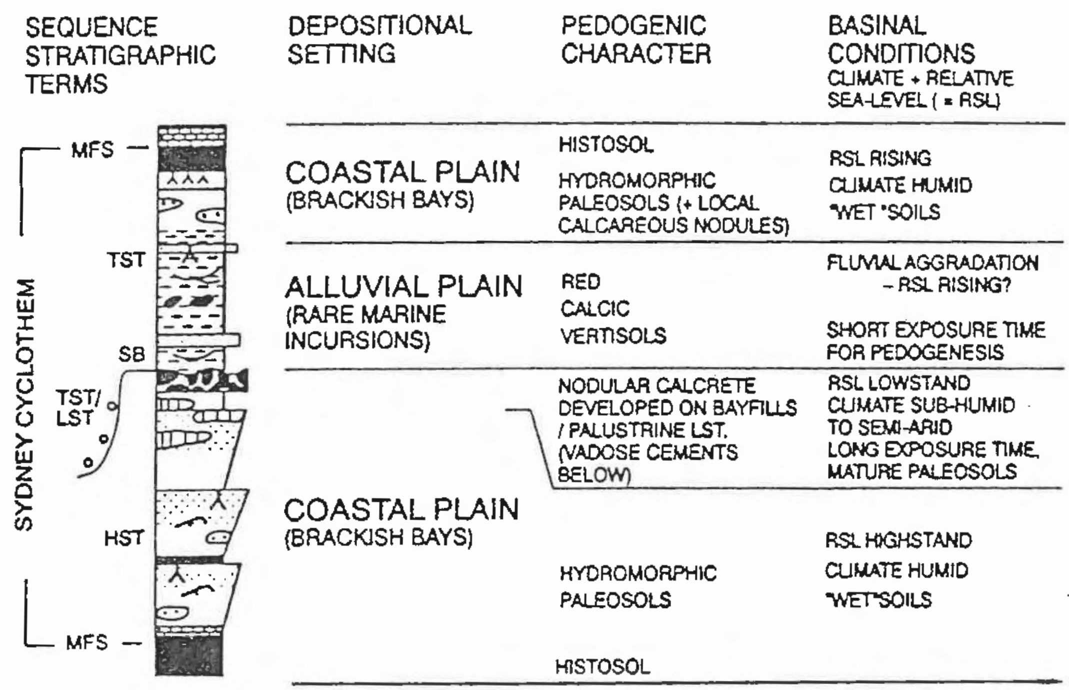

Figure 1.5.

Schematic cyclothem profile to show pedogenic character and inferred basinal conditions. Symbols: LST, TST and HST = lowstand, transgressive and highstand systems tracts, respectively; MFS = maximum flooding surface; SB = sequence boundary. See Van Wagoner *et al.* (1988) for an explanation of sequence stratigraphic terms used here. From Tandon and Gibling, in press.

Table 1.1.

Major facies of the Sydney Mines Formation cyclothems, Sydney Basin. From Tandon and Gibling, in press.

Facies	Description	Interpretation
Coal	Seams up to 4.3 m thick, sulphur rich (~2–6%). Cyclothems are capped by single, unsplit coals, or by a coal zone, with several split seams. Grey structureless 'seat earths' 1–2 m thick, with siderite nodules and abundant roots, underlie the coals; some yield agglutinated foraminifers.	Coastal mires with the accumulation of thick peats (histosols).
Red mudstone and sandstone	(A) Red mudstone with pseudo-anticlines, desiccation cracks, roots, and sparse calcite nodules. Intercalated sandstones form planar sheets a few decimetres thick, with lenses of reworked calcareous nodules.	Well-drained floodplains with soils (vertisols) and thin crevasse splays.
	(B) Erosionally based sandstone bodies, incised through red mudstones. Bodies are typically 1–2 m thick, up to 7 m, with low width : thickness ratios (one or both margins generally visible in outcrops). One or two vertically or laterally positioned storeys are mainly plane bedded, with ripple-drift cross-lamination, trough cross-beds, and planar cross-sets of carbonate gravel at channel bases. Some accretion surfaces with muddy layers, groove casts on bed bases, and rill casts. Topmost strata locally form 'wings' that thin into adjacent mudstones.	Ephemeral alluvial channels cut through oxidised floodplain deposits. Flow commonly in the upper flow regime, but subject to stage fluctuations.
Nodular calcrete	Sheets up to 1 m thick, with vertically stacked nodules, root traces and weak residual stratification. Sheets traceable for > 30 km along-strike. Subjacent beds locally have polygonal desiccation cracks filled with carbonate nodules. Tops of sheets are locally eroded and overlain by lenses of carbonate fragments.	Pedogenic calcrete, with tops locally exposed and reworked.
Grey mudstone and sandstone	(A) Coarsening-up shale to sandstone units 1–4 m thick. Basal shales are dark and platy with vascular plant debris, bivalves and agglutinated foraminifers. Overlying sandstones are ripple cross-laminated, with some trough cross-beds. Palaeosols in sandstone tops have roots, upright trunks, loss of stratification, drab mottles, and nodules of siderite and (rarely) calcite and pyrite. Some units are capped by thin coals or carbonaceous shales.	Fills of standing water bodies, from crevasse splays or small deltas that prograded into lakes or brackish bays ('bayfills'). Hydromorphic palaeosols in poorly drained settings.
	(B) Erosionally based sandstone bodies, 4–8 m thick. One to several storeys, low width : thickness ratios (one or both margins generally visible in outcrops). Trough cross-beds, minor plane beds, and lateral accretion surfaces.	Distributary channels, locally sinuous, with predominantly lower regime flow.
Dark limestone/shale	Sheets up to 1 m thick, with bivalves, ostracodes, fish, serpulids and agglutinated foraminifers. Total organic carbon up to 23%, principally sporinite and vitrinite. Traceable for > 30 km along-strike.	Subaqueous deposits, probably in brackish bays. Fossil abundance suggests condensation. Aerobic to anaerobic waters.

Descriptions are based on previous work by Gibling and Kalkreuth (1991), Gibling and Bird (1994), Gibling and Wightman (1994) and White et al. (1994).

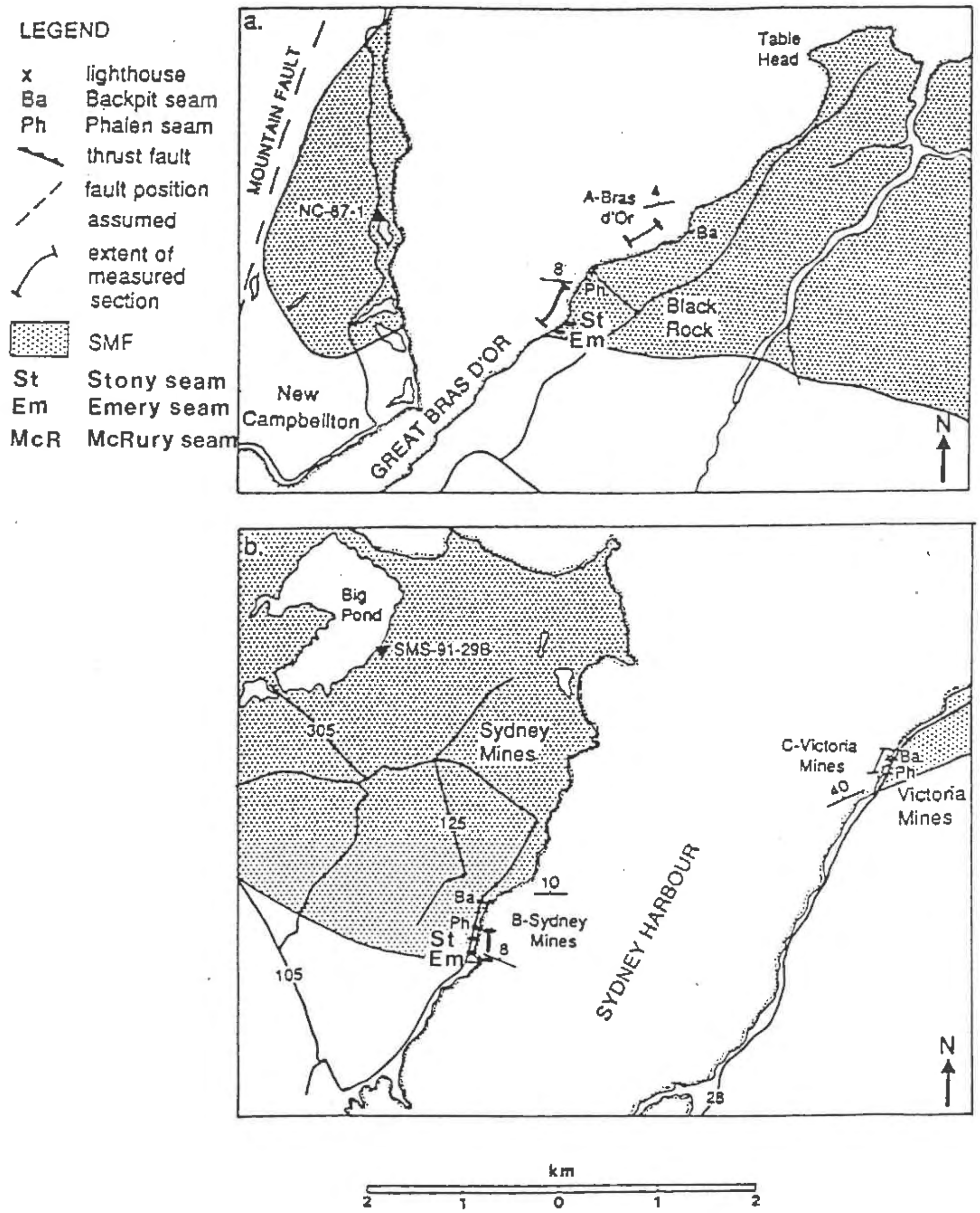

Figure 1.6.

Expanded area maps of measured sections: a. Black Rock Point and Big Bras d'Or. b. Sydney Mines and Victoria Mines. (Modified from White, 1992). See Figure 1.2 for location.

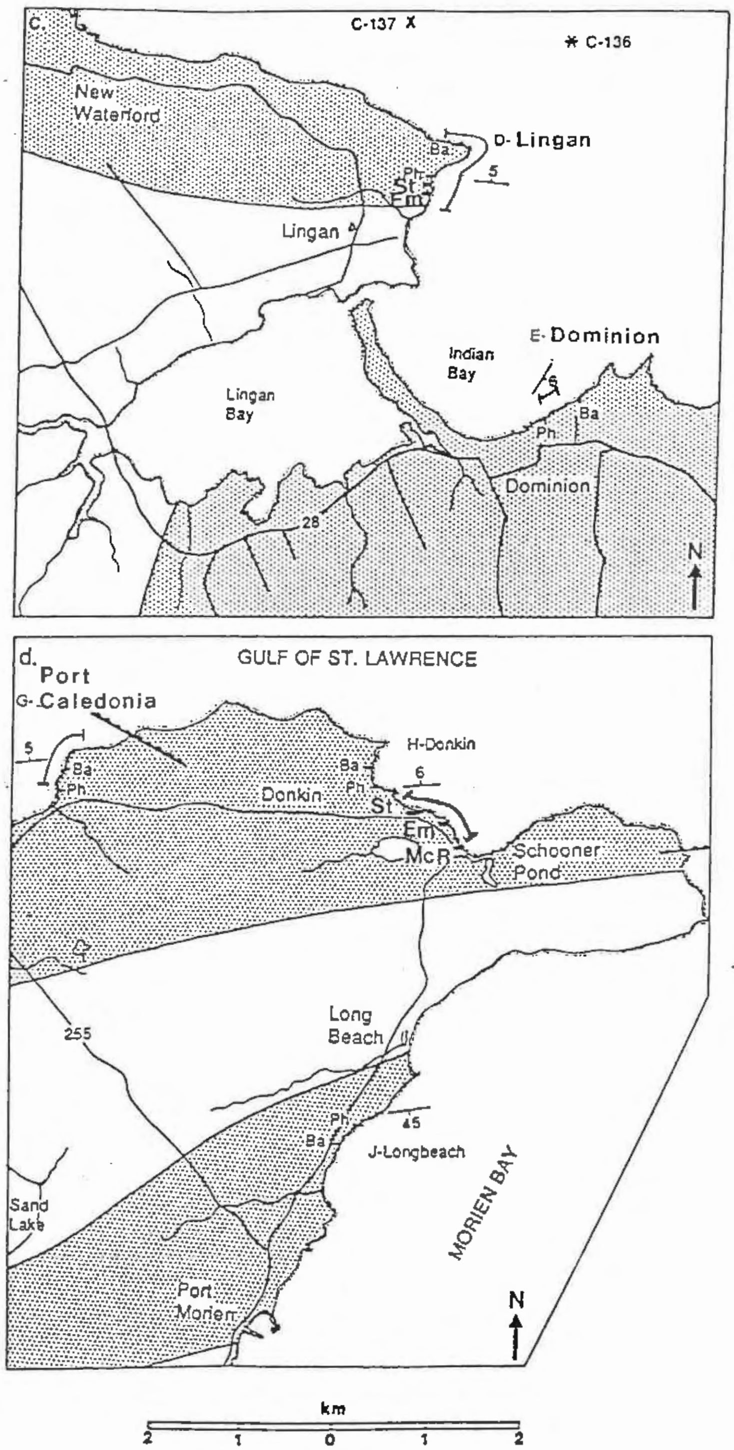

Figure 1.7.

Expanded area maps of measured sections: c. Lingan and Dominion. d. Port Caledonia and Donkin. (Modified from White, 1992). See Figure 1.2 for location.

CHAPTER 2: METHODS

2.1 FIELD METHODS

The thesis study was conducted over a protracted period as a part-time commitment. The field component of the study commenced in July of 1990 with an initial reconnaissance of the locations to be photographed and measured. Serial photos were then taken, from shore and boat, of the selected coastal exposures. Photomosaics were then constructed and initial tracings of sedimentary features were done on mylar. This procedure was complicated by distortion and scale problems (discussed below) that were introduced by the photographic process. Once the initial tracings were complete, combined photocopies of the photomosaics and tracings were made and initially interpreted. The sites were then revisited and the respective photocopies were used to precisely locate and record detailed stratigraphic measurements. These included sedimentary structures, grain size, bed set thicknesses and orientations and paleoflow indicators. The initial tracing interpretations were also verified. Outcrop access was hampered in part by talus, rock falls or position of cliff face relative to the shoreface or the high tide level. Where high tide was a concern, tide tables were used to maximize the time available for field work. Permission to enter the property of Nova Scotia Power, Inc. was required to access the coastal exposure at Lingan.

The measurement of paleoflow indicators was limited at many sites by the access to cliff exposures, as previously mentioned, and also by the nature of the cliff face weathering and erosion. Ripple cross-lamination was measured using ridge-and-furrows on bedding surfaces, either where directly accessible or where they were visible on undersides of bedding surfaces in cliff overhangs. Care was taken to ensure that noted paleoflow measurements were correctly associated with the appropriate specific bed sets (e.g. inclined surfaces). Paleoflow direction from trough cross-beds was measured from the orientation of trough intersections and collected directly on exposed surfaces or on adjacent wave cut platforms along strike.

The corrected field tracings were then transferred to the original tracings, thereby completing the initial facies analysis (discussed in more detail below). Field work continued the following summer of 1991. In order to deal with problems of photographic distortion, more serial photos were taken from boats.

Detailed work on channel body facies analysis and paleoflow analysis commenced in the autumn of 1991 and progressed through various stages of development and refinement. This was done concurrently with revisions to tracings over the course of five years, which included a return visit to the field to recheck section tracings and complete data collection of stratigraphic measurements in July, 1994.

2.2 PROFILE GENERATION

As was previously mentioned, peripheral distortion was quite noticeable in photos taken from the shore in close proximity to the cliff face. The advantage in taking photos from the shore was that more detail was discernible, and one was able to include a scale in each image. Photos taken from the boat remove the majority of distortion, but introduce a scaling problem where objects of known dimension are not visible. Compensation for boat movement and drift from shore affected the scale and resolution also. The distance from the cliff face was governed by the water depth relative to the draft of the boat. Distance from cliff face reduced resolving capability of some details.

Once the initial tracings had been checked and, in some cases, rechecked, the tracings were redone, and simplified, highlighting the significant and more continuous features that were considered to be diagnostic in facies identification. Within the channel bodies themselves, sedimentary structures and bounding surfaces (e.g. storey boundaries) were identified and annotated.

In order to produce a consistent and versatile reproduction for publication, the tracings were digitized. Forty-two tracings were digitized utilizing the AutoCAD 12 software and digitizing tablet facilities at Bedford Institute of Oceanography (B.I.O.). This allowed for preservation of tracing properties and features with great precision. The digitizing procedure began in December, 1995 and was completed in March, 1997. Plot files were also generated and output to a Versatec plotter.

To improve the presentation quality of the plots, the AutoCAD files were imported into CorelDraw, Version 6. This procedure was contracted out in December, 1996. Several generations of plots were produced, corrected and refined. The final output product was completed in July, 1997.

2.3 CHANNEL BODY ANALYSIS

The initial field observations of the channel bodies utilized the terminology described in McKee and Weir (1953). These observations were then integrated with the lithofacies codes devised by Miall (1978), (Table 2.1, Fig. 2.1). Table 2.1 shows Miall's (1978) codes for lithofacies types, based principally on grain size and sedimentary structures. The lithofacies types typically represent bedsets on the scale of a few decimetres to 1 - 2 metres, withhin channel bodies. They were found to be relavent in the study area, and were included on Enclosures 1 - 4. The most important facies in the channel bodies used in the present study were: 1) St,

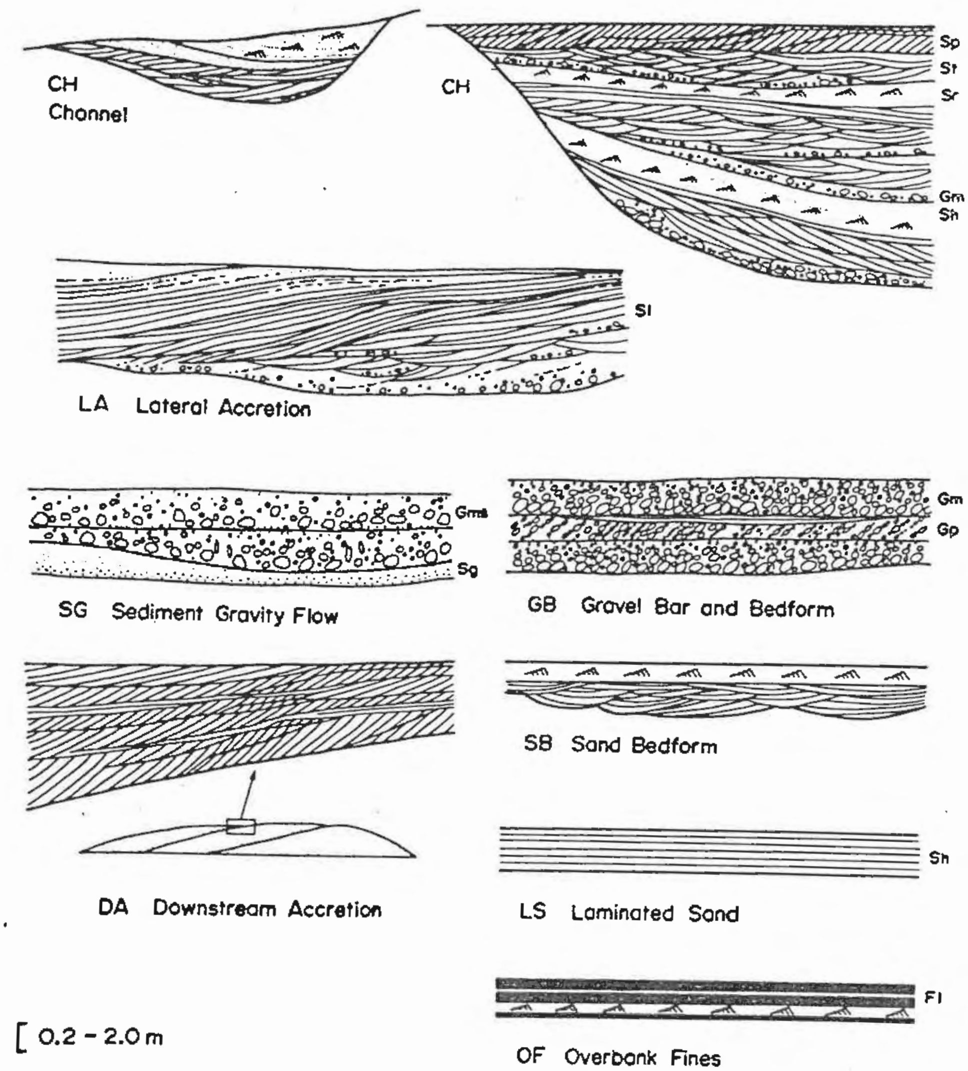

Figure 2.1.

The range of architectural elements in fluvial deposits.Lithofacies codes are those of Miall (1978). From Miall (1988).

Table 2.1.

Lithofacies and sedimentary structures of modern and ancient braided stream deposits. From Miall (1978).

Facies Code	Lithofacies	Sedimentary structures	Interpretation
Gms	massive, matrix supported gravel	none	debris flow deposits
Gm	massive or crudely bedded gravel	horizontal bedding, imbrication	longitudinal bars, lag deposits, sieve deposits
Gt	gravel, stratified	trough crossbeds	minor channel fills
Gp	gravel, stratified	planar crossbeds	linguoid bars or deltaic growths from older bar remnants
St	sand, medium to v. coarse, may be pebbly	solitary (theta) or grouped (pi) trough crossbeds	dunes (lower flow regime)
Sp	sand, medium to v. coarse, may be pebbly	solitary (alpha) or grouped (omikron) planar crossbeds	linguoid, transverse bars, sand waves (lower flow regime)
Sr	sand, very fine to coarse	ripple marks of all types	ripples (lower flow regime)
Sh	sand, very fine to very coarse, may be peubly	horizontal lamination, parting or streaming lineation	planar bed flow (l. and u. flow regime)
Sl	sand, fine	low angle (<10°) crossbeds	scour fills, crevasse splays, antidunes
Se	erosional scours with intraclasts	crude crossbedding	scour fills
Ss	sand, fine to coarse, may be pebbly	broad, shallow scours including eta cross-stratification	scour fills
Sse, She, Spe	sand	analogous to *Ss, Sh, Sp*	eolian deposits
Fl	sand, silt, mud	fine lamination, very small ripples	overbank or waning flood deposits
Fsc	silt, mud	laminated to massive	backswamp deposits
Fcf	mud	massive, with freshwater molluscs	backswamp pond deposits
Fm	mud, silt	massive, desiccation cracks	overbank or drape deposits
Fr	silt, mud	rootlets	seatearth
C	coal, carbonaceous mud	plants, mud films	swamp deposits
P	carbonate	pedogenic features	soil

composed of sand, medium to very coarse, may be pebbly, representing solitary or grouped trough crossbeds, forming dunes of lower flow regime; 2) Sp, composed of sand, medium to very coarse, may be pebbly, representing solitary or grouped planar crossbeds, forming lingoid, transverse bars, and sand waves in the lower flow rigime; 3) Sr, composed of sand, very fine to coarse, representing ripple marks of all types, forming ripples in the lower flow regime; 4) Sh, composed of sand, very fine to very coarse, may be pebbly, representing horizontal lamination, with parting or streaming lineation, interpreted as planar bed flow of both lower and upper flow regime; 5) Sl, composed of fine sand, representing low angle (<10°) crossbeds, found in scour fills, crevasse splays and antidunes; 6) Se, comprising erosional scours with intraclasts, representing crude crossbeding, interpreted as scour fills; 7) Ss, composed of sand, fine to coarse, may be pebbly, representing broad, shallow scours, forming scour fills.

Until the mid 1980's, channel bodies were represented mainly in vertical sections, as derived in simplified form from outcrops, drill core and wireline log signature interpretation. However, this approach was evidently lacking when dealing with complex three dimensional channel bodies, especially those present in coal mines and hydrocarbon reservoirs. Miall (1988) presented a hierarchical system for describing "alluvial architecture", using stratal surfaces (referred to as bounding surfaces in Table 2.2 and Table 2.3) and sediment bodies or macroforms (architectural elements: Table 2.3, Fig. 2.1), that was much more applicable to large, 2-D outcrops and 3-D outcrop / core studies. His system was found to be appropriate for the present study and was employed on Enclosures 1 - 4. Some problems arose in determining the ranking of bounding surfaces for storey identification. This was compounded by sparse or insufficient paleoflow data in certain cases. A storey (Friend *et al.*, 1979) is defined by the presence of similar cosets within composite sets forming macroforms. The bounding surfaces are

Table 2.2.

The range of scales of depositional units in fluvial sandstones. From Miall (1988).

Rank of bounding surface	Lateral extent of unit	Thickness of unit	Area of unit (ha)	Origin	Subsurface mapping methods
6	200×200 km	0–30 m	4×10^7	Members or submembers, subtle tectonic control	Regional correlation of wireline logs
5	1×10 km	10–20 m	10^4	Sheet sandstone of channel origin	Intra-field correlation of wireline logs, 3-D seismic
5	0.25×10 km	10–20 m	2500	Ribbon channel sandstone	Mapping very difficult except with very close well spacing, 3-D seismic
4	200×200 m	3–10 m	40	Macroform elements (elements LA,DA)	Dip of 4th- and 3rd-order surfaces may be recognizable in core
3	100×100 m	3–10 m	10	Reactivation of macroforms	Dip of 4th- and 3rd-order surfaces may be recognizable in core
2	100×100 m	5 m	10	Cosets of similar crossbed facies	Facies analysis of core
1	100×100 m	2 m	10	Individual crossbed sets	Facies analysis of core

Table 2.3.

Classification of architectural elements and bounding surfaces for alluvial strata of the Emery to Bouthillier Cyclothems.Modified from Miall (1988), from Gibling and Wightman (1994).

Architectural elements		
Sandy bed forms	SB	Sandstone sheet or lens, principally trough cross stratified, other bedforms subordinate
Lateral/downstream accretion deposit	LA/DA	Sandstone sheet or lens; large scale inclined surfaces with mudstone drapes; distinction of lateral from downstream accretion rarely possible as strata are mainly inaccessible for palaeoflow measurement
Laminated sand sheet	LS	Sheet of plane bedded sandstone, other bedforms subordinate
Gravel bars and bedforms	GB	Sheet or lens of planar cross stratified conglomerate
Channels	CH	Sediment body with concave up erosional base; less than 3 m thick, minor component of storeys
Abandoned channel fill	OF	Sheet or lens of interbedded sandstone and mudstone, occupying abandoned channel
Bounding surfaces		
6		Base of palaeovalley
5		Base of channel deposit or storey within multistoreyed deposit
4		Surface of macroform element
3		Reactivation surface within macroform
2		Coset boundary
1		Cross bed set boundary

typically erosional and paleoflow direction may change between storeys. The main types of bounding surfaces recognised in the SMF channel bodies were : 1) cross bed set boundary; 2) coset boundary (both 1 and 2 bounding surfaces were rarely indicated on the Enclosures because of scale constraints); 3) reactivation surface within macroform; 4) upper surface of macroform element; 5) base of channel deposit. It was decided to assign storey boundaries as 4th-order bounding surfaces and reactivation surfaces within storeys as 3rd-order bounding surfaces. The highest ranking discernible in this study was the base of channel bodies (5th-order). Some bounding surfaces could be traced over distances of 90 to 200 m. Individual occurances of elements were typically on the scale of 0.5 to 8 m. In the majority of cases, limited channel body exposure precluded the determination of channel body width to depth ratios (Leeder, 1973), so these calculations were not attempted. Similarly, degrees of sinuosity were not determined from paleoflow divergence (Miall, 1976). These calculations would have given a better idea of channel body dimensions.

The paleoflow analysis, described below, and grain size variations were used to determine the architectural elements of the channel bodies (Table 2.3, Fig. 2.1). These were, in turn, used to determine the depositional environments and classification of channel bodies. A key component in this analysis was the recognition of inclined surfaces and inclined heterolithic surfaces (IS/IHS), and their relationship to paleoflow indicators (Thomas *et al.*, 1987). The distinction of architectural elements LA from DA were not always clear cut. Paleoflow direction relative to the strike and dip of the inclined or inclined heterolithic surfaces was used as a criterion to differentiate between lateral and downstream accretion surfaces. Paleoflow should be parallel or sub-parallel to the depositional strike direction for LA and parallel or sub-parallel to dip direction for DA. In reality, however, variable and oblique flow patterns were commonly observed. Such variation is characteristic of many modern sediment bars and rivers. Thus, some uncertainty exists about distinguishing LA from DA.

2.4 PALEOFLOW ANALYSIS

Paleoflow analysis incorporated all measurements of IS/IHS, St, Sr, Sp, primary current lineation (PCL) on Sh. The statistical analysis was based on procedures described in Collinson and Thompson (1982). Statistical analysis was done where sufficient data was available, otherwise, individual measurements were plotted on rose diagrams.

To avoid visual bias on the rose diagrams, square roots of percentages of value sets were determined (Nemec, 1988). Where dips on IS/IHS exceeded an angle of 10^0, corrections for tectonic tilt were made using an equal area stereonet (Schmidt net), (Collinson and Thompson, 1982). Correction for dips $> 5^0$ on foresets (Sp) were also corrected for tectonic tilt. Tectonic tilt ranged from 4° to 41°.

CHAPTER 3: THE CHANNEL BODIES

3.1 BLACK ROCK CHANNEL-BODY

GENERAL DESCRIPTION

The Black Rock channel-body exposure starts approximately 600 m south of Black Rock lighthouse (Fig. 1.6). The channel body is located approximately 33 m above the South Bar Formation, and sits erosionally on floodplain deposits, about 1 to 1.5 m above the Stony Seam. A tectonic tilt measurement of 295°/10° NE was taken on a sandstone body, a possible crevasse splay, within the floodplain deposits. The cliff face trends 360° initially, which is nearly parallel to the paleoflow direction or sub-parallel to the accretion direction. When traced northward the orientation of the outcrop shifts to northeasterly. The channel-body terminates 22 m to the north of the tracing, where it is covered by talus, yielding an overall outcrop length of 231 m and a preserved thickness of about 13 m. The channel body has been subdivided into six storeys, defined by erosional surfaces each of which is assigned a bounding surface hierarchy of fourth-order. The basal bounding surface of the channel body has been assigned a fifth-order in the hierarchy (see Enclosure 1).

CHANNEL-BODY DESCRIPTION:

The lowermost storey, Storey # 1, has incised nearly one metre into the underlying floodplain deposits and at the 10 m position sits directly on a thin sand body below, interpreted to be a crevasse splay. The beds range in thickness from 3 to 25 cm, and dip at low angles. The lithofacies is Sh with Sr, with St increasing northward and vertically up section, and grain size is medium sand. A sideritic lag was noted at the channel base, and abundant carbonaceous plant fragments were found along partings. Scour surfaces were noted on some partings.

The corrected mean strike for IS is 261° and dips range from 3° to 20°. The mean accretion direction is 351° (Fig. 3.1). Paleoflow measurements were taken on Sr, St and PCL. There is reasonable agreement between Sr (average 015°) and St (360°); but PCL trends normal to these. The corrected mean orientation of IS indicates that the accretion direction is oblique to the paleoflow direction but that paleoflow was close to downdip of the accretion surfaces; the surfaces may thus form part of a DA macroform. There is some variability of IS orientation, and some of the macroforms could be LA. Storey # 1 forms a mound that crests at 70 m, eroded beneath Storey # 3.

Storey # 2 is erosive, incising about 2 m into Storey # 1. At its northern limit, Storey # 2 partly erodes and partly onlaps the mound described above. A 2 to 20 cm bed of impure coal, 20 m in length, lies at the base of the unit between 40 m and 60 m on Enclosure 1, but is cut out locally at the storey base. A drifted Calamites specimen was found along the base of Storey # 2 at 37 m. The Calamites and a block of peat, now coalified, could have fallen into the river at flood stage and would have been quickly covered by sand.

The bed sets in Storey # 2 are dominantly IS, with 2 to 30 cm layers. The grain size ranges from medium to coarse sand, fining upward, and the lithofacies consists of St with Sr. The corrected vector mean strike of IS is 002° (Fig. 3.1), with dips ranging form 10° to 27° and having variable directions. The accretion direction is 092°, which is normal to the mean direction of paleoflow, Sr (005°). The macroforms are inferred to be LA. Current direction is nearly normal to the paleoflow direction and parallel to the accretion direction, as in Storey # 1.

Storeys # 3 to # 6 form a coherent body of sandstone and are separated by erosional surfaces that are relatively planar and dip steadily northwards. The

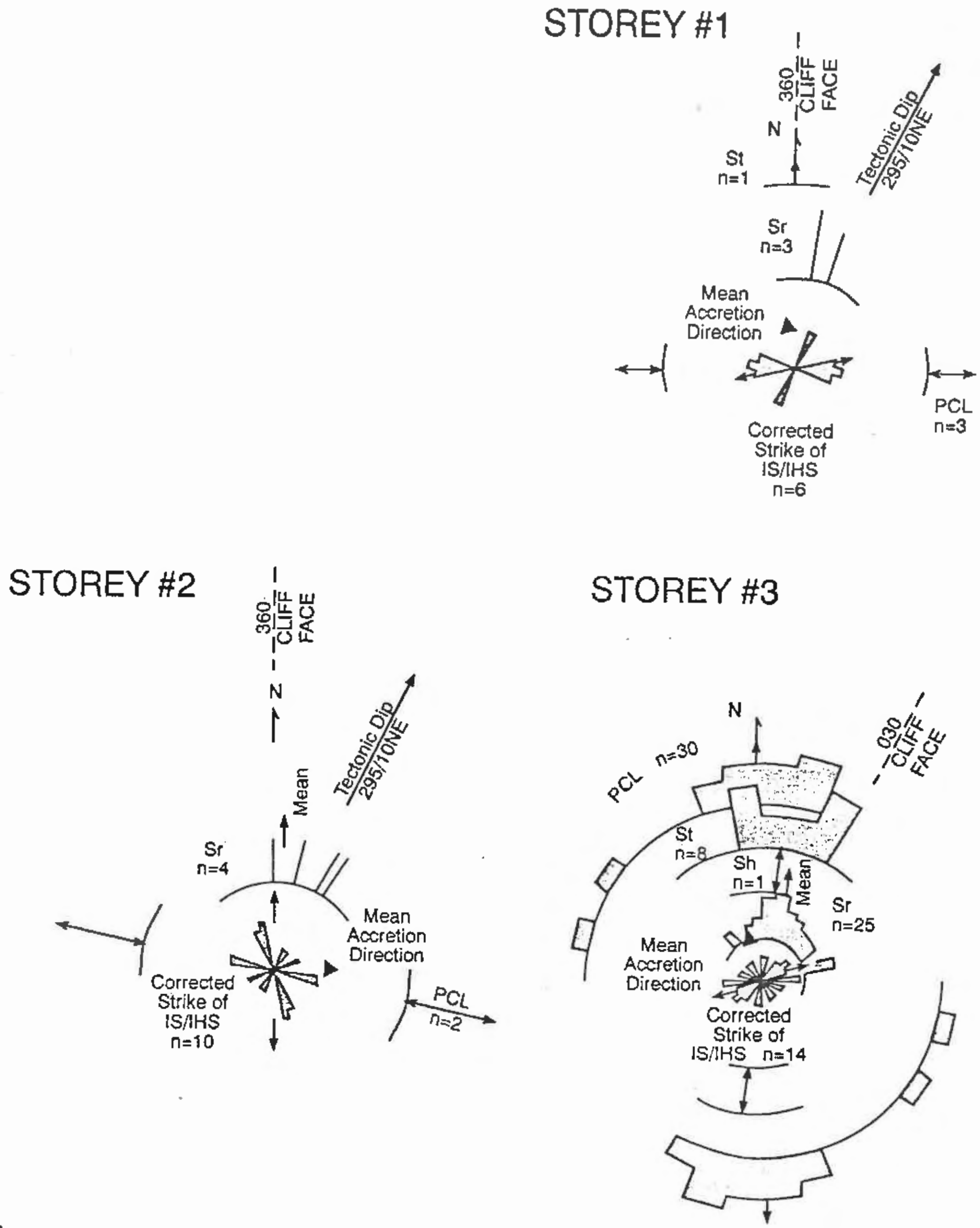

Figure 3.1.

Paleoflow measurements for channel body at Black Rock Point, Stories # 1 - 3. Tracing of channel body is shown on Enclosure 1.

Lithostratigraphic symbols:

Sr = ripple cross-lamination, ripple drift lamination
St = trough cross-beds
Sh = horizontal lamination
Sp = planar cross-lamination
IS/IHS = Inclined Stratification; Inclined Heterolithic Stratification
PCL = Primary current lineation

storeys range from 1.3 m to 5 m in thickness, varying laterally. Storey # 3 is erosively based, incising into Storey # 2 by about 2.5 m, displayed at 68 m as a fourth order bounding surface (Enclosure 1, Fig. 3.2). The grain size within each storey ranges from medium sand at the base, becoming medium to very fine sand upwards. Grain size in Storey # 6 changes from fine sand to very fine sand to silt, over a 2 m vertical interval in its topmost strata. The sediment also becomes micaceous and carbonaceous. The predominant lithofacies throughout Storeys # 3 to # 6 is St, each set 10 to 25 cm thick, averaging 15 cm, grouped in cosets up to 2.5 m thick, averaging 1 m. The frequency of occurrence of lithofacies Sr within St increases proportionately with the decrease in grain size and probable waning of flow velocity.

Bedsets of IS do not appear to be systematically developed within Storeys # 3 to # 6. However, northward dipping surfaces are present at numerous locations, with up to 2 m of vertical relief. The corrected vector mean strike direction for IS is 071° (Fig. 3.1), giving an average accretion direction of 341°. The strike directions on the IS are quite variable, however, reflecting, in part, the predominance of the St lithofacies. The corrected dip directions are consequently variable also, suggesting an SB element. The magnitude of dip ranges from 2° to 27°. Paleocurrent indicators give a fairly consistent range of directions. The PCL mean is about N/S at 359°/179°, the vector mean for Sr is 018°, and the mean direction for St is 010°. The paleoflow data indicate that the direction of flow is sub-parallel to the accretion direction, which implies that Storeys # 3 to # 6 include downstream accreting elements (DA).

INTERPRETATION

This is a significant channel body, being 13 m thick and having 6 storeys. All storeys typically fine upward (especially Storey # 6, which is fully preserved

Figure 3.2.

Part of Black Rock Point Channel-Body, 54 m to 77 m interval on Enclosure 1. Note parts of Storeys # 1 - 4, separated by poorly defined sandstone on sandstone erosional surfaces (apart from thin coal between Storeys # 1 and # 2). Stratification surfaces are generally sub-planar, with northward dipping foresets of trough cross-beds visible. Cliff outcrop is about 5 m high.

and 5 m thick). The amount of incision on the base of the channel body cannot be determined because of limited exposure, but is less than 1 m in the exposed section. The dominant bedforms are cosets of St, with minor plane beds and some Sr in St. This would imply predominantly lower-regime flow with stage fluctuations, and the predominance of trough cross-sets suggests relatively deep, possibly perennial flow.

The main architectural element is SB with DA, surfaces within the latter having at least 2 m vertical extent, and LA in Storey # 2. Deposition is inferred to have taken place in a mainly low sinuosity, sandy bedload system with in-channel bars (except in Storey # 2 for which bank-attached bars (LA) are indicated). The presence of a coalbed within the channel body between Storeys # 1 and # 2 indicates a gap in time during channel-body formation. Storey # 1 does not appear to be rooted and the coal is thin and only locally preserved, elsewhere absent or cut out, suggesting bank collapse and incorporation of peat into the base of Storey # 2. If this were the case, one might expect to see a more chaotic and 'torn' appearance to the coal, considering that the exposed length is 20 m. Another explanation might be that the channel body is adjacent to a coal split. The LA element in Storey # 2 would support this interpretation, implying a more sinuous channel geometry and bank-attached barforms. All storeys have apparent northward paleoflow.

3.2 BIG BRAS D'OR

GENERAL DESCRIPTION

The top of the channel body lies approximately 10 m below the base of the Backpit Seam. The channel body sits erosionally on, and incises through, what are interpreted to be subaqueous bayfill deposits and floodplain deposits. The channel-body comprises two storeys, the lower of which cuts through 1 m of fine-grained strata. The incision between Storeys # 1 and # 2 is noted between the 45 m to 55 m position by an erosional contact and two rotated slump blocks (S on Enclosure 1) that sit directly on the channel cut (fourth-order bounding surface). Storey # 2 displays ridge-and-swale topography that indicates the presence of scroll bars. The channel body is capped by a thin coal. Approximately 4 m below this thin coal is a 15 cm thick coal of the seam named the Unnamed Seam by White (1992). The measured tectonic tilt is 250°/4° N.

The full lateral extent of the channel body is not known. It disappears in talus and beach gravel, just beyond the 165 m mark. The maximum thickness of the channel body is not known either, because the base is not fully exposed. By projecting the profile of the fourth-order bounding surface, described above, it would appear that the channel-body base could cut down to, or even through, the Unnamed Seam. If that does occur, the vertical thickness of the channel-body could exceed 7 m at its deepest point of incision. The cliff face trends 050° which is sub-parallel to the vector mean of Sr lithofacies paleoflow indicator in Storey # 1 and the southern part of Storey # 2, but approximately normal to paleoflow for the rest of Storey # 2 (Fig. 3.3).

CHANNEL-BODY DESCRIPTION:

Storey # 1 is up to 2m thick and comprises very fine sandstone to siltstone with trough cross-beds and ripple cross-lamination. Although bed surfaces show slight, variable dips, no macroforms were noted and the strata are attributed to element SB. Contained within the storey are numerous small channel bodies with apparent widths < 5m and fill thickness from a few decimetres to 1 m. The basal surface is clearly erosional at some points but elsewhere grades up from

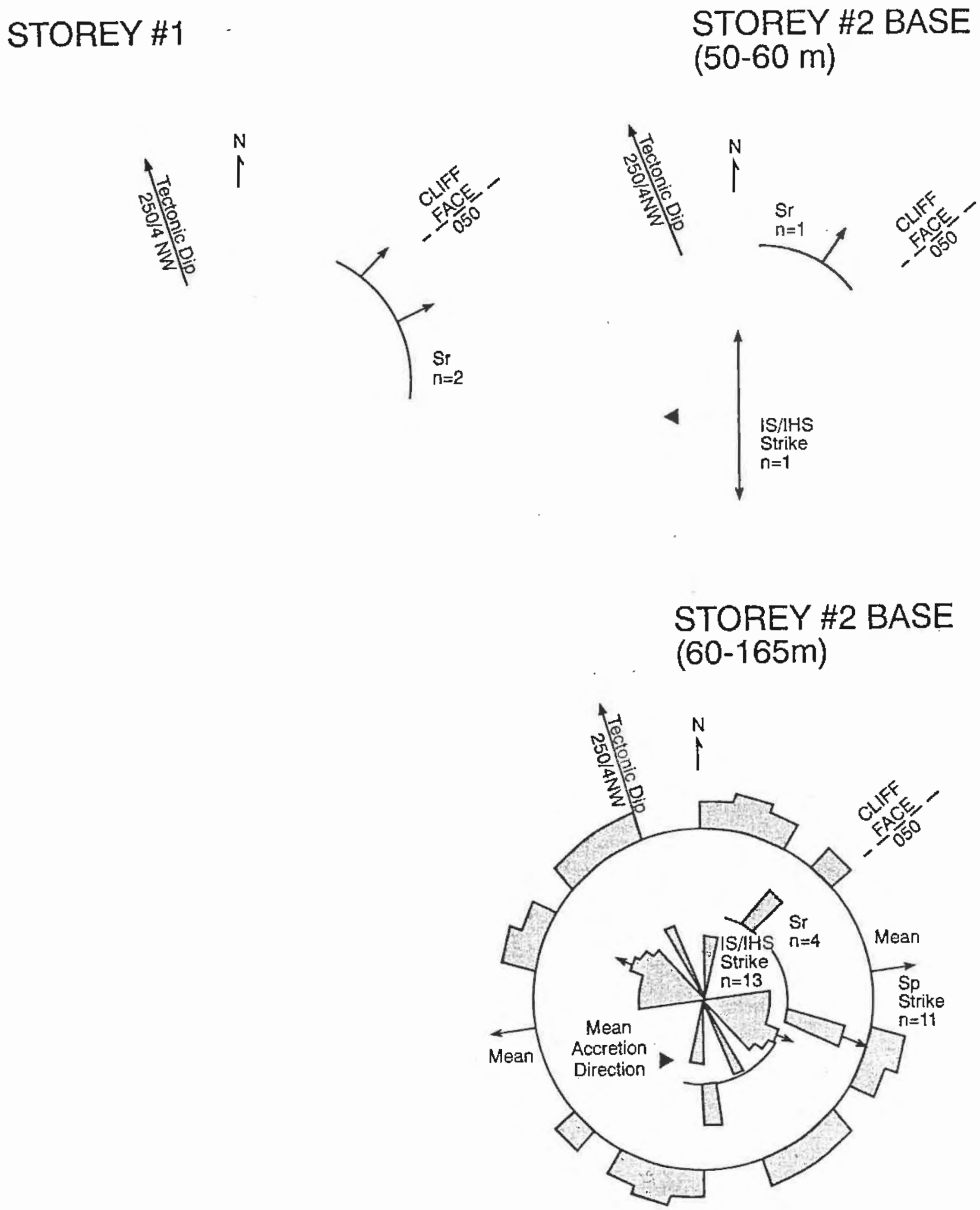

Figure 3.3.

Paleoflow measurements for channel body at Big Bras d'Or, Storeys #1 and #2.Tracing of channel body is shown on Enclosure 1. Lithostratigraphic symbols defined on Figure 3.1.

underlying mudstones without an apparent erosional break.

Storey # 2 cuts completely through Storey # 1, as noted above, and consists of fine to very fine sandstone and siltstone, generally fining upwards. The steep erosional base at 45 m to 55 m position is bordered and overlapped by a set of concave-up strata (to about the 60 m position), with two sandstone slumpblocks resting on the erosion surface. The dimensions of the upper slumpblock are: 1.5 m long x 0.5 m high; while the dimensions for the lower one are: 4.5 m long x 0.5 m high. Ripple cross-lamination and plane beds are present in the basal sandstones of the concave-up strata, with 1m of rooted siltstone above, forming an active to inactive discrete channel fill.

Northward along the outcrop, Storey # 2 shows a series of surfaces (IS, IHS) that dip southward at 7° to 19°. IHS predominates in beds 10 to 30 cm thick. Planar cross-sets (Sp) up to 40 cm thick have advanced systematically up these inclined surfaces - their strike is sub-parallel to that of the IS surfaces (Fig. 3.3) and their foresets dip up the IS slopes. They are especially well seen in the 70 to 80 m position. Ripple cross-lamination shows paleoflow sub-parallel to strike on the IS surfaces (Fig. 3.3). These data indicate that an LA macroform is present. Some plane beds are also present, with mudstone intraclasts and local scours. The IS/IHS surfaces flatten upwards, to generate sandstone mounds composed mainly of stacked Sp sets, well seen from 60 m to 125 m (Fig. 3.4). Relief on individual mound surfaces is up to 2 m. The mounds are interpreted as scroll bars which generate ridge-and-swale topography (RST) as channel point bars migrate laterally. The scroll bars (RST on Enclosure 1) are stacked locally to form compound sandy features that directly underlie the capping coal (eg. 68 m to 102 m). Between these areas, broad swales are filled with mudstone (eg. 75 m to 90 m; 105 m to 135 m). Both ridges and swale fills are rooted in their upper parts, and a Stigmaria axis was noted within IHS at a deeper level (61 m). The bounding

Figure 3.4.

Part of Big Bras d'Or Channel-Body (Storey #2), 75 m to 112 m interval on Enclosure 1. Note large, convex-up sandstone mounds (scroll bars) with IHS surfaces dipping south (to right) and planar cross-sets that have advanced up the surfaces. Areas between the mounds are mud-filled swales. About 3 m of outcrop is visible from sea to capping coal.

surfaces of sandstone mounds are given fourth-order status, and erosional surfaces within the mounds are given third-order status (reactivation surfaces).

INTERPRETATION

Storey # 1 may be a precursor to, and somewhat independent of, Storey # 2. Its base is locally gradational to erosional and the storey appears to be a coarse cap to an underlying bayfill deposit. The small concave-up surfaces labelled St, formed within very fine sandstone, suggest that Storey # 1 may comprise mouth bars and small channels of a prograding crevasse splay or bayhead delta.

Storey # 2 represents the main channel-body advancing over and partially through the underlying bayfill deposits. It may have been a major channel that was feeding the mouth bar and small-scale channels of Storey # 1. Storey # 2 exhibits an incised base, well developed IHS sets (LA macroform) with paleoflow along strike, plus Sp sets advancing up IHS slopes. Ridge-and-swale topography is very apparent, indicative of a sinuous (meandering) channel with point bars that accreted laterally through up-bar migration of scroll bars, in conjunction with vertical aggradation of muds in swales. There is a southward migration direction, shown by a systematic southward dip of IHS sets. The dominant lithofacies are Sr, Sh with Sp. The sequence fines up and is rooted at the top, indicating a stable period following abandonment.

3.3 SYDNEY MINES CHANNEL-BODY Nos. 1 AND 2

GENERAL DESCRIPTION

The Sydney Mines section comprises two channel bodies. The outcrop described is located on the coastal exposure along the Shore Drive at Stubbert

Point, Sydney Mines (Fig. 1.6). Channel-body No.1 rests erosionally on the Emery Seam. The top of the South Bar Formation (SBF) lies 10 m below the base of Channel-body No.1. The overall composite width to height measurement of the channel-body is 55 m x 7 m (both minima). The channel-body has been subdivided into six storeys. The cliff face trends 010° - 190°, which is nearly normal to depositional strike (Fig. 3.5). The tectonic tilt was measured in the uppermost body of the SBF at 280°/12° N.

Channel-body No.2 commences approximately 61 m north of Channel-body No.1. It rests erosionally on floodplain deposits 2-3 m thick above the Stony Seam. The cliff face here trends 025° - 205°, which is oblique to the depositional strike (paleoflow N to W, Fig. 3.8). The channel body consists of four vertically to laterally stacked storeys, with higher storeys overlapping lower storeys to rest upon the basal incised surfaces. The bed sets are predominantly inclined stratification (IS) for the entire channel-body.

<u>CHANNEL-BODY No.1 DESCRIPTION</u>:

The bed sets in Storey # 1 (1.8 m thick) of the channel-body are predominantly IS, with beds 5-25 cm thick, averaging 10 cm, and a few thin shale partings. The orientation of IS was measured near the channel base in Storey # 1 between the 25 m and 30 m positions. A stereonet reorientation was done to correct the IS for tectonic tilt. The mean strike direction of IS trends 070°/250°, and the corrected dip directions range from north to west (Fig. 3.5) with inclinations from 8° to 15°. The mean accretion direction is normal to the strike of the IS at about 340°. Ripple cross-lamination (Sr) within the macroform bed sets was used to determine paleocurrent direction. Fifteen measurements were taken using ridge-and-furrow structures on bed bases for all six storeys, and yielded a vector mean value for the paleocurrent direction of 347° (Fig. 3.5). The

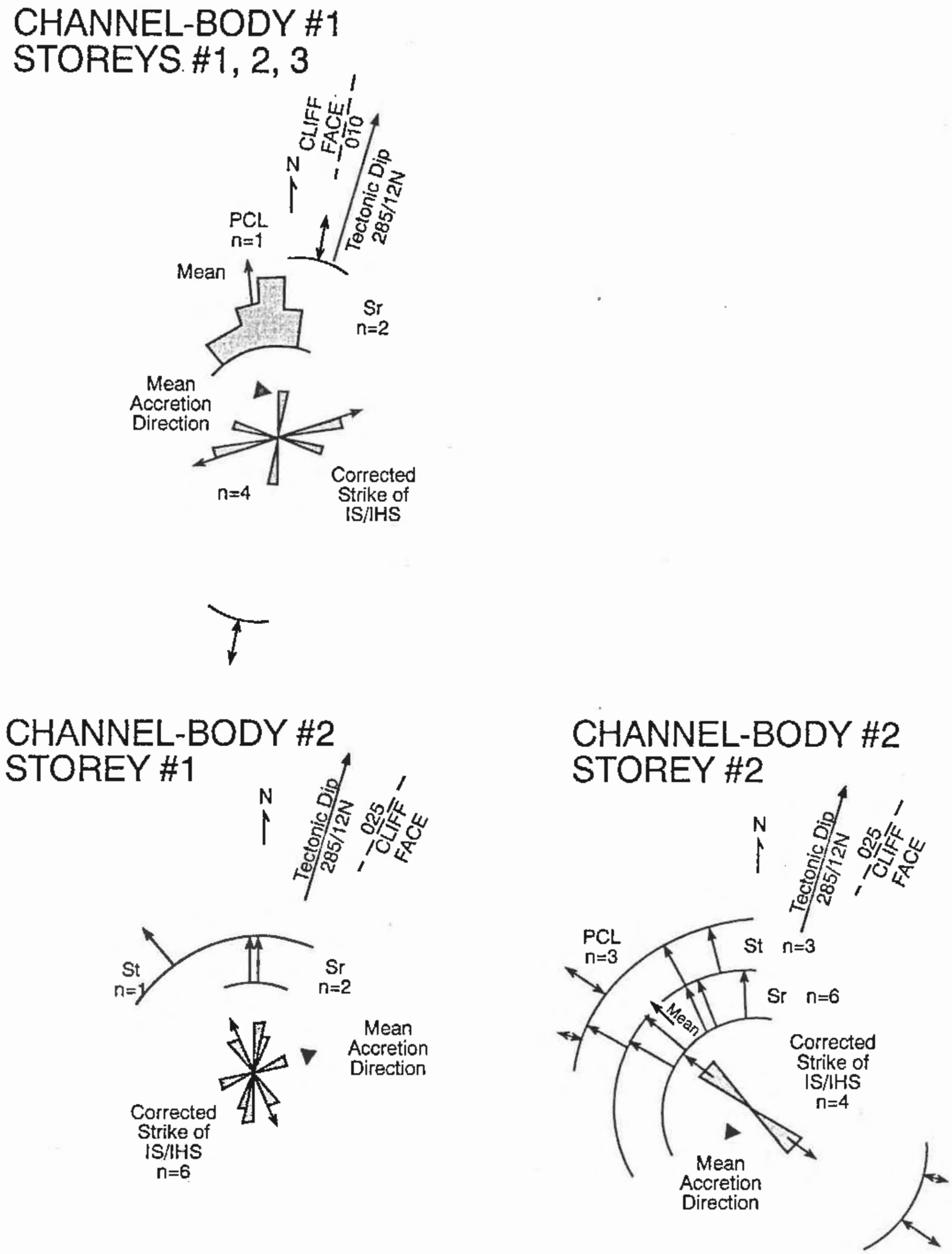

Figure 3.5.

Paleoflow measurements for Channel-Body # 1, Storeys # 1, 2, 3 and Channel-Body # 2, Storeys # 1 and # 2 at Sydney Mines. Tracing of channel bodies is shown on Enclosure 2. Lithostratigraphic symbols defined on Figure 3.1.

paleocurrent direction and accretion direction coincide reasonably closely. This would imply that the macroform is downstream accreting (DA).

The basal erosional surface of the channel-body is overlain by coal fragments that have been scoured out of the underlying Emery Seam. The surface has a slight relief of 10 cm. From the 0 m mark to about 17 m, the lower part of the channel body has planar stratification (Sh) in a unit 1 m thick at 0 m, wedging out towards the north (element LS). Some of the inclined surfaces between 5 m and 10 m are attributed to steeply dipping joint faces. The Sh passes into Sr with localized planar beds 1-2 cm thick. There is a pronounced inclination to the strata between 15 m and 30 m on Enclosure 2 that form the downstream accretion surfaces of element DA. The DA macroform in Storey # 1 appears to be an in-channel barform with a convex-up bounding surface (Fig. 3.6).

Storey # 2 is up to 1 m thick and its basal surface cuts Storey # 1, although it appears conformable in places. Although strata onlap the surface, no clearly defined macroform is evident. The beds contain ripple cross-lamination and are attributed to element SB (sandy bedforms). Siderite nodules are present along erosional surfaces and bedding planes.

Storey # 3 incises into Storey # 2 and is up to 1.3 m thick. A 25 cm scour can be seen at the 27-28 m position. A Calamites stem and plant fragments were also found in the same location on the scour surface. The barforms are flat lying bed sets (averaging 10 cm in thickness) with Sr (element SB).

Storey # 4 truncates underlying strata (Se) locally and is up to 1.5 m thick. It comprises trough cross-beds (St), of element SB. Local erosional surfaces within the storey are marked by siderite nodules and a 75 cm high upright tree trunk *in situ*. The strata pass upward from St to Sr in 2-10 cm bed sets, suggesting an upward reduction in flow power and/or water depth.

Two additional erosional surfaces mark the bases of Storeys # 5 and # 6,

Figure 3.6.

Part of Sydney Mines Channel-Body # 1, 17 m to 27 m interval on Enclosure 2. Note large-scale inclined surfaces with downflow accretion (Element DA) in basal storey (1) and three overlying storeys (2 - 4). Scale is 1 m long.

0.75 m and > 1 m thick, respectively. Ripple cross-lamination is present locally, and the strata are attributed to element SB.

Direct lateral correlation between the two outcrop sections is hampered by 20 m of bank-reinforcing concrete rubble 'riprap'. A correlation estimate would place this outlier stratigraphically equivalent to Storeys # 4 to # 6. Interdigitation with overbank fines suggest that this outcrop is near the edge of the channel-body. The outlier sequence is rooted at the top, suggesting that the outcrop represents nearly the original thickness of the channel body. The basal sandstone unit directly overlies recessive overbank fines, and consists of fine- to medium-grained sandstone, in the form of climbing ripples, of a sandy bedform element SB. This unit is, in turn, overlain by fine-grained sandstone displaying Sr with minor erosional surfaces (Se). Rill casts are present locally in the mudstone at the channel body margin. Siderite nodules are also present along bedding surfaces.

<u>INTERPRETATION</u>:

Some key features exhibited by Channel-body No.1 include: six thin storeys (< 1.8 m thick) separated by erosional surfaces; elements DA (downstream accreting) having inclined surfaces with 1.8 m of vertical extent, sandy bedforms (element SB) and laminated sand sheets (element LS). The presence of an erect tree trunk, and rill casts implies periodic subaerial exposure. The presence of siderite nodules along erosional surfaces may suggest the incorporation of nodules along these surfaces at the time of deposition, following previous growth of siderite around nuclei, by a local, *in situ* groundwater process in the underlying storey. The barforms indicate relatively shallow channels, possibly on the order of 2 m deep. This evidence suggests frequent flood events or channel switches, generating erosion, and ‘flashy’ seasonal flow with periodic upper-regime flow. These characteristics are consistent with a low-sinuosity channel belt geometry, possibly a braided stream system.

CHANNEL-BODY No.2 DESCRIPTION:

The lowermost storey incises the underlying floodplain deposits to a depth of 1 m (130 m position); in this region, the basal surface cuts steeply upwards to the south. The bed sets are composed of medium-grained sandstone, and range in thickness from 10 cm in the south, where trough cross-beds (St) contain ripple cross-lamination (Sr) and onlap the basal surface, to 25 cm thickness to the north, where the overall channel body thickens.

The strata are attributed to element SB (sandy bedforms). Paleocurrent flow indicators include one St measurement of 320° and two measurements from ripple cross-lamination within trough cross-beds, of 355° and 360° (the latter coincident with a groove cast), (Fig. 3.5). A Calamites stem in an inclined, possibly growth position, was located at the 150 m position. Abundant masserated plant fragment intraclasts with varied orientation were found near the base of the channel body, in addition to tree fragments 5 cm in width.

Storey # 2 is 3.2 m thick. It commences with an erosional scour on Storey # 1, most clearly visible over a ten metre interval between 140 m and 150 m (Fig. 3.7). The scour surface is overlain by a medium-grained sandstone lens, between 130 m and 140 m with Sr lithofacies and tree fragments similar to those described above, along with 1 cm mudstone intraclasts. At 130 m, Storey # 2 is truncated by the overlying Storey # 3. Storey # 2 can be traced to just beyond the 185 m mark, where it is covered by a rock fall. Resting on the erosional scour, between 140 m and 178 m, is a wedge of rubbly mudstone, up to 1 m thick, with siderite nodules locally (Fig. 3.7). This is erosionally overlain by a fine- to medium-grained sandstone macroform with large-scale inclined surfaces (IS and IHS) that can be traced for approximately 5 m in vertical extent (140 m to 155 m region). These

Figure 3.7.

Part of Sydney Mines Channel-Body # 2, 149 m to 156 m interval on Enclosure 2.Note erosional base on mudstone; Storey # 1 with trough cross-beds; rubbly mudstone at base of Storey # 2, overlain by inclined stratification with plane bedding (Element LA). Scale is 1 m long.

beds contain 3-5 cm sets of planar stratification (Sh) in the lower part, passing upward to 10-20 cm sets of trough cross-stratification (St) with ripple cross lamination (Sr) on inclined surfaces. Some inclined surfaces appear to be pronounced. This is attributed to steeply dipping joint faces at positions 137 m, 145m, and 150 m on Enclosure 2.

Between 152 m and 173 m is a wedge of medium-grained sandstone with inclined surfaces having 10-20 cm sets of lithofacies St, with Sr more abundant towards the north. At the 170 m mark, the strata are deformed, possibly due to current deflection around a tree trunk (not visible). The inclined surfaces are truncated by a third-order surface, with the bounding surface overlain by St and Sr lithofacies, which changes to Sh within 50 cm of vertical section. Where Storey # 2 is traced northwards, a sheet of planar-stratified sandstone < 1 m thick (Sh) is attributed to element LS. The sheet is overlain by a sheet of trough cross-bedded sandstone (element SB) about 1.5 m thick. The boundary between the two sheets is not a surface with significant erosion.

The corrected mean vector strike of IS is 307°, giving an accretion direction of 217° (Fig. 3.5). The corrected dips on the IS range from 7° NE to 15° SW. The vector mean for paleoflow direction indicator Sr is 315°, which is sub-parallel to the strike of IS. Similarly, measurement for St and primary current lineation (PCL) are sub-parallel to the strike of IS. This evidence indicates that Storey # 2 contains a laterally accreting macroform (LA).

Storey # 3 sits erosionally on Storey # 2, and overlaps the underlying Storeys # 1 and # 2 to rest erosionally on floodplain deposits, until it is eroded at the cliff top. Storey # 3 extends laterally to the 195 m mark where it is covered by a rock fall. The storey is up to 2m thick, but thins northward to less than 1 m. The basal bounding surface is well defined by a 5 cm mudstone bed with burrow casts on the base of the mudstone. Storey # 3 consists of fine- to medium-grained sandstone, having 3-5 cm sets of Sh in the lower half, changing upward to Sr lithofacies; the second-order bounding surface that separates Sh and Sr strata is traceable across the outcrop face. The change in lithofacies noted above indicates a falling stage and reduction in flow velocity.

One measurement on IS in the southern part of the storey indicates a corrected strike of 256° and a dip of 3° SE, yielding an accretion direction of 166° (Fig. 3.8). One measurement of Sr indicates a paleoflow direction of 290°. Eight PCL measurements give a bipolar vector mean of 282°, or 102°. The paleoflow indicates that the flow in this part of the channel body was oblique to the strike of the IS sets, but closer to strike-parallel than to dip-parallel. These sparse measurements suggest that Storey # 3 also contains a lateral accreting macroform (LA). In more northerly parts of the storey, the plane-bedded sheet forms element LS (laminated sand sheets).

Storey # 4 is up to 3.8 m thick and sits erosionally on Storey # 3, developing a major scour between 139 m and 155 m, with an incision on the order of 1 m deep. The base of this unit is marked by a 10 cm mudstone, grading upward to siltstone with siderite nodules. The lower 2 m of Storey # 4 has fine- to medium-grained sandstone, exhibiting Sh lithofacies of element LS (laminated sand sheets). Above this, marked by a second-order bounding surface, the grain size decreases to fine-grained sandstone and the lithofacies becomes Sr: an indication of falling stage and flow velocity decline. This unit tapers towards the north. Overlying this part of the channel-body is a 50 cm layer of very fine-grained sandstone that tapers to the north also.

The entire channel-body is overlain by overbank fines and ripple cross-laminated sandstones indicative of rapid channel abandonment. The whole sequence is capped by a calcrete layer and red mudstones that are rooted, indicating that a period of subaerial exposure, accompanied by conditions of good

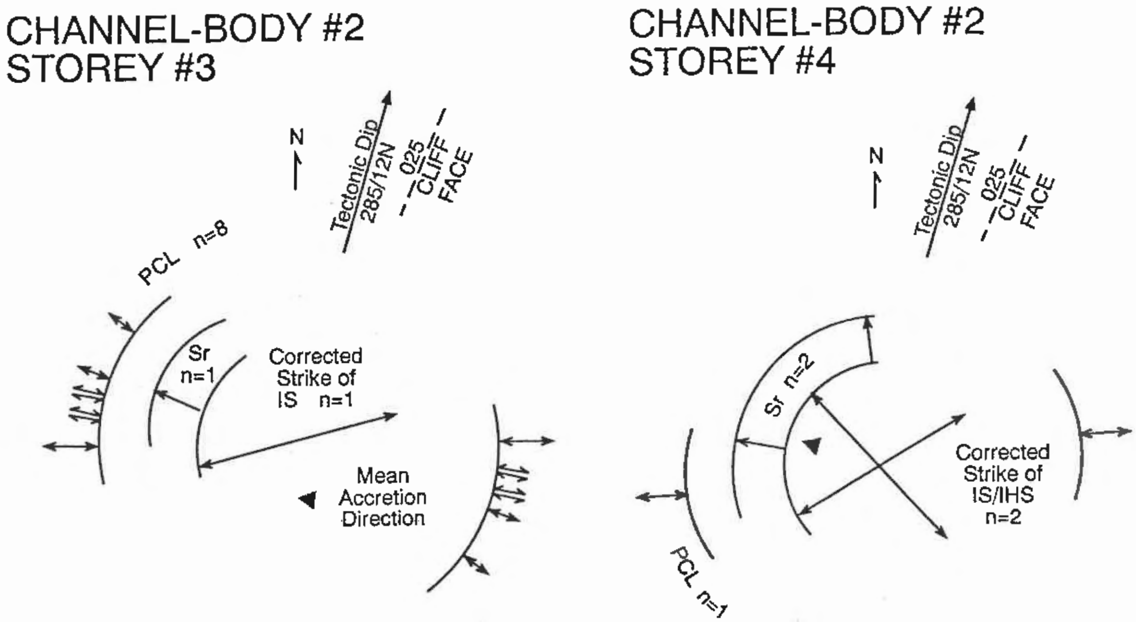

Figure 3.8.

Paleoflow measurements for Channel-Body # 2, Storeys # 3 and # 4 at Sydney Mines. Tracing of channel body is shown on Enclosure 2. Lithostratigraphic symbols defined on Figure 3.1.

drainage, followed channel abandonment. The sparse orientation data show a high degree of variability (Fig. 3.8), which precludes any interpretation of accretion direction and paleoflow direction for Storey # 4.

INTERPRETATION

Several observations can be made about this channel body. It has a significant total thickness of 8 m. There are four storeys, 2.0 m to 3.8 m thick, with variable paleoflow directions. There is a general westward migration (from north) of paleoflow, progressively upward through the storeys. Storey # 1 has DA element (downstream accreting), whereas Storey # 2 and # 3 have LA element (lateral accreting) with stacked (LS/SB), laminated sand sheets and sandy bedforms northward, with planar erosional surfaces. The storeys onlap an incised surface to the south with local strong incision, and Storey # 3 has significant relief (5m). Mudstone rubble is present at the bases of Storeys # 2 to # 4. There is an abandonment channel fill at the north end of the section. From these observations it may be inferred that the channel experienced periodic 'flashy' flow, generating laminated sand sheets. The channel may have been sinuous, and was relatively deep in the south of the outcrop belt (perhaps 5 m deep based on LA dimensions), with bank collapse (mudstone rubble), bordered by shallow sand flats to the north. Disruption of bedding in Storey # 2 may imply vegetation growing within the channel at some level on a sand flat or transported/buried vegetation. The channel may have been periodically inactive. Low flow stage, shallow water and channel abandonment in late stages, with replacement by dry, well drained floodplain deposits (calcrete) and red beds, fits the model of a well-developed cyclothem described by Gibling and Bird (1994).

3.4 VICTORIA MINES

GENERAL DESCRIPTION

The described section is located approximately 0.8 km north of McGillvray Point, off Highway # 8 which follows the shoreline facing Sydney Harbour north of Sydney (Fig. 1.6). The interval described occurs between the Phalen Seam, 61.6 m above the base of the Sydney Mines Formation (SMF), and the Backpit Seam, 96.3 m above the base of the SMF and succeeds the previous described interval at Sydney Mines. Within this interval there are three channel bodies.

Channel-body No.1 commences 5.62 m above the Phalen Seam and forms an abrupt planar and erosional contact on floodplain deposits (Figs. 3.9 & 3.10). The channel body has been sub-divided into four storeys with a total thickness of 5.5 m. Channel-body No.2 commences 2.3 m above Channel-body No.1 and is 0.7 m thick, with an abrupt and slightly erosional basal contact on floodplain deposits. Channel-body No.3 commences 3 m above Channel-body No.2. It has an erosional base incising into a coarsening up bayfill sequence of siltstone to fine sandstone, and is 4.7 m thick.

The cliff face orientation runs 030^0 /210^0 . Limited section is exposed in outcrop because of the steep dip. The steepness of dip did not allow for serial photography and construction of photomosaics here. Thus the absence of an enclosure for this location. Tectonic tilt was measured on a paleosol 10.4 m below the Phalen Seam giving an orientation of 065° /41° NW. The measured inclined strata were corrected to original orientation and plotted on rose diagrams.

CHANNEL-BODY No.1 DESCRIPTION:

Storey # 1 incises 0.5 m into underlying mudstone deposits. It is 1 m thick at beach level and thickens locally to about 1.5 m before it is truncated by Storey #

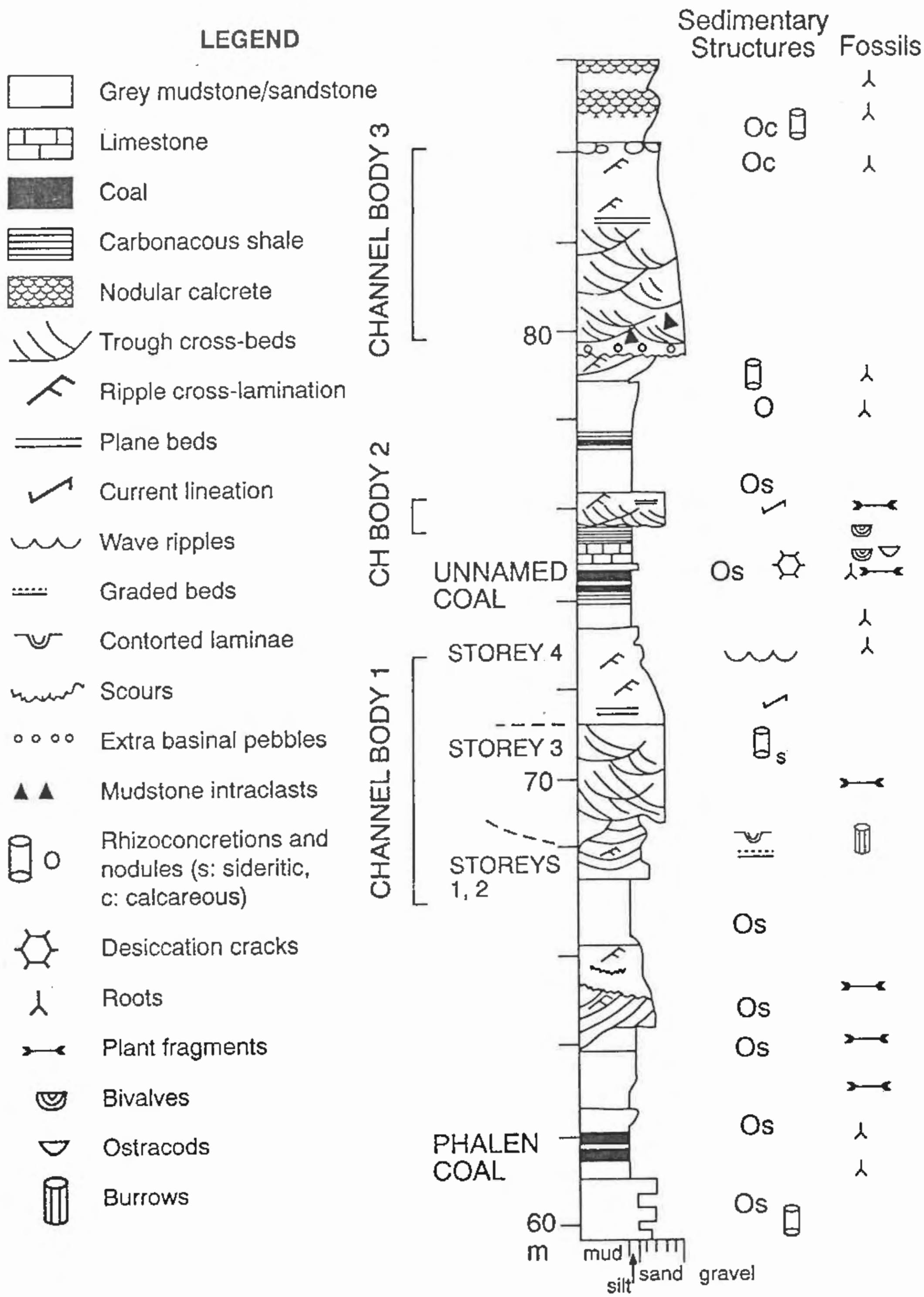

Figure 3.9.

Stratigraphic column of Victoria Mines section.

Figure 3.10.

Part of Victoria Mines Channel-Body # 1 ~ 60.5 m to 71 m interval on Figure 3.9. Note stratigraphic succession (right hand corner up to top centre), bayfill siltstone, sandstone, shale, Phalen Seam, floodplain mudstones and siltstones, a minor channel body, mudstones incised by low-angle inclined concordant fills with graded bedding in Storey # 1. Note the broad scour fill of Storey # 2, incised by Storey # 3 with trough cross-beds fining up from coarse to fine sandstone.

3. Storey # 1 comprises fine sandstone and pinches out laterally towards the water where it is also incised by Storey # 2. Near the water's edge there is local interfingering with medium to coarse sand size lenses 1-2 cm thick. The dominant lithofacies is St with inclined, concordant fills; beds 1-20 cm thick, with ripple and ripple-drift cross-lamination (0.5-2 cm sets), some slightly graded beds with erosional bases, load casts, burrows, but no discernible roots. The corrected strike of IS trends 037° /217°, dipping 9° SE. One measurement on ripple cross-lamination gave a paleoflow direction of 115° (Fig. 3.11), which is oblique to the accretion direction. This storey appears to be predominantly an SB element.

Storey # 2 has a broad, basal scour fill 0.5 m thick, with a coarse lag of fossil plant material and siderite. The scour fill onlaps Storey # 1 and wedges out laterally up the cliff face before being truncated by Storey # 3. The grain size is very fine sand. Corrected strike of IS is 065° /245° with a dip of 4° NW. One measurement of trough cross bedding trends 360°. One PCL measurement is also 360° /180° (Fig. 3.11). The dominance of St lithofacies and oblique paleoflow suggest SB element.

Storey # 3 is 2 m thick and coarse grained, with an erosional contact on Storeys # 1 and # 2, as described above. It has 50 cm trough cross-sets and a 5 cm shale break below a reactivation surface 1.5 m up from the base. The grain size is medium sand above the base. The mean paleoflow direction from ripple cross-lamination is 355° (Fig. 3.12), which is similar to the lower two storeys. St is the dominant lithofacies, with one St measurement (Gibling, 1997) oriented 010°. Approximately 1 m above the base, stratification is disturbed around compacted plant material. The predominance of St and Sr implies an SB architectural element.

Storey # 4 is 2 m thick and has a planar contact on a 5 cm shale parting above Storey # 3. The grain size is medium at the base, fining upward through fine sand to silt at the top. Ripple cross-lamination (locally ripple drift near the

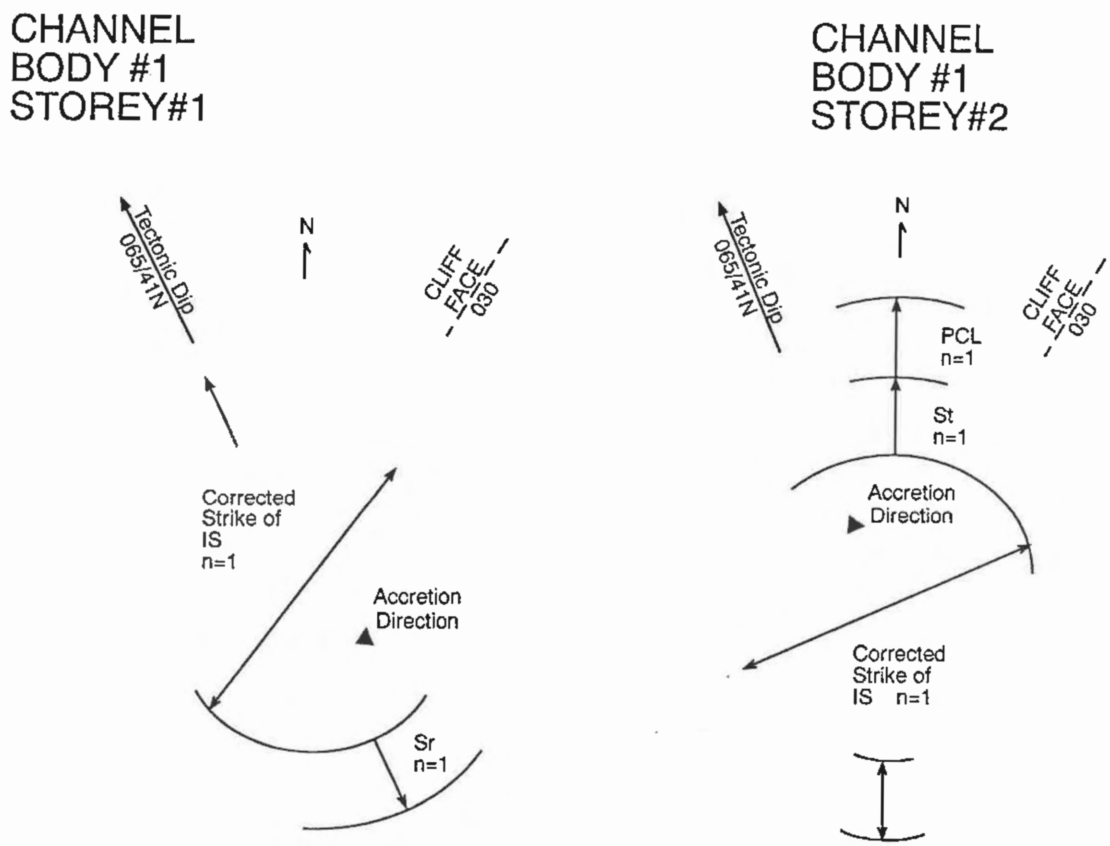

Figure 3.11.

Paleoflow measurements for Channel-Body # 1, Storeys # 1 and #2 at Victoria Mines.Stratigraphic interval shown on Figures 3.9 & 3.10. Lithostratigraphic symbols defined on Figure 3.1.

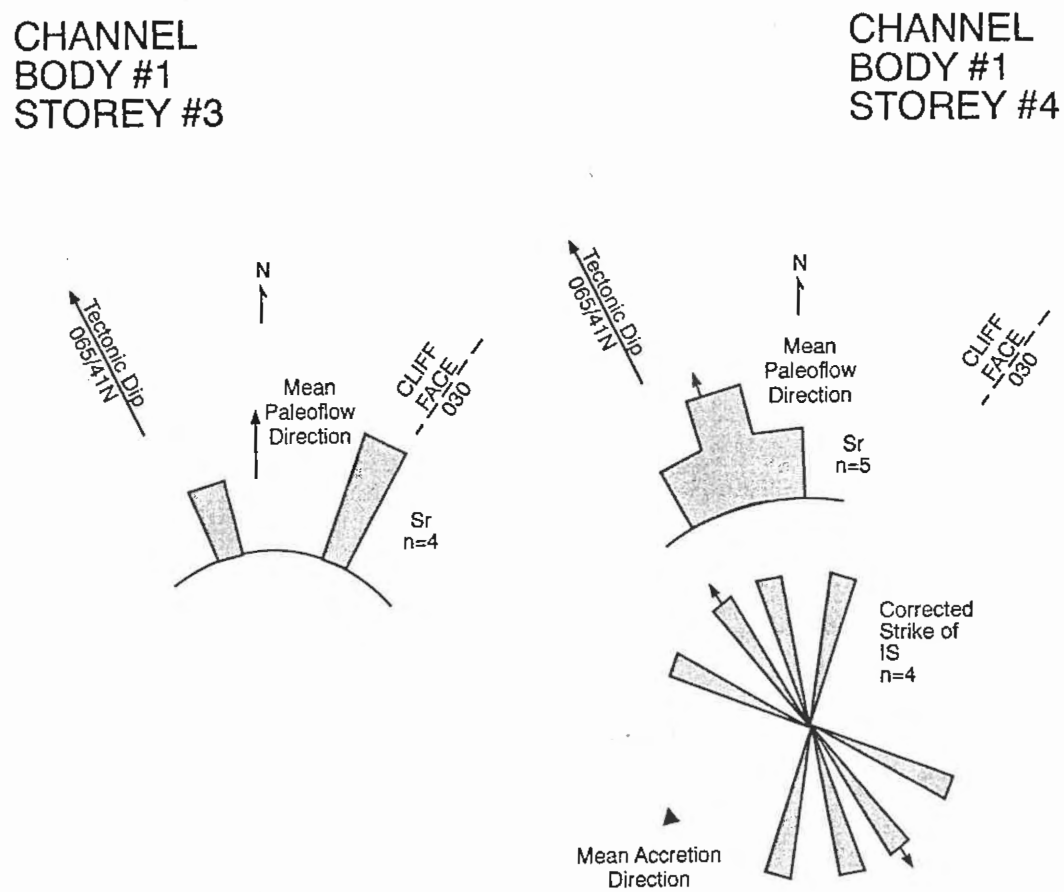

Figure 3.12.

Paleoflow measurements for Channel-Body # 1, Storeys # 3 and # 4 at Victoria Mines. Stratigraphic interval shown on Figures 3.9 & 3.10. Lithostratigraphic symbols defined on Figure 3.1.

top) and minor plane beds are present. Roots within siderite concretions are also present at the top. Corrected measurements on strike of IS give a mean strike of 327° /147° , and a mean accretion direction of 237° (Fig. 3.12). Dips range from 4° to 9° NW-SW. The mean paleoflow direction from Sr is 343°. The paleoflow is nearly strike-parallel with the IS sets, suggesting an LA macroform element.

INTERPRETATION

The channel body can essentially be subdivided into two types. The lower two storeys constitute low angle subaqueous channel fills, as indicated by the graded beds, ripple drift lamination, load casts, burrows and broad scours with coarse lag. The subaqueous nature of the lower two storeys implies that they might be mouth-bars or small channels prograding into a standing body of water, in advance of the main channel break through which is evident in the upper two storeys. Storey #3 incises into the lower units and has low sinuosity, indicated by the SB element with a downstream-accretion component. The abundant compacted plant material, around which stratification is disturbed, implies that the channel was cutting through a well vegetated area, possibly a swamp (Moore, 1987), or riparian wetland at flood stage in water depths of up to possibly 6 m, indicated by the 50 cm St sets (Allen, 1984). A detailed cataloguing of the fossil plant material would help to determine more precisely the type of paleowetland incised by this channel body (Dimichele and Phillips, 1994). Storey #4 has an LA element, fines upward, has increased Sr upward and is rooted at the top, implying that the channel body was at a sinuous mature stage prior to abandonment. The site subsequently reverted to a succession of floodplain, swamp and higher standing body of water, implied by the succussion of overlying mudstone, thin coal, thin carbonaceous mudstone, the Unnamed Seam, siltstone, carbonaceous and calcareous mudstone and fossiliferous (bivalves and ostracods) limestone and shale (marking a maximum flooding surface) and a condensed sequence (Gibling and Bird, 1994).

CHANNEL-BODY No.2 DESCRIPTION:

Channel-body No.2 is unusual in being very thin (70 cm) but it is erosionally based, has a relatively coarse grain size, and contains sandy bedforms (Fig. 3.9). The channel body is medium-grained sandstone at the base, becoming fine- to medium-grained sandstone upwards. It is light grey and highly calcareous. Trough cross-beds predominate in the lower half of the channel body, with ripple cross-lamination more abundant in the upper half. Planar beds are found at the centre with mounded forms and parting lineation. Abundant plant detritus is present in ripple troughs. The channel body thins laterally to 40 cm of medium-grained sandstone, with 0.5 cm sideritic nodules and abundant large, plant stems (up to 1 m in length). Inclined surfaces with a vertical extent of a few decimetres are present The corrected mean strike of these IS surfaces is 065°/245° , with a corrected dip of 7° SE and an accretion direction of 155°. One Sr and one St measurement gave paleoflow directions of 160° and 170°, respectively (Fig. 3.13). Comparison of paleoflow and mean accretion direction suggest that the channel body contains a small-scale DA macroform.

INTERPRETATION

Channel-body No.2 is similar in scale (<1 m thick) to crevasse splay deposits elsewhere in the section. However, it is erosionally based and coarse grained, and resembles more closely channel deposits in the section. There is reasonable compatibility of paleoflow data and the dip direction of inclined surfaces (element DA). The most notable feature of the deposit is the unusual abundance of large plant fragments. Channel-body #2 is interpreted as a small o

CHANNEL
BODY #2

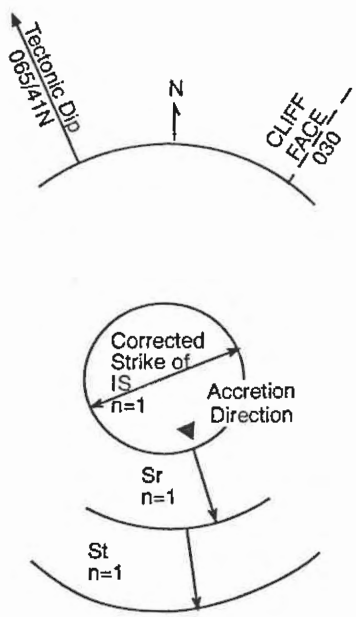

Figure 3.13.

Paleoflow measurements for Channel-Body # 2 at Victoria Mines. Stratigraphic interval shown on Figure 3.9. Lithostratigraphic symbols defined on Figure 3.1.

channel, perhaps tributary to larger channels, that experienced a very active flow event that may have been associated with erosion of a nearby forested area. The channel was subsequently abandoned.

CHANNEL-BODY No.3 DESCRIPTION:

Channel-body No.3 is a very coarse sandstone at its base, fining up to medium and fine sandstone. The channel body incises 25 cm into an underlying bayfill deposit as previously mentioned (Fig. 3.14). The corrected vector mean strike of IS in this underlying unit is 044°/224° and the mean accretion direction is 134° (Fig. 3.15). One measurement on ripple cross-lamination is 010° (Gibling, 1997), suggesting an LA element for the bayfill deposit. The erosional base of Channel-body No.3 has mudstone intraclasts up to 7 cm in size in the basal strata, fossil plant fragments, siderite nodules, black limestone and other rock fragments. The sediments are dominated by trough cross-beds at the base with 50 cm sets, with 30 cm sets higher up. About half way up, the strata are dominated by ripple and ripple-drift cross-lamination and plane beds. The topmost metre is cut by roots and large calcareous/ferruginous nodules up to 10 cm in diameter, forming up to 10% of the exposed face. The corrected vector mean strike of IS is 013°/193° and the mean accretion direction is 283°. The vector mean paleoflow direction of Sr is 335°, two measurements of St confirm paleoflow at 328° and 335°, and one PCL measurement trends 037°/217°. There is considerable variability in corrected strike of IS (Fig. 3.15), and the paleoflow direction is oblique to the accretion direction. This, plus the dominance of St, suggests an SB element.

INTERPRETATION

Channel-body No.3 has large (50 cm) trough sets in the lower part of the

Figure 3.14.

Victoria Mines Channel-Body # 3 ~ 77 m to 86 m interval on Figure 3.9 (from right to left hand side).The very coarse sandstone that forms the basal lag deposit above an erosional surface on bayfill siltstones to fine sandstones is partially obscured by talus and rock fall material. Note the 50 cm to 30 cm bed sets in the broad trough cross-bedding overlain by 50 cm of plane beds, ripple cross-laminated bedding, rooted and nodular at the top. Scale is 1 m long.

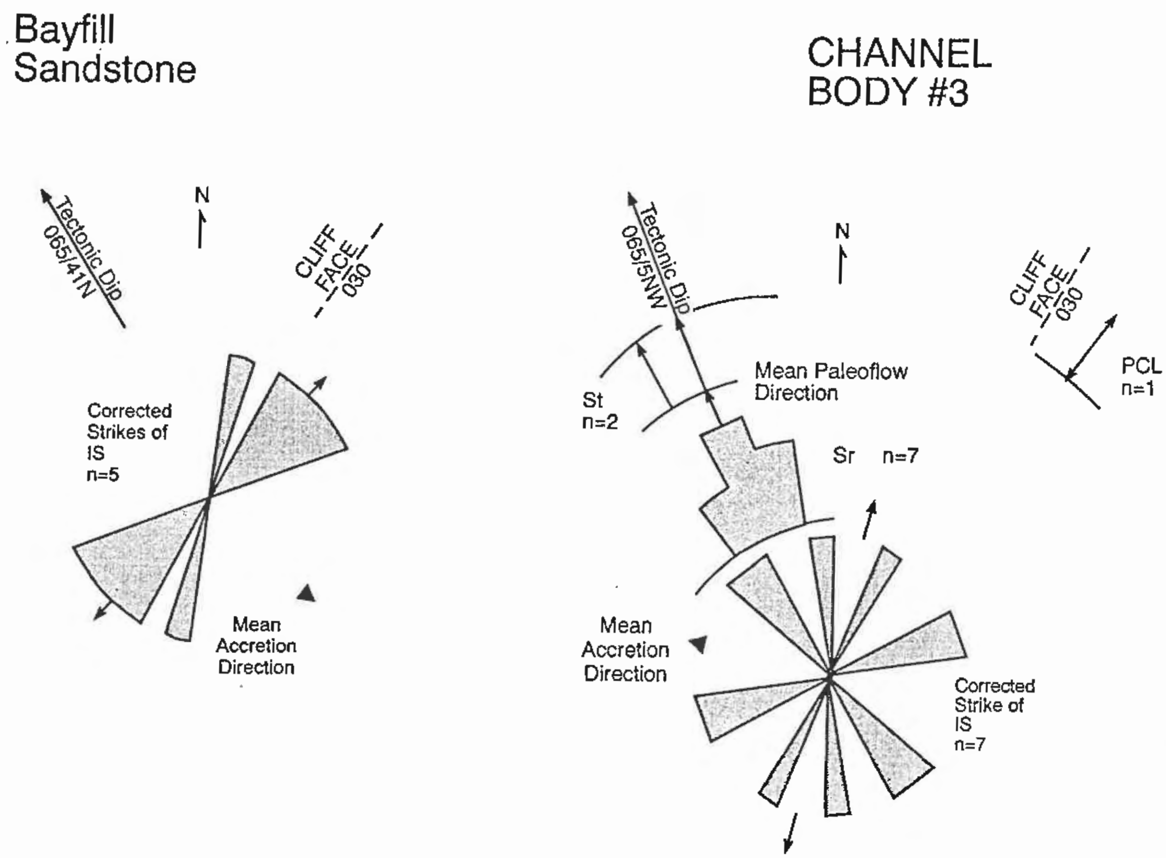

Figure 3.15.

Paleoflow measurements for bayfill sandstone below and for Channel-Body # 3 at Victoria Mines. Stratigraphic interval shown on Figures 3.9 & 3.14. Lithostratigraphic symbols defined on Figure 3.1.

unit, suggesting approximate water depth in the range of 1.5-6 m, based on a compilation of modern-river data by Allen (1984, Fig. 8-20). The smaller amplitude of troughs and increase of ripple cross-lamination and ripple-drift cross-lamination in the upper part, coupled with roots and calcareous/ferruginous nodules at the top, indicates channel flow velocity waning, swallowing/shoaling water and then abandonment and a drying period. The black limestone intraclasts at the base of the channel body implies strong incision through underlying proximal lacustrine/bayfill deposits, although such incision is not seen in the outcrop.

3.5 LINGAN

GENERAL DESCRIPTION

The section described is located below the Power Plant at Lingan in Laffin Cove and extends to North Head (Fig. 1.7). Three channel bodies have been identified in the section, two between the Phalen and Backpit Seams and one above the Backpit Seam. The latter is only briefly described, since no measurements were taken.

Channel-body No.1 sits directly on and incises part of the Phalen Seam and partly sits on fine sandstone to siltstone beds with ripple cross-lamination and roots. The channel-body is accessible between 350 m and 520 m (see Enclosure 3). It comprises three stories in the lower Unit A with a composite thickness equal to 12 metres, and is overlain by a largely inaccessible 7 metre unit of interbedded very fine sandstone and siltstone of Unit B, interpreted as bayfill deposits. This unit is, in turn, incised by an upper channel body unit, 6 metres in thickness, described as Storey #4.

Channel-body #2 is 8 metres thick and is accessible between 540 m and 620 m at North Head (see Enclosure 3). It is capped by a sequence of floodplain deposits, the Backpit Seam and black limestone.

Channel-body #3 is 7 metres thick and can be seen in the upper cliff exposure at 550 m and becomes covered several metres beyond the described section. It is mostly inaccessible.

The cliff face trends 070° over most of the described section, becoming 060° near North Head where Channel-body No.2 meets the water. The cliff face is oriented parallel to depositional strike in Channel-body #1, Unit A, Storey # 1, oblique to depositional strike in Storeys # 2 and # 4 above. The cliff face is oriented sub-parallel to depositional strike in Storey # 3 of Unit A and also Channel-body No.2 (Fig. 3.16). The IS and IHS measurements were corrected for tectonic tilt of 285°/10°NE, taken on the black limestone at 280 m.

CHANNEL-BODY No.1 DESCRIPTION:

Storey # 1 has a maximum thickness of 4 m, Storey # 2 is 3 m at its maximum thickness, and Storey # 3 is 5 m thick but may exceed this thickness northward. A composite thickness of 6 m can be seen in Unit A between 380 m and 400 m. Unit B has a thickness of 7 m. Storey # 4 has a maximum thickness of 6 m. Therefore, the total composite thickness of Channel-body No.1, including Unit B, is 25 m.

Storey # 1 of Channel-body No.1 has an erosional contact on the Phalen Seam locally, with up to 0.5 m of erosion, but elsewhere rests upon fine-grained bayfill strata. Grain size is medium sandstone. Inclined strata (IS) are present but not systematically developed, and contain ripple cross-lamination and plane beds. Vector mean of strike directions of IS sets is 066°, with a predominant SE dip direction of 3° - 12° (corrected for tectonic tilt), (Fig. 3.16). Paleoflow from ripple

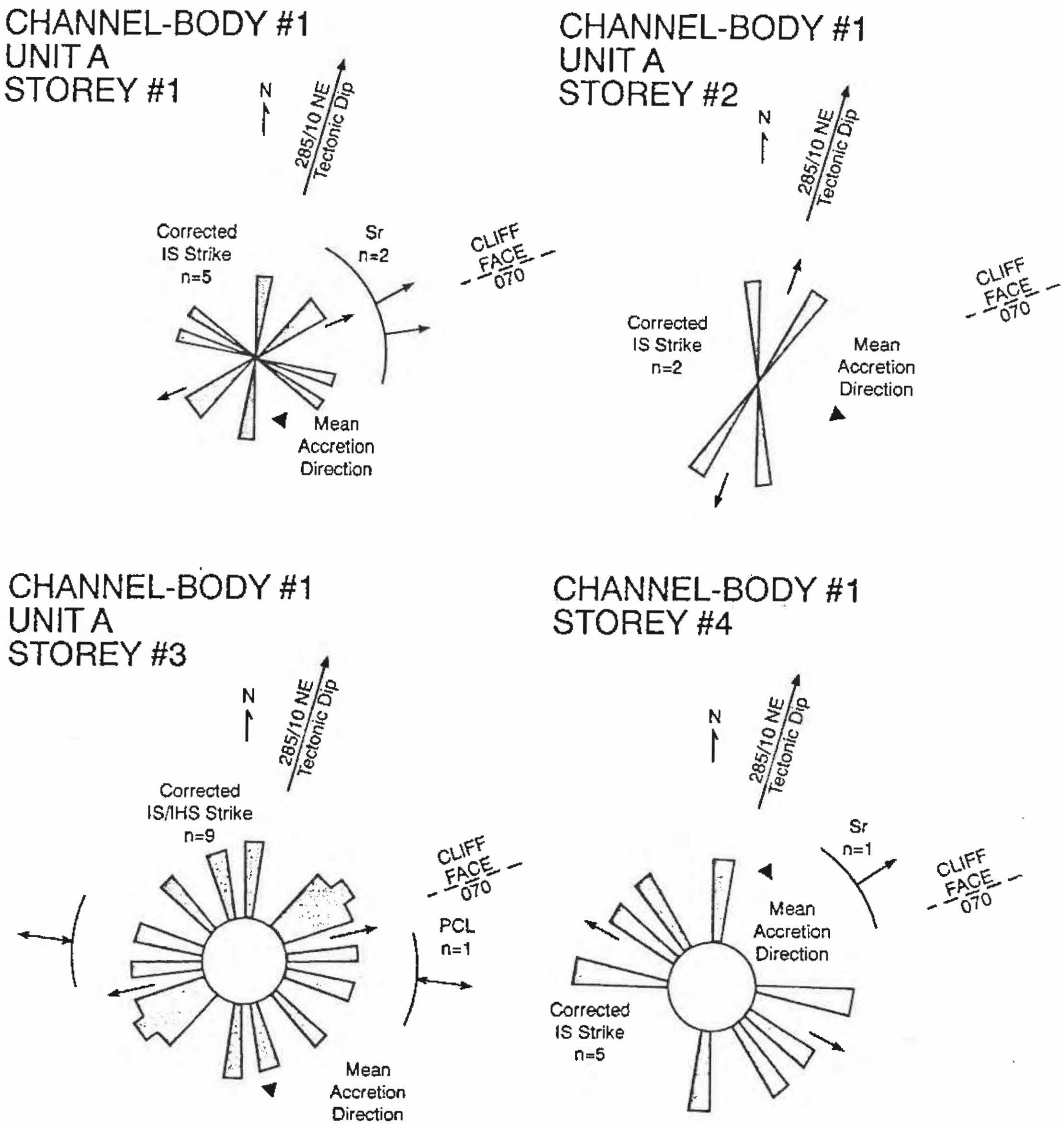

Figure 3.16.

Paleoflow measurements for Channel-Body # 1, Unit A, Storeys # 1 - 3 and # 4 at Lingan.Tracing of channel body is shown on Enclosure 3. Lithostratigraphic symbols defined on Figure 3.1.

cross-lamination is approximately along strike of the inclined surfaces, suggesting that LA macroforms are present, with a NE to E paleoflow. Fossil plant material is common near the storey base.

Storey # 2 cuts about 3 m down through Storey # 1, and at the margins of Storey # 1's incision, rests upon the underlying fine-grained strata (400 m position). It is mainly medium-grained sandstone with 25 cm mudstone clasts and Calamites fragments along the basal surface. Inclined strata (IS) with plant fragments on their surfaces can be traced for up to 2 m in vertical extent; although they appear to dip systematically along the outcrop, two measurements on IS surfaces gave variable trends after correction for tilt. Vector mean of strike direction of IS sets is 018° with predominant SE dip of 3° - 6° (corrected for tectonic tilt), (Fig. 3.16).

Storey # 3 has a relatively planar erosional base that cuts out Storey # 2 up-dip (360 m). The base is overlain by coarse-grained sandstone with carbonaceous material. IS and IHS surfaces have a mean corrected strike of 077°, with 2° - 27° dips to the SE (Fig. 3.16). Grain size becomes medium sand at higher levels. One current lineation measurement gave a 095° trend, roughly along strike of the inclined surfaces and suggesting the presence of an LA macroform. However, the inclined surfaces are not systematically developed along the cliff face. Broad (~ 10 m), concave-up surfaces are present, indicating shallow scours.

Unit A (Storeys # 1 to # 3) shows a general coarsening-up trend and a planar upper surface across the outcrop below the well bedded, very fine sandstone to siltstone of Unit B, which is largely inaccessible. Although inclined to planar erosional surfaces are present, they are rarely overlain by sandstone units thicker than about 1 m. An exception is the thick (6 m) and extensive sandstone body designated as Storey # 4, which cuts down about 6 m, and possibly more, over a 60 m distance (440 m - 500 m) to amalgamate with the top of Storey # 3

(Unit A), (Fig. 3.17). The storey has medium-grained sandstone at the base and fines upward, with a mudstone plug 2 m thick at the top, possibly an abandoned channel hollow-fill. Large-scale inclined surfaces (IS) dip systematically northeastward, with a vector mean of strike of 116° (Fig. 3.16). The IS surfaces dip at 3° - 13°, and are not highly continuous in the plane of section, but in the top 2 m to 3 m of the storey they curve over to form mounds with a vertical relief along individual surfaces of 1.5 m. The top of the storey thus has a ridge-and-swale topography (RST), well seen at the 480 m position (Fig. 3.17). The ridges have clearly accreted in a NE direction, as indicated by their systematic stacking pattern, and this strongly suggests that the channel-body has formed by lateral-accretion of a point bar (LA macroform). One paleoflow measurement on ripple cross-lamination gave 055°, oblique to the mean IS strike direction.

Unit B is capped across the entire outcrop by a mudstone sheet that is continuous with the top of Storey # 4 and coarsens up to fine sandstone, 1.2 m thick, capped by a 30 cm nodular calcrete, well seen on the wave-out platform ("paleosol" on Enclosure 3). An overlying 1.3 m recessive unit of poorly stratified mudstone is capped by a massive, 10 cm limestone with mudcracks, directly below the base of Channel-body No.2.

INTERPRETATION

The key features exhibited by Unit A are that there are three storeys developed, with overall fining up cycles within a generally coarsening sequence. All three storeys have erosional bases partially incising lower strata. Storeys # 1 and # 3 have probable LA macroforms, implying a sinuous channel planform. The general coarsening of the sequence suggests a progradation of alluvial material over bayfill and associated channel deposits .

Unit B, with its planar strata of very fine sandstone to siltstone, is

Figure 3.17.

Part of Lingan Channel-Body # 1 and # 2, 465 m to 498 m interval on Enclosure 3. Note the broad inclined surfaces (IS) of Storey # 4 incising through sandstone with inclined planar erosional surfaces in Unit B and amalgamating with the top of Storey # 3 of Unit A (right side of photo). Also note the ridge-and-swale topography capping Storey # 4, overlain by a succession of overbank fines (mudstones), a nodular calcrete (prominant resistant ledge below roosting black cormorants), poorly stratified mudstones, a 10 cm limestone, then a fining up sequence of trough cross-stratified sandstone of Channel-Body # 2.

interpreted as a succeeding set of proximal bayfill deposits that lack substantial channel fills, following temporary site abandonment by the main channel body. The deeply incised Storey # 4 has medium sandstone fining up to fine-grained sandstone capped by an abandonment fill of overbank fines (OF), succeeded by a well-cemented, calcareous paleosol and additional OF strata. Ridge-and-swale topography indicative of point bar deposition is present in the upper part of the channel body and was formed prior to abandonment.

The presence of a well cemented calcareous paleosol (nodular calcrete), suggests an exposure event under relatively dry climatic conditions and represents a sequence boundary (Tandon and Gibling, 1994). This was followed by a non-calcareous mudstone containing two carbonaceous bands, with a zone of calcareous nodules between them, possibly indicating climatic change. This is succeeded by a thin pale grey limestone with a wavy surface and weak stratification. There are mudcracks 15-35 cm in diameter on the upper surface , indicating drying conditions again. The limestone may represent temporary flooding conditions, perhaps seasonal, and indicate a palustrine environment, with the absence of bivalves or ostracods. It should be noted that the Unnamed Seam is absent in this interval, implying that it was either not deposited, or has been removed by Channel-body No.2. An alternative explanation may be that the two carbonaceous bands mentioned above may be equivalent to the Unnamed Seam. The development of the paleosol under general drying conditions, plus possible seasonal fluctuations, may have forced a regression causing channel incision prior to the aggradation of Channel-body No.2.

CHANNEL-BODY No.2 DESCRIPTION:

Channel-body No.2, 8 m thick, has a planar but erosional basal surface and is significantly coarser-grained than Channel-body No.1. The basal 2 m is very coarse sandstone with mudstone clasts up to 25 cm in diameter, siderite pebbles, and blocky fragments of the underlying limestone. The channel body fines up, apparently gradually, to medium and fine sandstone. Trough cross-beds are the predominant bedform, with ripple cross-lamination and plane beds (Fig. 3.17). Large-scale inclined surfaces with a vertical extent of at least 1 m show a mean corrected strike of 052° and NW dips of 2° - 28°. However, they do not show systematic sets in the outcrop face. Cross-beds (St and Sr) show northerly paleoflow (Fig. 3.18). Planar to concave-up erosional surfaces are present, but are localized and do not enable well-defined storeys to be identified. The predominant architectural element appears to be sandy bedforms (SB). The channel body is capped by floodplain deposits, overlain by the regionally extensive Backpit Coal and overlying limestone. Between 565 m and 590 m on Enclosure 3, the morphology appears to be changing. Here, in the upper 2.5 m of the channel body, a wing extends for 10 m to the southwest into the overlying floodplain deposits. There are also asymmetric convex-up inclined surfaces that appear to be lateral accretion surfaces migrating to the northeast. However, there is not any paleoflow data to substantiate this.

INTERPRETATION

Channel-body No.2 fines up from very coarse and coarse sandstone at the erosional base. IS and IHS sets are poorly developed, but northerly directed, large trough cross-beds with Sr are the predominant feature (SB element). These bedforms indicate transport in the lower flow regime with a good supply of unusually coarse sediment, possibly in high stage flood events. The predominant SB element also implies a low sinuosity channel system and possibly perennial flow. There does, however, appear to be some variability in the orientation of inclined surfaces coupled with an upward reduction in grain size. The apparent

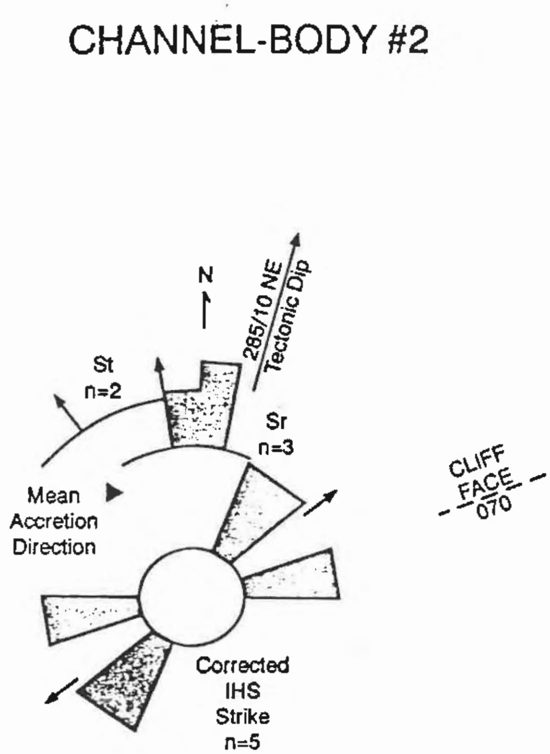

Figure 3.18.

Paleoflow measurements for Channel-Body # 2 at Lingan. Tracing of channel body is shown on Enclosure 3. Lithostratigraphic symbols defined on Figure 3.1.

change in morphology near the top of the channel body suggests a transition to a more sinuous system as the flood stage waned. The inclusion of limestone intraclasts in the basal 2 m of the channel body implies significant erosive power during high flood stage. The underlying limestone was not transected however, which implies that some induration had taken place over some time prior to incision. It also implies that the tenacity of the limestone may have forced the channel body to migrate laterally. The capping coal and limestone suggests a rise in base level (possibly sea level).

CHANNEL-BODY No.3 DESCRIPTION:

Channel-body No.3 rests on mudstone or locally, on an underlying thin rider coal above the Backpit Seam. It is at least 14 m thick, up to a well-defined planar sandstone surface below the cliff top. The cliff face is largely inaccessible and no detailed measurements were recorded. The channel body is divided into two units, A and B, and are each 7 m thick, respectively, at their maxima. Unit 3A comprises two storeys of medium sandstone with inclined surfaces well developed in both storeys. Broad trough cross-beds (1 m high x 5 m wide) are developed in the lower part of Storey #1 and plane beds dominate the upper part. All of Storey #2 is plane bedded (Sh). This storey has well developed stacked convex-up barforms with 1 to 2 m relief, seen between 630 m to 650 m. Near the limit of the outcrop (730 m position), Unit 3A and the base of Unit 3B lap against a steep erosional surface cut through 6 m of fine-grained strata over a distance of 18 m (Fig. 3.19). Unit 3B is very much finer grained than Unit 3A (very fine sandstone to siltstone) with sub-planar beds and ripple cross-lamination and some fills over low-angled erosion surfaces. Unit 3B may consist of bayfill deposits. Overlying strata (~ 10 m thick) include a nodular calcrete and red and grey mudstones, below the Bouthillier Seam (not shown on Enclosure 3).

Figure 3.19.

Part of Lingan Channel-Body # 3, 725 m to 752 m interval on Enclosure 3. Note the steep erosional surface incising through fine grained strata (lower right centre) onlapped by Units A and B. Unit A exhibits trough cross-beds and some planar strata (lower left centre). Unit B is finer grained, ripple cross-laminated, very fine sandstone and siltstone (above top of incision).

INTERPRETATION

The lower part of Storey #1 in Unit A has medium sandstone, some IS sets and some St lithofacies developed, with an erosional base that cuts down to a rider seam in places, suggesting SB element, lower flow regime and deep water (up to 10 m) (Allen, 1984). The upper part of Storey #1 has planar surfaces, indicative of Sh lithofacies and of an LS macroform; this implies low sinuosity channels and 'flashy' flow.

Storey #2 has a similar characteristic to the upper part of Storey #1. The convex-up barforms may be in-channel sand sheets. The deposition of Unit 3A channel fill followed a deep incision into underlying floodplain deposits, suggesting a response to base level fall and/or bank-cutting. This was followed by abandonment and deposition of bayfill deposits. The subsequent overlying unit of nodular calcrete, suggests subaerial exposure in a drying period.

3.6 DOMINION

GENERAL DESCRIPTION

The Dominion channel body lies closely above the Phalen Seam in the vicinity of an abandoned quarry and dock facility with concrete pyramidal pylons (Fig. 1.7). At this locality the Phalen Seam has a 60 cm upper leaf overlain by 1.2 m of fossiliferous limestone, black and grey shale. The channel body has a planar contact on grey shale over a distance of 80 m (Enclosure 3). Tectonic dip is 050°/5° NW. The cliff face trends 060°, approximately normal to paleoflow direction. The total channel-body thickness is about 7 m, possibly more, and it is divided into three storeys.

CHANNEL-BODY DESCRIPTION:

Storey # 1 has a maximum thickness of 2 m. The erosional base has 50 cm of relief, and the basal surface has grooves, gutter casts and current crescents. The bedding is planar with well developed plane beds with current lineation, and small channel fills with inclined surfaces are present. These features suggest that the storey represents an LS element (laminated sand sheets). Paleoflow direction is to the NW as indicated by PCL and unipolar current crescents (Fig. 3.20).

The basal surface of Storey # 2 cuts through Storey # 1 giving about 2 m of relief on the surface. It cuts down steeply at the 80 m position, and runs sub-parallel to the base of the channel body northward (Fig. 3.21). Coarse sandstone is present at the base with St lithofacies, suggesting SB element (sandy bedforms). Plant fragments, sideritic pebble layers, contorted beds and large load casts are also present. Storey # 2 fines upward to thin-bedded, medium to fine sandstone with Sr and Sh (with PCL), (Fig. 3.20) , suggesting an upward transition to element LS, and a thin tongue extends southward over Storey # 1. Roots are present 1.5 m above the base. Although the outcrop is oriented approximately normal to paleoflow (NW), Storey # 2 shows no systematic large-scale inclined surfaces, and element SB is suggested. The top of Storey #2 is obscured by talus, but judging by the angle of cut on the overlying basal surface of abandonment fill, the thickness of this storey may have been at least 5 m.

Storey # 2 is cut by a northward dipping erosional surface overlain by a thin sandstone and a mud-rich abandoned channel fill at least 4 m thick. The fill comprises grey rooted mudstone with vertical rhizoconcretions (the main rock type); thin layers of coarse sandstone; grey, finely laminated mudstone with siderite bands; platy, shaly coal; a thin tough limestone and an upper shaly 50cm thick limestone with bivalves (Gibling, 1997). Stigmaria and Calamites are found

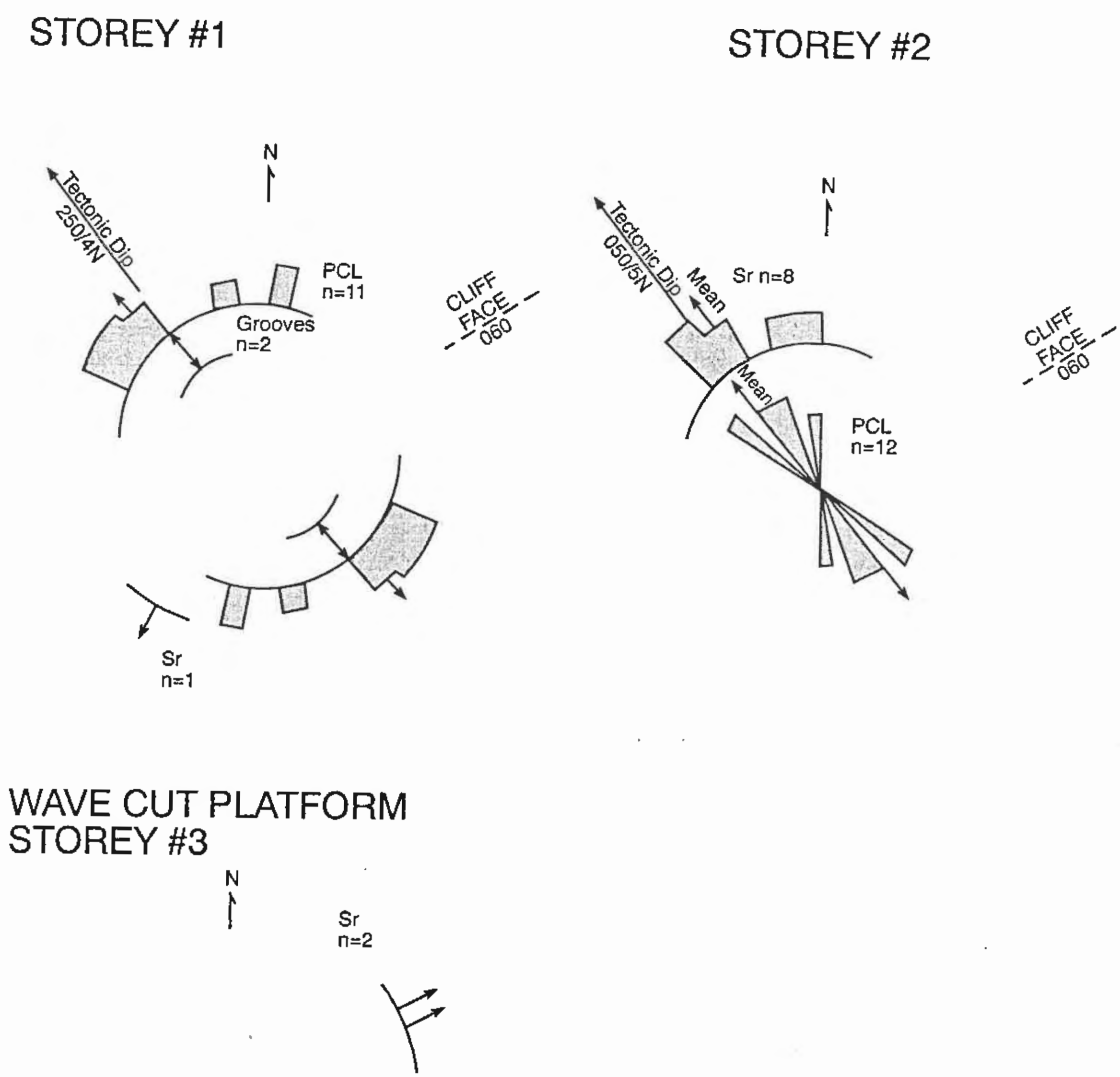

Figure 3.20.

Paleoflow measurements for channel body at Dominion, Storey # 1 - 3.Tracing of channel body is shown on Enclosure 3. Lithostratigraphic symbols defined on Figure 3.1.

Figure 3.21.

Part of Dominion Channel-Body, 72 m to 123 m interval on Enclosure 3. Note plane-bedded Storey # 1 (right hand side) incised below Storey # 2. Abandoned-channel fill at left hand side (4 m thick), capped by limestone (resistant planar bed). Phalen coal and capping limestone/shale underlie the channel body.

At approximately the 150 m position on Enclosure 3, coarse to fine sandstones are present on a wave-cut platform. The sandstones show ridge-and-swale topography, with St, Sr (some in St) and Sh + PCL. Paleoflow is to the NE (Fig. 3.20). The relationship of these sandstones to the rest of the channel body is not clear. However, they probably form a third storey cutting into Storey # 2, with the abandoned-channel fill described above abutting against the exposed strata of Storey # 2. The full extent of Storey #3 is not known.

INTERPRETATION

Storey # 1 has a sheet-like appearance with architectural element LS (laminated sand sheets) from 40 m to 90 m. From 90 m to 110 m, St bedforms dominate, suggesting a transition from SB element (sandy bedforms). This association may also imply perennial flow conditions similar to those described on the South Saskatchewan River by Cant and Walker (1978). Both Storey # 1 and Storey # 2 have a similar NW paleoflow direction. Storey # 2 incises and onlaps Storey # 1, suggesting an incised fill, channel depth of 4-5m, and a possible basal SB element, becoming LS upwards. There are no indications of well-developed macroforms in Storey # 2. Although there is evidence for vertical aggradation of bedforms St, Sr and Sh, Sr and PCL are sub-parallel, so a (DA) element cannot be ruled out. Roots in Storey # 2 indicate subaerial exposure. Storey # 3, inferred from relationships observed in the wave cut platform, has NE paleoflow, and the presence of ridge-and-swale topography suggests a sinuous channel with LA macroform prior to mud deposition in the abandonment fill.

The overall sequence includes well developed plane beds, and appears to be lower to upper flow regime in Storeys #1 and #2, forming in-channel sand sheets, and mainly lower flow regime in Storey #3, forming bank attached point bars. The thin layers of coarse sandstone within the abandonment fill may be crevasse splays off Storey #3. The close association of fossiliferous limestone beds below this channel-body suggests base level influence during deposition, in association with a marine to brackish bay system, indicating a maximum flooding surface. The limestone within the abandonment fill and directly above it appears to be of a freshwater origin.

3.7 PORT CALEDONIA

GENERAL DESCRIPTION

The section described is located at Port Caledonia and commences just above a paleosol in the wave cut platform, approximately 130 m SW of the headland that forms part of Whelan Point (Fig. 1.7). The section continues NE for an additional 65 m on the other side of the headland (Enclosure 4).

The section comprises four channel bodies; only Channel-bodies No.2 and No.3 have field measurements because of limited quality exposure of the bounding channel bodies. Channel-body No.1 sits on and partly incises into floodplain deposits that overlie a paleosol (nodular calcrete) exposed in the wave cut platform. The channel body is about 3 m thick and is capped by another similar paleosol 0.5 m thick. A 1 m thick sandstone unit, interpreted as a bayfill deposit, rests on the paleosol.

Channel-body No.2 comprises three storeys totalling 5.7 m in thickness and cuts into the bayfill deposits. The topmost storey is overlain by the Backpit Seam 1 m thick, overlain in turn by a black limestone 0.5 m thick and floodplain deposits up to 0.5 m thick.

Channel-body No.3 incises into the floodplain deposits and in places sits directly on the black limestone as seen between 83 m - 97 m on Enclosure 4. This channel body has been subdivided into seven storeys exposed on both sides of the headland. The total thickness is about 9.5 m. The uppermost storey fines upward into rooted floodplain deposits of variable thickness, up to 0.5 m thick.

Channel-body No.4 incises into and locally through the floodplain deposits and into Channel-body No.3. This unit is about 4 m thick, capped by floodplain deposits.

The overall trend of the cliff face is 030° to 020° near the beginning and end of the section, but there is considerable variability in cliff face orientation between 53 m and the tip of the headland at 130 m. Here wave erosion has carved an amphitheater-like shape into the cliff face, resulting in an extensive wave cut platform (Enclosure 4). The variability of cliff face orientation coupled with the headland introduced complications to correlation of strata and presentation of measurements.

The tectonic tilt was measured on the paleosol that sits on top of Channel-body No.1 at 30 m (120°/8°NE). The IS and IHS measurements were not corrected for tectonic tilt.

CHANNEL-BODY No.1 DESCRIPTION:

Channel-body No.1 was poorly exposed and only partly accessible, so no measurements were taken in this unit. It fines upward and exhibits ridge-and-swale topography, with a systematic stacking pattern of ridges (scroll bars) in an apparent SW migration direction. The channel body is overlain by a nodular calcrete paleosol.

INTERPRETATION

The presence of LA element (lateral-accretion macroform) and a fining-up sequence suggests a sinuous channel system. The capping paleosol indicates a period of subaerial exposure, followed by a flood event with the deposition of bayfill sandstone in advance of the main Channel-body No.2.

CHANNEL-BODY No.2 DESCRIPTION:

Storey # 1 is 2.2 m thick and has a cliff face orientation normal to depositional strike (Fig. 3.22). The storey has an erosive contact on a bayfill sandstone unit. The grain size is medium sand. Inclined strata (IS) and inclined heterolithic strata (IHS) outline broad asymmetric, convex-up barforms in the upper 1.5 m of this storey. Ripple cross-lamination is found within the IS/IHS. The relief on the convex-up barforms ranges from 0.5 m to 1 m. The vector mean strike of the IS/IHS sets trends 095°/275°, giving an accretion direction of 005°, and dips range from 4° to 29° NE - NW. The mean paleoflow direction determined from Sr is 021°, which is subparallel to the IS/IHS accretion direction. This suggests a downstream-accreting, or DA architectural element.

Storey # 2 is 2 m thick. The cliff face exposure is oriented N to NE (030°-360°-040°) which is sub-parallel to the paleoflow direction (Fig. 3.22). Storey # 2 partially incises Storey # 1, as seen between 50 m - 60 m in Enclosure 4. The grain size ranges from very fine to fine sand, and some trough cross-beds are developed in the basal part of Storey # 2. Inclined strata with Sr form a similar convex-up pattern to that seen in Storey # 1. No measurements were taken on IS. Primary current lineation (PCL) has a vector mean trend of 340°/160°, and the mean paleoflow direction from Sr is 020°, which is similar to that of Storey # 1. Without measurements of IS surfaces, it would be speculative to assign an architectural element to this storey, but the similar nature of the bedforms suggests

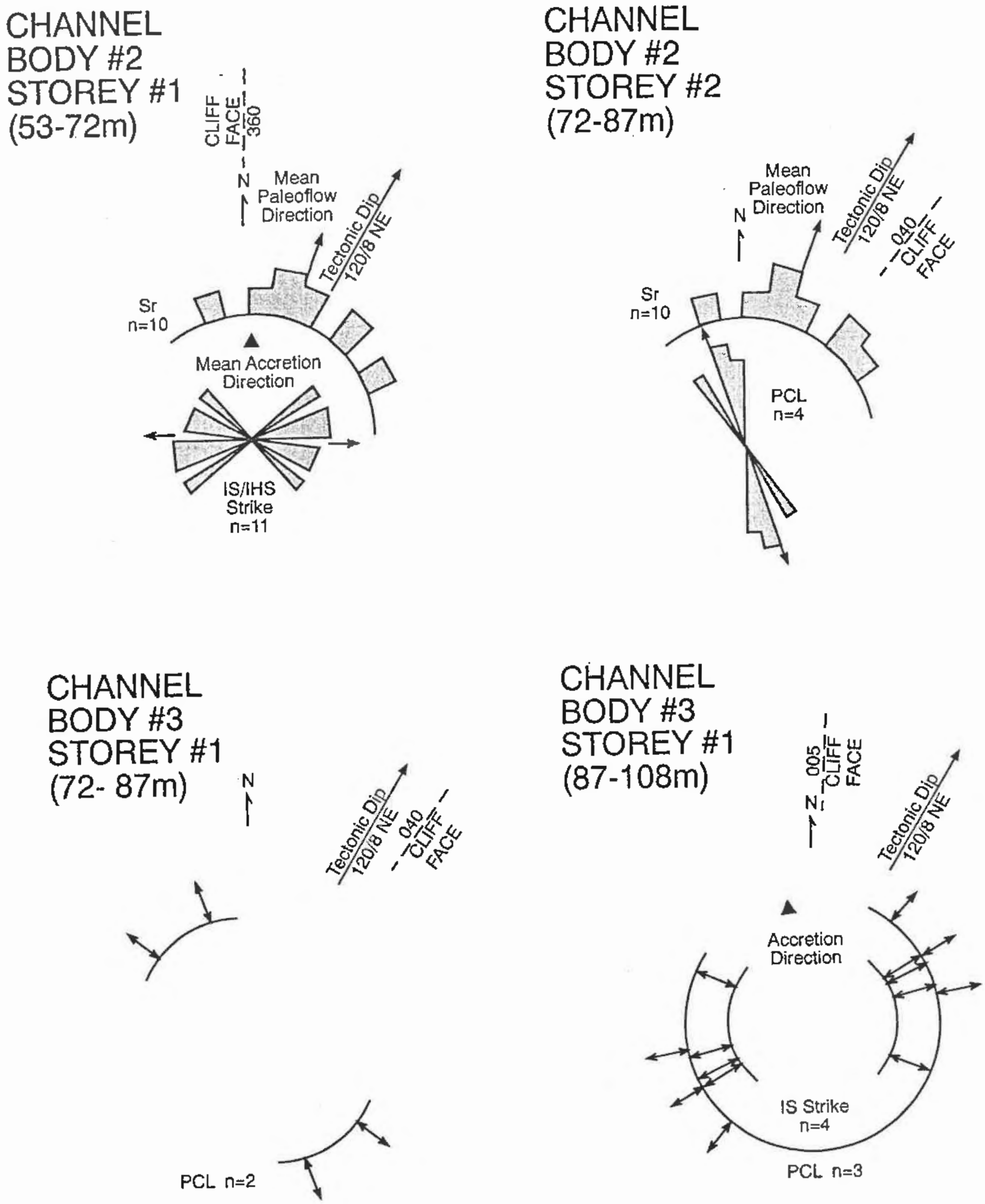

Figure 3.22.

Paleoflow measurements for Channel-Body # 2, Storeys # 1 and # 2 and Channel-Body # 3, Storey # 1 at Port Caledonia.Tracing of channel body is shown on Enclosure 4. Lithostratigraphic symbols defined on Figure 3.1.

a repeat of Storey # 1, i.e. downstream-accreting.

Storey # 3 is 1.5 m thick and was inaccessible. However, it too appears to have similar features to those of the lower storeys. It has an erosional contact on Storey # 2, incising about 1 m into it, between 51 m - 64 m. The barforms have a relief on the order of 1 m.

INTERPRETATION

Channel-body No.2 has repetitive cycles or pulses of flashy flow, within channels that were probably of low sinuosity. Storey # 1 has St developed in medium sand, IS and IHS surfaces and a probable DA element. Water depth was probably about 2 m as indicated by the amplitude of the IHS surfaces. Storeys # 2 and # 3 are "flashier" units in water depths of perhaps 1 m, based on the barform relief (Allen, 1984). St and Sr and a very fine to fine sand size, suggest lower velocity flow than for Storey # 1.

CHANNEL-BODY No.3 DESCRIPTION:

Channel-body No.3 has seven storeys, as mentioned above. The cliff line is highly irregular and cliff-face orientation variable (see Enclosure 4), yielding varied views with respect to paleoflow orientation.

Storey # 1 has a maximum thickness of 3.5 m between 83 m - 86 m, with a lateral extent of 75 m to the tip of the headland. Between 87 m and 108 m, the cliff face is oriented approximately normal to depositional strike, and between 128 m and 136 m the cliff face is oriented sub-parallel to the depositional strike (Fig. 3.22). Storey # 1 has an erosional contact on floodplain deposits and partly incises (about 0.5 m) through them to a lower black limestone unit, as seen at 85 m. Inclined strata are well developed in medium sandstone between 87 m to 110 m where the plane of the cliff face is sub-parallel to the mean northerly accretion element DA. A broad (7 m) concave-up surface is located near the base of the storey, centred at 82 m, and indicative of shallow scours. Trough cross-beds (St) are exposed between 110 m and 130 m. The cliff face orientation here, is sub-parallel to the paleoflow direction indicated by PCL and oblique to one accretion direction. The variability of accretion directions seen in Figure 3.24 probably reflects the predominance of large troughs, and an SB element is indicated, with downstream-accreting macroforms (DA) locally.

Storey # 2 onlaps against an incision into Storey # 1 between 106 m and 110 m and is cut out by Storey # 3, forming a wedge at 106.5 m (Enclosure 4). The unit extends for 21 m to the tip of the headland where the cliff face is oriented sub-parallel to depositional strike (Fig. 3.24). On the opposite side of the headland, the cliff face is oblique to depositional strike (Fig. 3.24). Inclined strata are developed in medium sandstone in the plane of section. A small scour approximately 0.5 m deep is developed between 115 m - 117 m. The mean accretion direction appears to be approximately 045°, and PCL appears to be trend sub-parallel to depositional strike. Macerated fossil plant material (carbonaceous material) is present at the base of the storey, seen between 130 m and 135 m. The dominant architectural element is probably LA.

Storey # 3 has an erosional contact on Storey # 1 and # 2, and averages 2 m in thickness. Its extent is 71 m, from 57 m to 128 m. On the other side of the headland it disappears into the beach gravel at 157 m. Bedding was measured at 108 m where the cliff face is oriented oblique to the depositional strike (Fig. 3.25). Siderite nodules and fossil plant material (carbonaceous material) are incorporated into the basal strata. The grain size is medium sand. Inclined strata are present

Figure 3.23.

Part of Port Caledonia Channel-Body # 3, 87 m to 103 m interval on Enclosure 4. Channel body closely overlies a dark limestone above the Backpit coal. Storey # 1 shows well developed inclined surfaces with current lineation trending along strike (LA macroform). Storey # 2 also shows inclined surfaces with flow along strike. Scale is 1 m long.

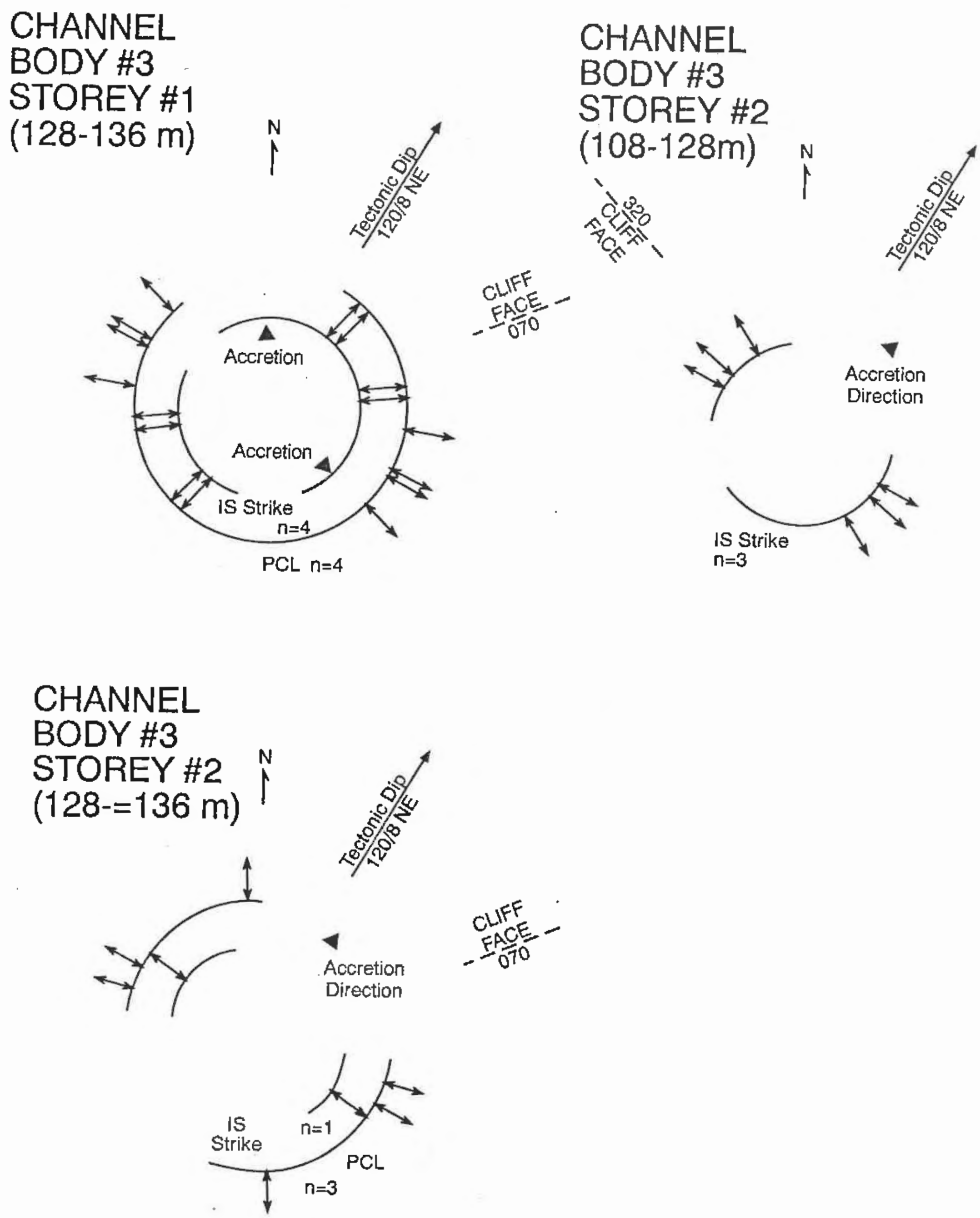

Figure 3.24.

Paleoflow measurements for Channel-Body # 3, Storeys # 1 and # 2 at Port Caledonia. Tracing of channel body is shown on Enclosure 4. Lithostratigraphic symbols defined on Figure 3.1.

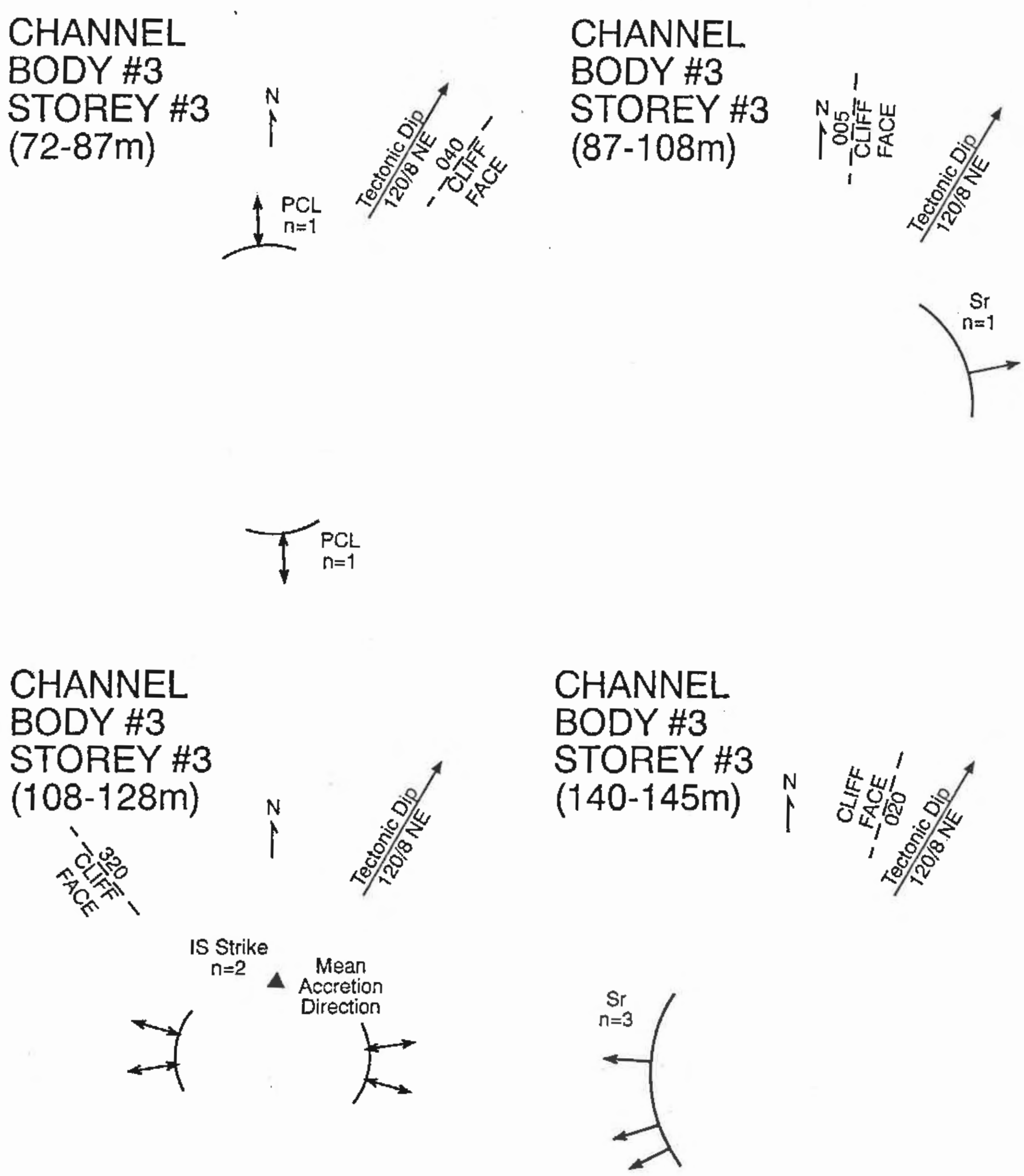

Figure 3.25.

Paleoflow measurements for Channel-Body # 3, Storey # 3 at Port Caledonia.Tracing of channel body is shown on Enclosure 4. Lithostratigraphic symbols defined on Figure 3.1.

but are not systematically developed, with a mean strike W-E and a northerly are present but are not systematically developed, with a mean strike W-E and a northerly accretion direction. Sr is present in the inclined layers, and paleoflow is sub-parallel to depositional strike. Siderite nodules are present near the top of the storey, and appear to be *in situ*.

Storey # 4 has limited exposure and appears to onlap an erosive surface and wedge out at 140 m where Storey # 6 truncates it. This storey averages 2 m in thickness. The cliff face orientation is normal to depositional strike (Fig. 3.26). Some siderite nodules are found near the base. The grain size is medium sand. Inclined strata form a convex-up bedform, with bed sets up to 0.5 m thick. The vector mean strike of IS trends 116°/296° with dips ranging from 6° - 14° NE to SW, reflecting the change in dip direction of the convex-up bedform. PCL trends subparallel to the mean IS strike. Ripple cross-lamination is present but a sparsity of measurements precludes a conclusive evaluation. The PCL trend suggests the presence of an LA element, although some strata might also be ascribed to an SB element. *In situ* siderite nodules are plentiful near the top of this storey, suggesting root development and subaerial exposure following deposition.

Storey # 5 onlaps Storey # 4 and is truncated by Storey # 6 at 115 m. There is only about 20 m of exposed section for Storey # 5 and no measurements were taken. The storey appears to have similar features to Storey # 4, and the grain size is medium sand. An erosional outlier of this storey is located between 146 m and 154 m, forming an erosional mound beneath Storey # 6. The exposure has the appearance of ridge-and-swale topography, implying that this storey could include an LA element. Siderite nodules are present near the top.

Storey # 6 appears in the upper cliff face at 87 m and incises into Storey # 3 and through Storeys # 4 and # 5. It disappears into the beach gravel and a rock fall at 187 m. The cliff face is roughly normal to the depositional strike (Fig. 3.26).

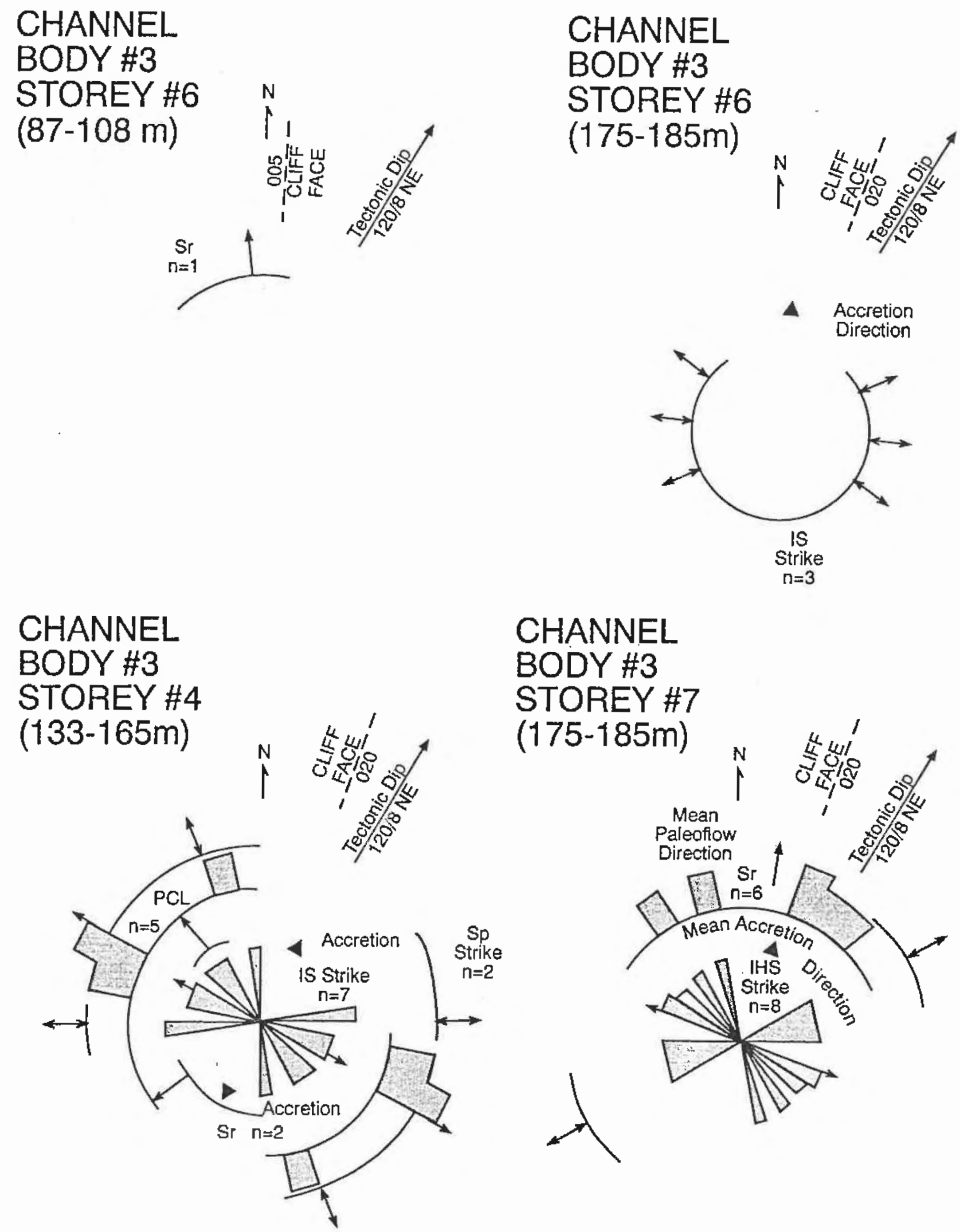

Figure 3.26.

Paleoflow measurements for Channel-Body # 3, Storeys # 4, # 6, and # 7 at Port Caledonia.Tracing of channel body is shown on Enclosure 4. Lithostratigraphic symbols defined on Figure 3.1.

The medium sandstone has some inclined strata but these are not systematically developed. The strike of IS trends E-W with a northerly accretion direction. One Sr measurement trends 355° suggesting a possible DA element. The dominant lithofacies is St with concave-up, scour forms visible in Enclosure 4, having a relief of 0.5 m. This storey may be an SB element.

Storey # 7 has an erosive and somewhat planar base with broad, filled scours ranging in width from 2.5 m to 6 m and in thickness from 0.5 m to 1 m. It appears in the upper cliff face at 99 m and disappears in beach gravels at 193 m. The cliff face between 136 m and 193 m is oriented normal to depositional strike (Fig. 3.26). Some inclined heterolithic strata are developed but not systematically. The dominant bedform present is St, best seen between 166 m - 175 m. Two significant reactivation surfaces can be seen across the NW facing exposure from 130 m to 187 m (third-order bounding surfaces). The grain size in the lower part of the storey is medium sand size, fining upward to very fine sand size above the upper third-order bounding surface. In this upper part of the storey, small mounds and troughs are present, suggesting that ridge-and-swale topography developed prior to channel abandonment. The vector mean of strike on IHS trends 110°/290° with dips ranging from 3° - 20° NE and a mean accretion direction of 020° (Fig. 3.26). Sr within St yielded a mean paleoflow direction of 011° which is sub-parallel to the accretion direction, suggesting a DA macroform element. This is applicable in the lower part of the storey but an LA element is probably present in the upper part as indicated by the ridge-and-swale topography. There are no measurements to verify paleoflow patterns at this level.

INTERPRETATION

Channel-body No.3 appears to be a "flashy" possibly seasonal flow sequence with a water depth up to 2 m in Storey # 6, shallowing to approximately

1 m in Storey # 7. There were intervening periods of subaerial exposure and vegetation establishment between Storey # 2 through # 6. Storey # 1 appears to be going through a transition from downstream-accreting to lateral-accreting macroforms in a northerly direction. This may have been influenced by the tenacity of the underlying limestone and Backpit Seam. The base of Storey # 6 is particularly erosive. Sandy bedforms (SB element) is present in much of the sequence, suggesting low sinuosity channel systems in Storey #6 and the lower part of Storey #7, becoming more sinuous near the top of Storey # 7, prior to channel abandonment. The apparent LA element in Storeys # 4 and # 5 suggests that the channels were more sinuous prior to the major erosive event of Storey # 6. The *in situ* position of the siderite nodules near the tops of many of the storeys suggests root development and subaerial exposure perhaps prior to successive channel fill cycles. This may also imply some seasonality controls to the depositional and intervening non-depositional periods.

CHANNEL-BODY No.4 DESCRIPTION:

Channel-body No.4 appears in the upper cliff face at 155 m and continues beyond the described section. Within the confines of the described section, it was weathered or inaccessible; hence no measurements were taken.

Channel-body No.4 has a planar and slightly erosional base, partly incising into the upper part of Channel-body No.3, best seen between 157 m and 170 m and between 183 m and 192 m. Two storeys are present. Storey # 1 has a systematic stacking of ridge-and-swale topography, suggesting lateral-accretion and point-bar development (element LA). Ridge stacking patterns suggest channel migration towards the SW. The grain size is variable, with interdigitation of siltstone, very fine to fine sandstone. Storey # 2 has an erosional base with broad scours averaging 3 m across and 0.5 m in thickness. The dominant bedform appears to be St, and the grain size is medium sand. The predominance of St suggests SB architectural element.

INTERPRETATION

Channel-body No.4 appears to have been deposited in sinuous channels for Storey # 1, with ridge-and-swale topography indicative of lateral-accretion, point bar development, and interdigitation of varied strata. Channels apparently became less sinuous above, with medium sand and St bedforms in Storey # 2.

3.8 DONKIN

GENERAL DESCRIPTION

The section is located at Donkin and commences just above the Emery Seam 120 m NW along the shore from a lower buried leaf of the McRury Seam in beach gravels (Fig. 1.7). The section contains numerous thin coals not readily correlated with named seams. The channel body located between about 15 m and 80 m was not described because it is poorly exposed (see Enclosure 4). The section comprises four channel bodies of which only three have been measured.

Channel-body No.1 rests on floodplain deposits just above a leaf of the Emery Seam, commencing at about 120 m and disappearing below beach gravels near 200 m. It is about 11 m thick and has three storeys. A sequence of floodplain deposits and bayfills overlies Channel-body No.1. A 10 cm thick coal seam is developed between bayfills (243 m - 277 m).

Channel-body No.2 appears in the cliff at 277 m forming an erosional contact on floodplain deposits. It disappears laterally into the water and a major rock fall at 342 m. It is capped by about 7 m of floodplain deposits with a 7 cm coal seam 1.5 to 2 m above the top of the channel body.

Channel-body No.3 cuts into the floodplain deposits and commences in the cliff face at 346 m and disappears into beach gravel at about 487 m. This channel body has been subdivided into three storeys. The channel body has an exposed thickness of about 9 m, and is capped by floodplain deposits (1.5 m), bayfill sandstones (1.5 m) and 1-1.5 m of floodplain deposits, covered by 7 m of bayfill deposits that are incised by Channel-body No.4.

Channel-body No.4 forms an erosional contact on bayfill deposits that are capped by a thin coal on a thin limestone. Upright trees are rooted in the coal, and extend 0.5 m up into the base of the channel body. The channel body is visible in the cliff face at 490 m but is not accessible until 575 m. It can be traced west along the coast for an additional 190 m beyond the view of section. The channel body has been subdivided into two storeys with a total visible thickness of about 5.5 m. Storey # 1 is 3 m thick, and Storey # 2 is 2.5 m thick. No measurements were taken in this channel body, due to time constraints. It was thought that this channel body would not add a significant amount to the overall analysis, since this interval had been described at other locations, therefore, it was decided to forego a description and interpretation at this site.

The cliff face orientation trends dominantly NW/SE and swings to E/W at 380 m. The tectonic tilt was measured on the Emery Seam at 125 m (265°/5° N/W). Inclined strata were not corrected for tectonic tilt.

<u>CHANNEL-BODY No.1 DESCRIPTION</u>:

Channel-body No.1 has three storeys. Storey # 1 is about 3 m thick, and the cliff face exposure is oriented oblique to depositional strike and mean paleoflow (Fig. 3.27). Storey # 2 is about 1.5 m thick, but has limited exposure and no measurements were recorded here. The cliff face orientation becomes

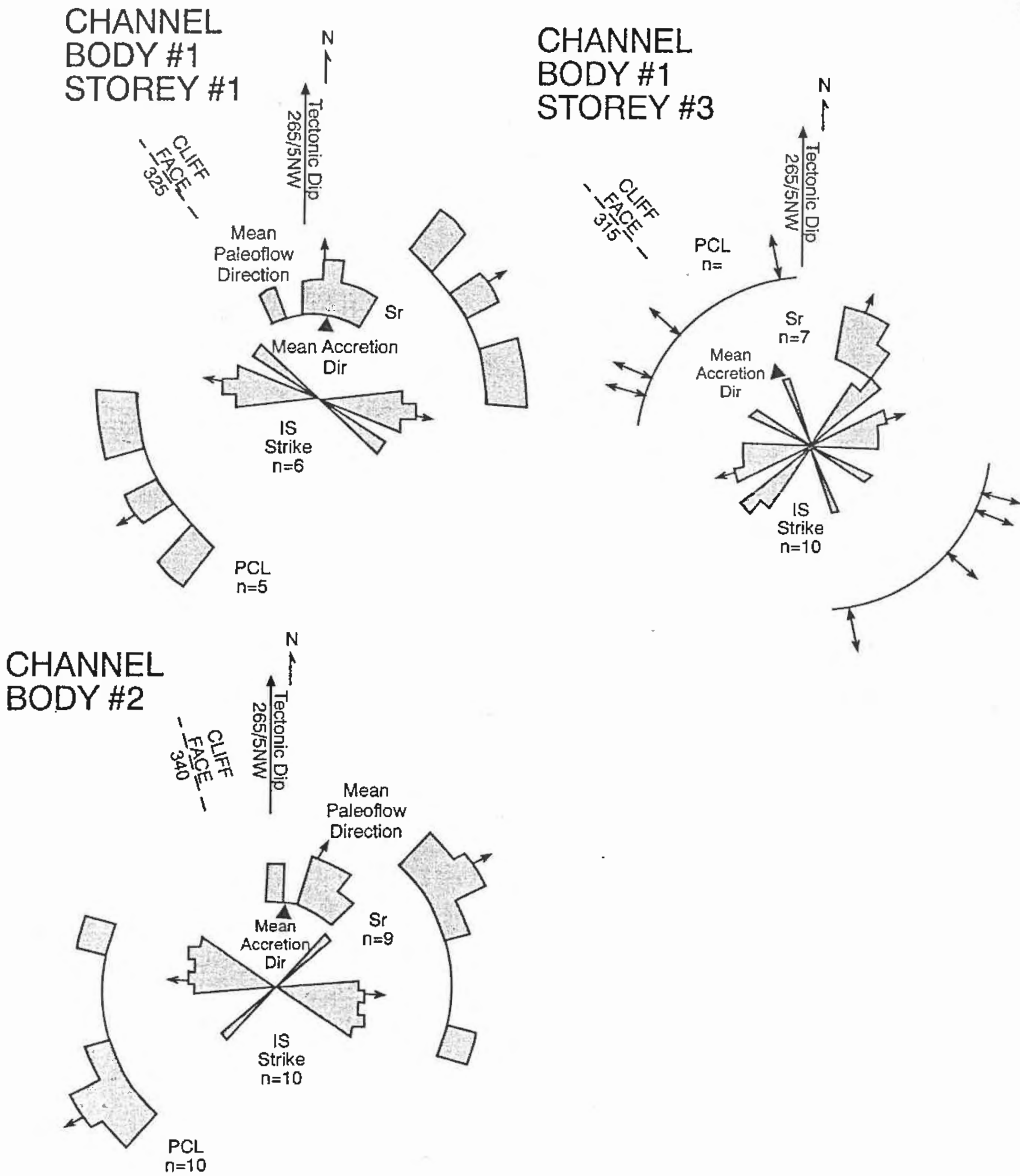

Figure 3.27.

Paleoflow measurements for Channel-Body # 1, Storeys # 1 and # 3, and Channel-Body # 2 at Donkin. Tracing of channel body is shown on Enclosure 4. Lithostratigraphic symbols defined on Figure 3.1.

more westerly between Storeys # 2 and # 3. For Storey # 3, the cliff face exposure is roughly oriented normal to the depositional strike and oblique to mean paleoflow direction (Fig. 3.27). The thickness of this storey is 5 m, and it rests upon a thin 25 cm coal, partially exposed above the gravels, which appears to be cut out below Storey # 3.

Channel-body No.1 has a erosional scoured base, partly incising through floodplain deposits into underlying bayfill deposits. The grain size is medium sand throughout all three storeys. Storey # 1 exhibits dominant St bedforms, with sets 5-10 cm thick and cosets 40 cm thick. Inclined strata are present, and the vector mean of IS strike trends 278°/098°. The mean accretion direction is 008°, and dips range from 12° - 28° NE to NW. Ripple cross-lamination (Sr) gives a mean paleoflow direction of 002° which is sub-parallel to the accretion direction. Primary current lineation gives a vector mean orientation of strike 053°/233° which is oblique to depositional strike. The predominance of St suggests an SB element. The sub-parallel orientation of Sr to the accretion direction additionally suggests that downstream-accreting macroforms (DA) are present locally. Stigmaria and an *in situ* fossil tree stump of a lepidodendrid are found at the top of this storey, suggesting continuous waterlogged conditions (Phillips, 1979; DiMichele and Phillips, 1994) and stabilization by vegetation before another major flood event.

Storey # 2 has an erosional contact on Storey # 1. There is a predominance of St bedforms suggesting an SB architectural element. The presence of coal, although poorly exposed, suggests a prolonged period of floodplain stability and waterlogging during which mire vegetation accumulated.

Storey # 3 has an erosional base where the contact is visible. Inclined strata are present, and St bedforms dominate, with some ripple cross-lamination and plane beds. Broad concave-up surfaces are present, approximately 3 m across by 0.5 m in vertical relief. A third-order reactivation surface is visible between 147 m and 163 m (Enclosure 4). Contorted beds are observable at 166 m, suggesting disrupted flow around an obstruction in the channel, possibly a log, or collapse around it after deposition. *In situ* siderite nodules are present at the top of the storey, and suggest rooting by vegetation after channel abandonment. The vector mean strike of IS trends 246°/066° with dips ranging from 7° - 26° NW and a mean accretion direction of 330°. Measurements of Sr give a mean paleoflow direction of 019° which is oblique to the depositional strike, but the average orientation of PCL is sub-parallel to the accretion direction. The dominance of St suggests an SB element, and the inclined surfaces suggest the presence of macroforms with variable paleoflow directions on their surfaces (LA/DA).

INTERPRETATION

Channel-body No.1 appears to be dominated by SB architectural element, with plane beds present, suggesting low sinuosity channels and "flashy" depositional cycles. A probable DA macroform is also present. There appears to have been quiescent periods with prolonged waterlogging conditions between all three storeys, as indicated by the presence of a fossil tree stump *in situ* and a coal seam. The section as a whole, in the Emery to Stony interval, resembles the architecture of seam splitting amongst sandstones, with intervening coals and erect trees, as at Table Head (Calder *et al.*, 1996).

CHANNEL-BODY No.2 DESCRIPTION:

Channel-body No.2 is about 7 m thick, and rests upon fine-grained deposits that include thin coal and limestone beds. The cliff face orientation is 340 which is oblique to the mean depositional strike of IS and oblique to the mean paleoflow direction (Fig. 3.27). A planar and slightly erosive basal contact is visible on floodplain deposits. The grain size is fine sand. The lower part of the channel body is plane bedded (Sh), characteristic of architectural element LS and periodic upper regime flow. IS is systematically developed at a higher level, with a vector mean strike of IS of 272° or 092° and dips ranging from 9° - 15° NW/NE. The mean accretion direction is 002°. Some broad concave up troughs are developed near the top of the channel body, suggesting St bedforms. Sr measurements yielded a mean paleoflow direction of 015° which is sub-parallel to the accretion direction, suggesting a DA element for the majority of the channel body. PCL measurements give a vector mean of 054°/234° which is oblique to the accretion direction. The upper part of the channel body may contain a transition between DA and SB elements.

INTERPRETATION

Channel-body No.2 has low sinuosity indicated by the LS, DA and SB elements. The presence of element LS indicates upper regime flow, and the water depth may have decreased near the top of the channel body with the development of St, possibly as dune trains or scours cutting the top of the DA macroform. The close association of the channel body with underlying coal and limestone suggests that this channel body may be part of a prograding lake or bay delta deposit.

CHANNEL-BODY No.3 DESCRIPTION:

Channel-body No.3 has three storeys. Storey # 1 is about 4.5 m thick, Storey # 2 is about 3 m thick and Storey # 3 is about 5 m thick. The measured section has a cliff face orientation of 340 which is oblique to the depositional strike and sub-parallel to the mean paleoflow direction in Storey # 1 (Fig. 3.28). The cliff face orientation changes to 270° in Storey # 2 making it sub-parallel to depositional strike of IS and nearly normal to the mean paleoflow direction (Fig. 3.28). In Storey # 3 the cliff face is oriented sub-parallel to depositional strike and

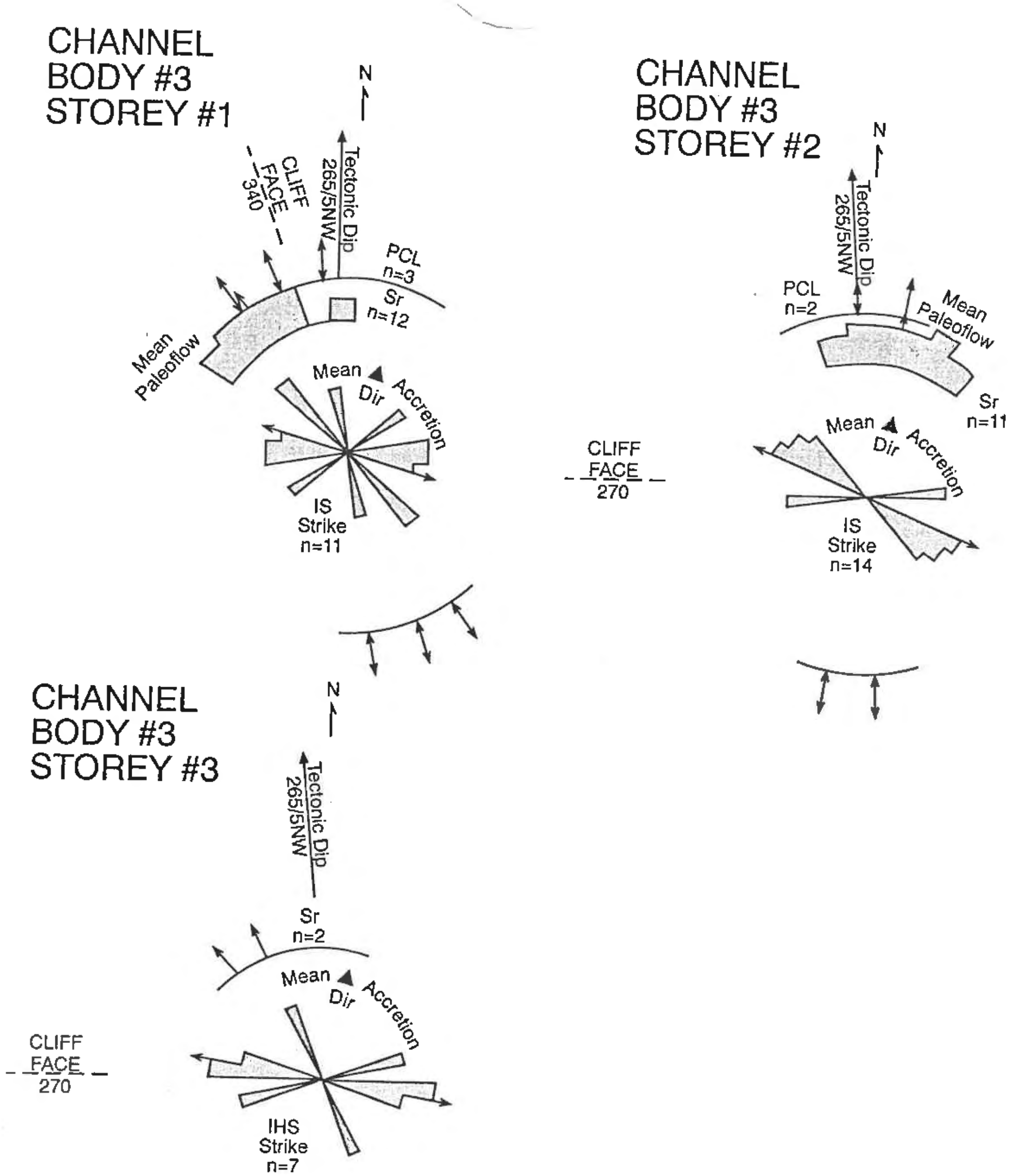

Figure 3.28.

Paleoflow measurements for Channel-Body # 3, Storeys # 1 - 3 at Donkin.Tracing of channel body is shown on Enclosure 4. Lithostratigraphic symbols defined on Figure 3.1.

oblique to the mean paleoflow direction (Fig. 3.28).

Channel-body No.3 incises through an upper sequence of floodplain deposits, a partly covered 1.4 m thick coal seam (Stony Seam?) and into a lower sequence of floodplain deposits (380 m position: Enclosure 4). The channel body may downcut farther into Channel-body No.2 offshore which could increase the total thickness of Channel-body No.3 to about 12 m. Coal rip-up intraclasts were noted near the base of Storey # 1 at 385 m. Storey # 1 has IS with St, Sr and Sh bedforms. Bedsets range from 10-45 cm thickness, and the grain size is medium sand. Broad concave-up surfaces are present with up to 1.5 m relief and widths up to 15 m. The vector mean strike of IS is 289°/109° with dips ranging from 9° - 29° NW to NE. The mean accretion direction is 019°. The mean paleoflow direction from Sr is 323° which is oblique to depositional strike, and three PCL measurements recorded a sub-parallel trend . Storey # 1 appears to be of SB element.

Storey # 2 has an erosional contact with Storey # 1. The grain size is medium sand size, and St, Sr and inclined strata are present. The vector mean strike of IS is 294°/114°, with a mean accretion direction of 024° and dips ranging from 17° - 28° NE. The mean paleoflow direction from Sr is 009° which is sub-parallel to the accretion direction, suggesting a DA element. The predominance of St also suggests the possibility of an SB element.

Storey # 3 has an erosional to planar bounding surface on Storey # 2. An incision of 1 m can be seen at 390 m. The grain size is fine sand. Broad, systematically stacked and asymmetrical convex-up barforms are found in association with IHS, as seen from about 420 m to 470 m on Enclosure 4. The relief on the barforms ranges from 1-2 m. The vector mean of the IHS strike trends 280°/100° giving a mean accretion direction of 010° and dips ranging from 3° - 14° NE. Sparse Sr data indicate paleoflow direction oblique to depositional strike. The St bedforms suggest an SB element.

INTERPRETATION

Channel-body No.3 has a major erosive base with at least 4 m of incision visible and broad concave-up surfaces, suggesting frequent erosional events and perhaps low sinuosity channels. Flow was periodically in the upper regime for Storey # 1, as indicated by the presence of plane beds with current lineation. Storey # 2 has similar flow characteristics, with slightly lower flow velocity as indicated by the smaller scale of scours. Storey # 3 has lower flow velocity with fine sand size and IHS. The St bedforms suggest low sinuosity channels and a 'flashy' depositional style also.

A summary of the descriptions of all the channel bodies and storeys in the Emery to Backpit interval, from this and all the other outcrop sites in the study area, are tabulated on Table 3.1.

Table 3.1 **Summary description of Channel Bodies and Stories in the Emery to Backpit interval, Sydney Basin**

Channel Body/ Storey	Thickness (m)	Architectural Elements & Variations	Facies	Associated Strata	Grain Size & Variation
Black Rock Point					
1/1 St. # 1	4+	DA/LA	Sh, Sr, St, Se	Incises Bayfill sst and OF above STONY SEAM (IS)	MS
St. # 2	3	LA	St, Sr, Se	Incises Storey # 1. Cut out by Storey # 3. Thin coal lens at base (IS)	M - CS
St. # 3 - 6	1.3 - 3.8	SB/DA	St, Sr, Se	Incises each successive storey capped by OF. IS in 5 & 6	F-MS(3)*, MS (4)*, M-FS(5)*, M-FS, FS, VFS(6)* *(3) Storey #
	Composite 13 m				
Big Bras D'Or					
St. # 1	2	SB	St, Sr	Gradational to erosional basal contact on floodplain deposits rooted at top	VFS, ST/VFS
St. # 2	~7	LA	Sh, Sr, Sp, Se	Incision of Storey # 1, underlying OF and possibly Unnamed Seam, rooted top, thin rider seam on top, RST, IS/IHS	Interdigitation MST + ST/VFS, FS
	Composite 9 m+				
Sydney Mines					
1/2 St. # 1	1.8	LS/DA	Sh, Sr, Se	Incises partly Emery Seam, Plant fragments, IS	FS
St. #2	1	SB	Se, Sr	Partial onlap/incision of Storey # 1, Siderite nodules, IS	FS
St. # 3	1.3	SB	Sr, Se, Ss	Incises Storey # 2, Plant fragments, Calamites, scour fill	FS
St. # 4	1.5	SB	Se, St, Sr	Siderite nodules, upright tree trunk , rests on & interfingers with OF in outlier	FS, F-MS in outlier

St. # 5	0.75	SB	Se, Sr	Siderite nodules, upright tree trunk , rests on & interfingers with OF in outlier	FS
St. # 6	1	SB	Se, Sr	Siderite nodules, upright tree trunk, rests on & interfingers with OF in outlier	FS
	Composite 7.35m				
Sydney Mines					
2/2 St. #1	2	SB	Se, St, Sr	Siderite nodules, Calamites. Incision (1m) into OF partial onlap of OF	MS
St. # 2	3.2	LA → LS LA + SB IS + IHS	Se, Sh, Sr, St	MST Rubble with siderite nodules at base. Incision of Storey # 1 partial onlap	F - MS, MS
St. # 3	2	LA - LS	Se, Sh, Sr	Incision of Storey # 2 overlap of Storey # 1 onlap of OF, siderite nodules in MST at base	F - MS
St. # 4	3.8	LS	Se, Sh, Sr	Incision of Storey # 3, siderite nodules in MST at base, channel abandonment fill at top & Bayfill sst, Paleosol, Red beds	F - MS, FS, VFS, ST fine upward
	Composite 11m				
Victoria Mines					
1/3 St. # 1	1	SB	Sr, St	Incises bayfill deposits, IS, Concordant fills, slightly graded beds	FS, M-CS lenses
St. # 2	0.5	SB	St	Broad basal scour, coarse lag, fossil plant material + siderite, incision and onlap of Storey # 1, IS	VFS
St. # 3	2	SB + DA	St, Sr	Disturbed stratification plant material, incises Storey # 1 and # 2	CS at base, MS
St. # 4	2	LA	Sr, minor Sh	Planar contact on Storey # 3, rooted at top, sideritic, IS, floodplain deposits on top	MS fines up to ST
	Composite 5.5m				

Victoria Mines					
2/3	0.7	DA? or SB	St, Sr	Erosional base on floodplain deposits, abundant plants, close proximity to underlying limestone and Unnamed Coal	MS → F-MS
3/3	4.7	SB	St, Sr, Sh	Incises bayfill, FS and ST, basal intraclasts of fossil fragments, limestone, IS, rooted at top with ferruginous and calcareous nodules	VCS at base, fines up to FS
Lingan					
1/3 Unit A St. # 1	4	LA	Se, Sr, Sh	IS, partial incision of Phalen Seam and Bayfill deposits, fossil plant material at base	MS
St. # 2	3	LA?	Se, St	IS, incises Storey # 1, plant fragments near base with MST intraclasts, Calamites	MS, VCS at base
St. #3	5	LA	Se, St	IS + IHS, incises and partially cuts out Storey # 2, carbonaceous material at base	CS at base, MS
	Composite 12m				
Unit B	7	Bayfill		Capped by MST flood-plain deposit, incised by Storey # 4, small sand filled scours at top	VFS + ST, FS at top
1/3 St. # 4	6	LA	Se, St	IS, RST, incises through Unit B, amalgamates with Storey # 3, capped by floodplain MST, paleosol, MST, limestone with mudcracks	MS - FS
2/3	8	SB	Se, St, Sr	IS & IHS, MST, siderite pebbles, blocky limestone intraclasts at base, broad troughs capped by floodplain deposits, Backpit Seam, black limestone	VCS - CS at base, fines up to MS, FS
3/3 Unit A St. # 1	4	SB LS at top	Se, St, Sh	IS, incises floodplain MST and locally, rider coal seam, onlaps deep incision	MS
St. # 2	3	LS	Sh	IS, stacked convex-up barforms onlap deep incision, capped by bayfill MST, sst	MS
	Composite 7m				
3/3 Unit B	7	Bayfill		Subplanar beds, Sr, fills over low-angle surfaces capped by nodular calcrete, red and grey MST below Bouthillier Seam	MST/VFS/ST

Dominion					
St. # 1	2	LS, SB at base	Sh, St	Sits on black shale above black and grey limestone	MS
St. # 2	5	LS, SB at base	Sh, St, Sr	Incises and onlaps Storey # 1	MS CS at base
St. # 3	~ 2	LA	St, Sr, Sh	Incises Storeys # 1 & 2, fines up Stigmaria & Calamites below abandonment fill on Storey # 2, could be part of Storey # 3, RST, abandonment channel fill covered by black limestone	CS to FS
	Composite ~9m				
Port Caledonia					
1/4	3	LA	Sp	IHS, RST, sits on, partly incises floodplain deposits above paleosol. Capped by paleosol	FS to VFS to ST + MST
2/4 St. # 1	2.2	DA	Sr, Ss	IS/IHS, convex-up barforms, erosive contact on bayfill sst	MS
St. # 2	2	DA?	St, Sr, Ss	IS, erosional contact on Storey # 1, convex-up barforms	MS fining up to FS/VFS
St. # 3	1.5	DA	Ss	IS, erosional contact on Storey # 2 convex-up barforms, capped by Backpit Seam, black limestone, floodplain deposits	
	Composite 5.7 m				
3/4 St. # 1	3.5	DA, SB, LA	Se, St	IS, incises partly through floodplain deposits to limestone	MS
St. # 2	1.8	LA	Se	IS, onlaps incision into Storey # 1, fossil plant material at base	MS
St. # 3	2	LA	Se, Sr	IS, fossil plant material and siderite nodules at base, siderite at top	MS
St. # 4	2	LA, SB?		IS, RST, onlaps incision on Storey # 3, siderite nodules at base and top	MS
St. # 5	2	LA		IS, RST, siderite nodules near top. Erosional outlier, onlaps Storey # 4	MS
St. # 6	3.8	SB	Se, Sr, St	IS, incises to Storey # 3 and cuts out parts of Storey # 4 and # 5. Siderite nodules near base and top	MS
St. # 7	3.5	DA/LA	Se, St, Sr	IHS, RST near top, capped by floodplain deposits, rooted	MS, fines up to VFS

	Composite 18.6m				
4/4 St. # 1	1.8	LA	Se	HS, RST, incises floodplain deposits and part of ridges at top of Channel Body # 3	ST/VES/FS
St. # 2	2.2	SB	Se, St		MS
	Composite 4m				
Donkin					
1/3 St. # 1	3	SB/DA	Se, St, Sr	IS, Stigmaria and *in situ* fossil tree stump at top	MS
St. # 2	1.5	SB	St, Se	Thin coal at top, erosional contact on Storey # 1	MS
St. # 3	5	SB LA/DA	Se, St, Sr, Sh, Ss	IS, reactivation surface, broad concave-up surfaces, contorted beds, incises Storey # 2, capped by floodplain deposits & bayfills	MS
	Composite 9.5m				
2/3	7	DA - SB	St, Sr, Se, Ss	IS, planar, slightly erosive, contact on floodplain deposits, broad concave-up troughs, capped by floodplain deposits	FS
3/3 St. # 1	4.5	SB	St, Sr, Sh, Se, Ss	IS, incises floodplain deposits and STONY SEAM possibly down to Channel Body #2, broad concave-up surfaces	MS
St. # 2	3	DA/SB	St, Sr, Se	IS, erosional contact on Storey # 1	MS
St. # 3	5	SB	St, Sr, Se	HS, convex-up barforms asymmetrically stacked	FS
	Composite 12.5m				

CHAPTER 4: FLUVIAL STYLE & STRATIGRAPHIC TRENDS

4.1 CLASSIFICATION OF CHANNEL BODIES

The channel bodies and storeys were evaluated for common characteristic features such as thickness, architectural elements, grain size distribution, and morphology. From this evaluation a classification scheme was derived which is described below and summarized in Table 4.1. The classification scheme is listed as follows: Group A, multi-storey bedload systems; Group B, low sinuosity sand flat systems; Group C_1, sinuous mixed load channels; Group C_2, sinuous suspended load channels; Group D_1, distributary, bed load channels; Group D_2, distributary, mixed load channels; Group E, channel flood fill.

Multi-storey bedload systems (Group A channel bodies and storeys) are well represented across the entire Sydney Basin in all stratigraphic intervals studied. Individual stories range in thickness from 1.3 m to 8 m and composite thicknesses of channel bodies that contain storeys attributed to Group A range from 4 m to 18.6 m. The diagnostic architectural element is sandy bedforms (SB) with minor associated elements of downstream-accretion deposits (DA), laminated sand sheets (LS), and lateral-accretion deposits (LA). They typically have very coarse grained sandstone above an erosional base, becoming medium sand size with slight upward fining. Storeys generally have sub-planar erosional bases and are vertically stacked, but locally they cut out underlying storeys (eg. Black Rock Point). In the available outcrops, their basal surfaces were noted to incise up to 6 m into underlying strata (eg. Lingan Channel-Body No. 3). The channel bodies are the product of large sandy bedload systems, with low sinuosity, possibly braided channels. They have the potential of being valley fills, however, given

Table 4.1 Classification of Channel Bodies and Storeys in the Emery to Backpit interval, Sydney Basin

Group	Bodies/Storeys	Thickness (m)		Architectural Elements & Grain Size	Interpretation
		Storeys	Composite		
A Multi-storey bedload systems	B.R.P., Sty 1, 3-6 V.M., CB# 1, Sty 3 CB# 3 Lingan, CB# 2 CB# 3, Sty 1 (lower) Pt.Cal., CB# 2 CB# 3, Sty 1,6,7 (lower) CB# 4, Sty 2 Donkin, CB# 1, 2,3,4?	1.3 - 4 2 4.7 8 ~ 3 1.5 - 2.2 1.75 -3.8 2.2 1.5 - 7	13 2 4.7 8 4 5.7 18.6 4 9.5, 7,12.5	SB; minor DA, LS, LA, typically very coarse to medium sand, with slight upward fining	Large sandy bedload systems, with low sinuosity (braided) channels; possibly valley fills
B Low Sinuosity sand flat systems	S.M., CB # 1 CB # 2, Sty 1, 2 (upper), 3 (upper), 4 Lingan, CB # 3, Sty 1 (upper) Sty 2 Dominion, Sty 1, 2	0.75 - 1.8 1 - 3.8 ~ 1 3 2 - 5	7.35 11 4 7 ~9	LS, DA; ± SB in lower deeper channel, typically medium sand	Planar sand sheets and within-channel bars in shallow channels, upper regime flow (flashy); local, deeper channels with 3-D dunes and probable perennial flow
C_1 Sinuous mixed load channels	B.R.P., Sty 2 S.M., CB # 2, Stys 2,3 (lower) V.M., CB # 1, Sty 4 Lingan CB # 1, Sty 1, 2, 3, 4 (lower) Dominion, Sty 3 Pt. Cal., CB # 3, Sty 2-5	3 1 - 3.2 2 3 - 5 ~ 2 1.8 - 2	13 11 2 12 6 ~ 9 18.6	LA, typically medium sand with upward fining	Sinuous (meandering) channels with lateral accretion surfaces and ridge-and-swale topography (point-bar and scroll-bar deposits) sometimes observed; coarser than C_2, mixed load; commonly associated with Group A and B channel bodies
C_2 Sinuous suspended load channels	B.B.D., Sty 2 Lingan, CB# 1, Sty 4 (upper) Pt.Cal., CB# 1 CB# 3, Sty 7 (upper) CB# 4, Sty 1	~ 7 ~ 3 3 1.75 1.8	~ 9 6 3 3.5 4	LA, mainly fine sand to clay	Sinuous (meandering) channels with lateral accretion surfaces and ridge-and-swale topography (point-bar and scroll-bar deposits); suspended load prominent; commonly associated with floodplain fines (Lingan), form topmost storey of Group A or C_1 channel bodies (Pt. Caledonia), or overlie Group D_1 body (B.B.D.)

D_1 Distributary, bedload channels	B.B.D., Sty 1	2	2	SB, mainly fine sand to silt	Small channel cutting into mouth-bars and bayfills, possibly distributary channel, overlain by large storey (Group C_2), (B.B.D., Sty 2)
D_2 Distributary, mixed load channels	V.M., CB# 1, Sty 1, 2	0.5 - 1	1.5	SB, with graded bedding; mixed coarse to very fine sand, with silt and clay prominent	Subaqueous channels prograding into standing body of water in advance of main channel body (Group A), (V.M., CB # 1, Sty 3, 4)
E Channel flood fill	V.M., CB# 2	0.7	0.7	DA, SB; medium sand, slight fining up	Shallow channel with sandy bedload and abundant large plant material, indicative of rapid isolated flood event

that the dimensions of the majority of channel bodies appear small, it is more likely that these and all subsequent channel body groups are channel fills. An exception to this may be present in the Phalen Mine offshore from New Waterford, at a stratigraphic level equivalent to Lingan Channel-Body No. 2 and Victoria Mines Channel-Body No. 3 in outcrop (Enclosure 3, Fig. 3.6). The Phalen Mine channel body incises at least 10 m through strata equivalent to Lingan Channel-Body No. 1 and into the Phalen Seam (Naylor *et al.*, 1996).

Low sinuosity sand flat systems (Group B channel bodies and storeys) are represented at Sydney Mines, Lingan and Dominion as indicated on Table 4.1 and on Enclosures 2 and 3. Individual storeys range in thickness from 0.75 m to 5 m while composite thicknesses range from 4 m to 11 m. The dominant architectural element present in this type of channel body is laminated sand sheets (LS), commonly associated with downstream-accretion deposits (DA). A sandy bedform (SB element) may be present in the lower deeper part of the channel body. Group B is well represented at Dominion. The grain size averages medium sand. The channel bodies of this classification represent planar sand sheets and within-channel bars in shallow channels, formed in the upper flow regime. Locally, deeper channels may develop 3-D dunes with SB element and probable perennial flow, sustained at lower stage and flow velocity (Cant and Walker,1978). Some shoaling may be evident as indicated by *in situ* erect vegetation in the channel bodies at Sydney Mines.

Sinuous mixed load channels (Group C_1 channel bodies and storeys), (Table 4.1), are common across the Sydney Basin also, but were not encountered at Big Bras d'Or, Victoria Mines or Donkin. The best exposures of this channel body type are in Storey # 2 at Black Rock Point, Channel-Body No.2 at Sydney Mines; Channel-Body No.1 at Lingan, and Channel-Body No.3 at Port Caledonia. The dominant architectural element is lateral-accretion deposits (LA). The diagnostic characteristic that sets them apart from Group C_2, described below, is their coarser grain size and an absence of mud thalweg and swale fills. They represent sinuous (meandering) channels with lateral accretion surfaces and mixed load. They are commonly associated with Groups A and B channel bodies where they represent channels with bank attached bar forms within an overall low sinuosity bedload system. Ridge-and-swale topography attributed to point-bar and scroll-bar deposits is locally observed, but is commonly truncated and difficult to recognize. Thus, is the relationship of paleoflow direction and orientation of inclined surfaces, whereby the paleoflow indicators show an orientation parallel or sub-parallel to the mean strike of the inclined surfaces. The thickness of individual storeys of Group C_1 ranges from 1 - 5 m, (average 3 m) and they can be part of channel bodies with a composite thickness ranging from 2 to 18.6 m.

Sinuous suspended load channels (Group C_2 channel bodies and storeys), (Table 4.1), represent the classic meandering fluvial channels with lateral accretion surfaces (LA), ridge-and-swale topography (point-bar and scroll-bar deposits) clearly preserved in outcrop. Suspended load is prominent with LA architectural elements, with mainly fine to very fine sand in the bank attached point-bars and interdigitation of very fine sand to silt and clay in thalwegs and swales. This type of channel body is commonly associated with floodplain fines at Lingan (Channel-Body No.1, upper part of Storey # 4), or at Port Caledonia (Channel-Body No.1). They also form topmost storeys of Group A or C_1 channel bodies, including Channel-Body No.3, Storey # 7 at Port Caledonia and Lingan Channel-Body No.1. In addition, the Group C_2 type of channel body locally overlies Group D_1 bodies, described below. This association is well represented at Big Bras d'Or (Enclosure 1). More sinuous suspended load channels may have been formed throughout the stratigraphic intervals studied but complete preservation was limited to three sites. Individual storeys range in thickness from 1.75 m to 7 m, possibly greater, and composite thickness of channel bodies that include C_2 deposits range from 3 m to 9 m or more.

Distributary, bedload channel deposits (Group D_1) are relatively small (2 m in thickness). The dominant architectural element is sandy bedform (SB) with prominent trough forms and small scour fills. The grain size ranges from fine sand to silt. These channel bodies typically cut into mouth-bar and bayfill deposits and are single storeyed. They are significant in that they represent possible distributary channels that are a precursor to subsequent larger channel body development, such as the channel body at Big Bras d'Or (Enclosure 1). At this site the distributary channel incises into grey laminated shales (bayfill deposits), has local concentrations of siderite nodules at the base, and is rooted on top. Other occurrences of this type of channel body are present across the basin and have generally been described as crevasse splay channels or parts of bayfill deposits. This site is the only one noted in the study interval that clearly shows the direct association of distributary channel to overlying successor channel (see also Group D_2 channel body at Victoria Mines).

Distributary, mixed load channel deposits (Group D_2) are similar to those of Group D_1, in that the dominant architectural element is SB and thicknesses are similar (Table 4.1). However, Group D_2 channel bodies can have more than one storey and they have graded bedding on concordant surfaces within troughs, indicative of a subaqueous site deposition. The troughs are low-angled erosional surfaces with concordant fills, rather than scours associated with the downstream migration of coherent sets of dunes, and the storeys are made up of grouped scour fills. The grain size ranges from mixed coarse to very fine sand, with silt and clay prominent upward. These channel bodies represent subaqueous channels prograding into a standing body of water, perhaps a brackish bay or interfluve lake, in advance of the main channel body of Group A. The only example of this type of channel body association is found within the Phalen to Unnamed cyclothem at Victoria Mines (Figures 3.9 and 3.10), where it is overlain by a multi-storey, bedload channel body, the paleoflow direction between storeys can be quite variable. Other occurrences of this type of channel body were not recognized in any other cyclothems studied. Although Groups D_1 and D_2 are both the product of distributary channels, no locality was noted where the two groups are associated.

A channel flood fill (Group E) is only recognized at Victoria Mines (Figure 3.9). It is only 0.7 m thick and single storeyed. It is identified by its architectural elements downstream-accretion deposits (DA) with sandy bedforms (SB). The grain size is predominantly medium sand with slight fining upward. It has been interpreted as the deposit of a shallow channel with a sandy bedload, and it contains abundant large fossil plant material, indicative of a rapid isolated flood event. The channel body incised through a forested swamp and may have linked up with a larger, higher order channel to the east. The paleoflow direction indicates 160°, unusual within the study area, and this direction may be a function of local topography and the site of exposure. This channel body represents a catastrophic, ephemeral event, possibly a side tributary. Other examples of this channel body may be amalgamated into the basal scour fills of larger multi-storey units described at several locations.

4.2 STRATIGRAPHIC RELATIONSHIP AND DEPOSITIONAL HISTORY

Introduction

The stratigraphic relationship and depositional history of the lower Sydney Mines Formation is described in terms of cyclothem intervals below. Gibling and

Bird (1994) describe a well developed cyclothem in terms of sequence stratigraphic units. The sequence stratigraphic model, developed by the Exxon Group (Van Wagoner *et al.*, 1988) and refined by others, is an eloquent tool for packaging stratigraphic units. As pointed out by Saunders (1995), the model works best in areas where the section runs from a proximal to distal basinal setting, including a marine component, and where there is reasonable seismic coverage. The absence of a marine section presents some difficulty in the application of the sequence stratigraphy model to the lower SMF strata. However, there are some inferences that can be made by using the model. The principal units or bounding surfaces, employed in the sequence stratigraphy model are: the sequence boundary, the transgressive surface and the maximum flooding surface. These principal bounding surfaces envelop three systems tracts: lowstand, transgressive and highstand systems tracts (Van Wagoner *et al.*, 1988).

The inferred sequence boundary within a typical cyclothem commences on top of a nodular calcrete/palustrine limestone paleosol (Tandon and Gibling, in press). This surface implies a lowstand systems tract. Calcretes may be sequence boundaries, equivalent to some paleovalleys, or may be local dryland facies capping abandoned channel belts (see Fig. 1.5). It is also inferred that channel incision may have occur concurrently, bypassing the dryland site and prograding seaward as a forced regression (Van Wagoner *et al.*, 1988), not preserved in outcrop. The climatic conditions inferred during this sequence boundary development is that of sub-humid to semi-arid (Tandon and Gibling, in press). A gradual return to more humid conditions is indicated by base level rise and a transgressive systems tract consisting of aggrading major channel body fills, local red calcic vertisols or oxidized redbeds (Tandon and Gibling, in press), in an alluvial plain setting. This is followed by a transition to coastal plain, wet climatic conditions and the development of hydromorphic paleosols and local calcareous nodules, and peat accumulation in regional mires (Fig. 1.5).

The top of a major coal seam indicates a maximum flooding surface. This is followed by organic-rich black shale and limestone, with possible marine influence, representing a condensed section (Gibling and Bird, 1994), and the commencement of a highstand systems tract (Tandon and Gibling, in press). The highstand systems tract consists of coarsening up bayfill deposits, minor coal splits and hydromorphic paleosols (Tandon and Gibling, in press) with siderite nodules. Gradually, relative sea-level would have begun to drop and a return to drier conditions would have brought about the development of another sequence boundary. This gives the framework for sequence stratigraphy development within the individual cyclothem intervals described below.

McRury to Emery Interval

The lower most cyclothem in the study area is represented by the McRury to Emery seam interval at Donkin. Other coastal outcrops may be preserved within the Glace Bay Syncline area between Donkin and Lingan Bay, south of Port Caledonia and Dominion sections (Boehner and Giles, 1986). Within this area the formation base of the Sydney Mines Formation is lower and includes the Gardiner Seam interval. To the west of Lingan the lower boundary of the Sydney Mines Formation commences progressively higher stratigraphically: just below the Emery Seam from Lingan to Sydney Mines; just below the Stony Seam at Black Rock Point. At the time of deposition of the McRury to Emery seam interval, it would appear that the Glace Bay Syncline area was a topographic low, allowing for peat accumulation and associated deposits (Hacquebard and Donaldson, 1969), while the area immediately to the west was relatively higher. The area around the Bridgeport Anticline axis was a positive feature at this time and might have formed a low drainage divide. This would imply a coastal plain to embayment environment and set some limit of coastline and maximum regional transgression across the basin study area. It also implies that the Glace Bay Syncline area could have been a major locus for a receiving basin. The Emery seam zone marks the maximum regional flooding limit that would have resulted from inundation of the region, presumably to the north in the section offshore. No evidence of limestone or marine influence was noted in outcrop.

Interpretation of this interval is very speculative, however, it would appear that the limited exposure indicates a low sinuosity, braided channel system with a sandy bed load (Group A). Paleoflow measurements from ripple cross-lamination shift vertically, channel base to top, from NW to NE (Table 4.2, Fig. 4.4). This paleoflow variability suggests channel switching . Third-order bounding surfaces separate each unit within the channel body (Enclosure 4), implying reactivation surfaces. However, they could be higher order bounding surfaces which would indicate discrete storeys within the channel body.

Emery to Stony Interval

Following peat deposition in the Emery mire, sediment supply was reactivated and Channel-Bodies # 1 at the Donkin and Sydney Mines sites were formed (Fig. 4.1). The depositional style is similar at both locations, in that there is evidence for episodic flow and subaerial exposure during and between storey deposition. This allowed time for some vegetation to become established before the next sediment influx. There is some variance in channel development between the two sites, however, as indicated by the multi-storey bedload systems at Donkin (Group A), (possibly more proximal braided river) and the low sinuosity sand flat systems at Sydney Mines (Group B). The Donkin site could have been part of a broad paleovalley and the dominant receiving basin at this time. The equivalent section at Lingan shows bayfill and well drained floodplain deposition as indicated

Table 4.2 **Channel Body Groups and Paleoflow Directions related to Stratigraphic Intervals**

Stratigraphic Interval	Channel Body Group	Paleoflow Direction Variation	Comments
McRury-Emery	A (Donkin)	288° - 005° - 023°	Paleoflow shifts from NW-NE upwards low sinuosity flow dominates
Emery-Stony	A (Donkin) CB # 1	002° - 019°	Paleoflow shift upwards from N-NE; episodic to perennial flow; low sinuosity
	CB # 2	015°	
	B (S.M.) CB # 1	347°	NW paleoflow, abundant fossil plant material, at storey bases and within storeys; low sinuosity
Stoney-Phalen	A (B.R.P.) Sty 1, 3-6	015°, 005°	NE-N paleoflow upward
	(Donkin) CB # 3, 4?	323° - 010°	NW-NE paleoflow upward
	B (S.M.) CB # 2, Sty 1, 2 (upper), 3 (upper), 4	360° - 290°	N-NW paleoflow upward migration
	C_1 (B.R.P.) Sty 2	005°	
	(S.M.) CB # 2, Sty 2 (lower), Sty 3, (lower)	360° - 290°	N-NW paleoflow upward migration, becoming more sinuous upward N-NW paleoflow
Phalen-Unnamed	A (V.M.) CB # 1, Sty 3	355°	N paleoflow
	B (Dominion) Stys 1,2	NW	
	C_1 (Lingan) CB # 1, Stys 1, 2, 3, 4 (lower)	070°	NE paleoflow
	(Dominion) Sty 3	NE	
	(V.M.) CB # 1, Sty 4	343°	NW paleoflow
	C_2 (Lingan) CB # 1, Sty 4 (upper)	055°	NE paleoflow
	D_2 (V.M.) CB # 1, Stys 1, 2	115°, 360°	Variable paleoflow, sequence becomes more sinuous upward
Unnamed-Backpit	A (Lingan) CB # 2	N	
	(Pt. Cal.) CB # 2	021°	NW to NE paleoflow
	(V.M.) CB # 3	335°	
	C_2 (B.B.D.) Sty 2	105°	SE paleoflow
	(Pt. Cal.) CB # 1		
	D_1 (B.B.D.) Sty 1	055°	NE paleoflow
	E (V.M.) CB # 2	160°	SE paleoflow; possible side tributary

Backpit-Bouthillier	A (Lingan) CB # 3, Sty 1(lower) (Pt. Cal.) CB # 3, Stys 1, 6, 7 (lower) CB # 4, Sty 2 B (Lingan) CB # 3, Sty 1 (upper), Sty 2 C_1 (Pt. Cal.) CB # 3, Stys 2-5 C_2 (Pt. Cal.) CB # 3, Sty 7 (upper), CB # 4, Sty 1	310° - 011° - 240° - 323° -	Upward migration of paleoflow NW-NE Upward migration of paleoflow SW-NW In general, Group A channel bodies have NW to NE (northerly) paleoflow in all cyclothems; Group B channel bodies have NW paleoflow; Group C_1 and C_2 channel bodies have variable paleoflow and are more common in younger cyclothems.

KEY:
B.R.P. = Black Rock Point
B.B.D. = Big Bras d'Or
S.M. = Sydney Mines
V.M. = Victoria Mines
Pt. Cal. = Port Caledonia

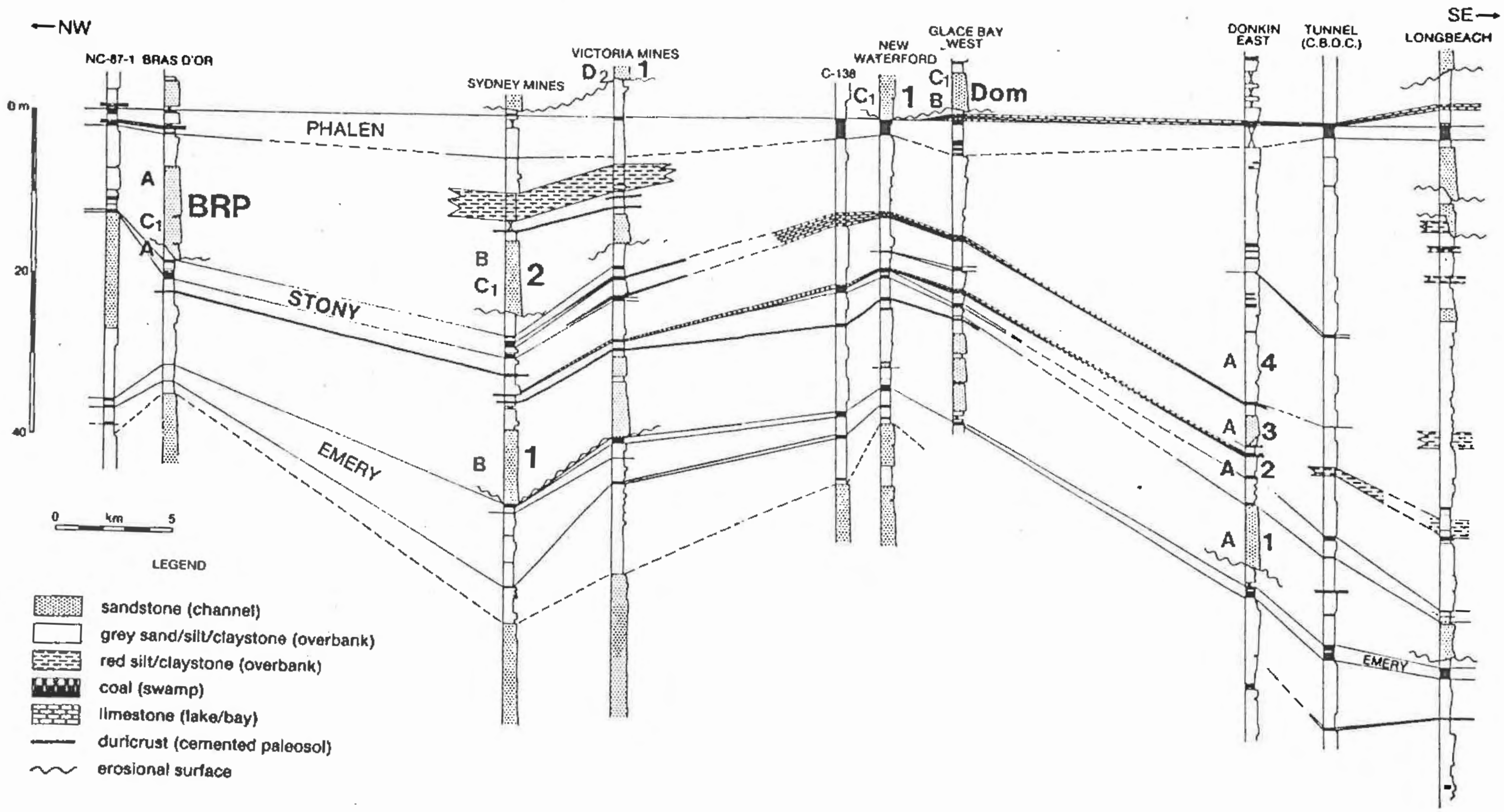

Figure 4.1

General west to east cross-section of the Emery to Phalen seam interval. Modified from J. Paul (unpublished data). Numbers refer to channel bodies in this study. Channel bodies # 2 and # 4 at Donkin were formerly interpreted as bayfills. B.R.P. = Black Rock Point; New Waterford = Lingan; Dom = Dominion. (A; B; C_1) refer to channel body Group.

by the presence of calcrete paleosols (Fig. 4.1, Enclosure 3). The presence of calcretes implies seasonally arid conditions (Tandon and Gibling, 1994) and may also indicate the presence of a sequence boundary.

Channel deposition was subsequently abandoned at Donkin and replaced by bayfill and well drained floodplain deposits equivalent in part to those at Lingan. The channel body at Sydney Mines was also abandoned (Enclosure 2). The intervening section up to the Stony Seam is mostly covered, but the Stony Seam sits on bayfills. At Sydney Mines the Emery to Stony interval is thicker than at Donkin (Fig. 4.1), implying enhanced crustal subsidence to accommodate the sediment supply.

At Donkin, a second pulse of sediment resulted in the deposition of Channel-Body No. 2 (Group A) over a thin limestone. This indicates that water level had risen, drowning the bayfills perhaps to a maximum highstand prior to channel deposition. A thin limestone was also recognized at Lingan resting directly on a thin coal just below bayfills and a poorly developed Stony Seam (Enclosure 3).

Stony to Phalen Interval

The Stony to Phalen Seam interval has well developed channel bodies at Black Rock Point, Sydney Mines and Donkin (Table 4.2, Fig. 4.1). The equivalent section at Lingan is dominated by interbedded bayfills and well drained floodplain deposits (Enclosure 3).

The channel body at Black Rock Point incises bayfill deposits just above the Stony Seam. This channel body has a predominant multi-storey bedload system style (Group A) with minor associated sinuous mixed load deposition (Group C_1). There is episodic flow with intervening subaerial exposure. Paleoflow shifts from NE to N upward through the section (Figure 4.4). Storey #

2 has incised a thin peat layer now preserved as coal at the storey base. This coal may be a lower leaf of the Phalen Seam (Naylor *et al.*, 1996). At Sydney Mines, Channel-Body No. 2 incises floodplain deposits above the Stony Seam. The channel body has storeys that represent sinuous mixed load channels (Group C_1) associated with storeys that represent low sinuosity sand flat systems (Group B), (Table 4.1). The sinuous channels contained bank attached barforms that were laterally equivalent to the sand flat systems and within-channel bars. Paleoflows swings from N to NW upward through the section (Table 4.2, Fig. 4.4). The channel body was abandoned and capped by well drained floodplain deposits that include a calcrete paleosol and red mudstones. Although calcretes are developed in the Emery to Stony interval at Donkin, this is the first indication of oxidation of floodplain sediments during prolonged subaerial exposure having taken place in any of the cyclothems. A stratigraphically equivalent unit was described by J. Paul (unpublished data) at Victoria Mines (Fig. 4.1). The Phalen Seam is poorly developed at both locations. At Sydney Mines, coal splits of 5 cm and 20 cm respectively, are separated by 4.9 m of mudstone. The equivalent Phalen Seam at Victoria Mines has 18 cm and 25 cm coal splits separated by 15 cm of carbonaceous mudstone.

Correlation across the basin at this interval to the Donkin site is problematic. There appears to be some structural complications that are unresolved in the Port Caledonia - Donkin area (J. Paul, unpublished data). At Donkin, Channel-Body No. 3 incises floodplain deposits and cuts out what has been interpreted to be the Stony Seam (Enclosure 4, Fig. 4.1). This channel body represents a multi-storey bedload system (Group A). The paleoflow shifts from NW to NE upward through the section (Fig. 4.4). The sequence is followed by a succession of poorly drained to well drained floodplain deposits and bayfills. This, in turn, is followed by Channel-Body No. 4 and a thick succession of overlying interbedded floodplain and bayfill deposits described by J. Paul (unpublished data). Redbeds are not present.

A clear pattern is seen for the first time in this cyclothem, in which coal seams formed at or near a maximum highstand are succeeded by a major clastic sediment influx channel associated with major bodies and/or valley fill development. The succession is linked to climate change and progradation. Progradation is typically followed by a drying period, further marine regression and/or base-level lowering, development of paleosols and localized oxidation resulting in redbeds.

Phalen to Unnamed Interval

The Phalen to Unnamed seam interval is represented by channel bodies at Victoria Mines (Channel-Body No. 1), Lingan (Channel-Body No. 1) and Dominion (Table 4.2, Fig. 4.2). Channel-Body No. 1 at Victoria Mines incises bayfills and comprises two lower storeys described as distributary mixed load subaqueous channel deposits (Group D_2). Paleoflow at Victoria Mines is quite variable, from 115° to 360°, reflecting the rapid trough fill in a low gradient subaqueous environment. The distributary channels prograded perhaps into a brackish bay or interfluve lake. They were subsequently incised by Storey # 3, a Group A type channel body, followed by a more sinuous mixed load (Group C_1) Storey # 4. Paleoflow is N to NW in an upward succession (Fig. 4.2). The channel body was abandoned and the site drowned , resulting in the Unnamed Seam and an overlying medium to dark grey wavy limestone with bivalves and ostracods, suggesting a brackish bay setting. Detailed faunal identification would verify a more precise interpretation of depositional environment. This limestone has been correlated basin wide by Naylor *et al.* (1996) and is referred to as the Phalen Limestone. This is significant because it represents a regional flooding

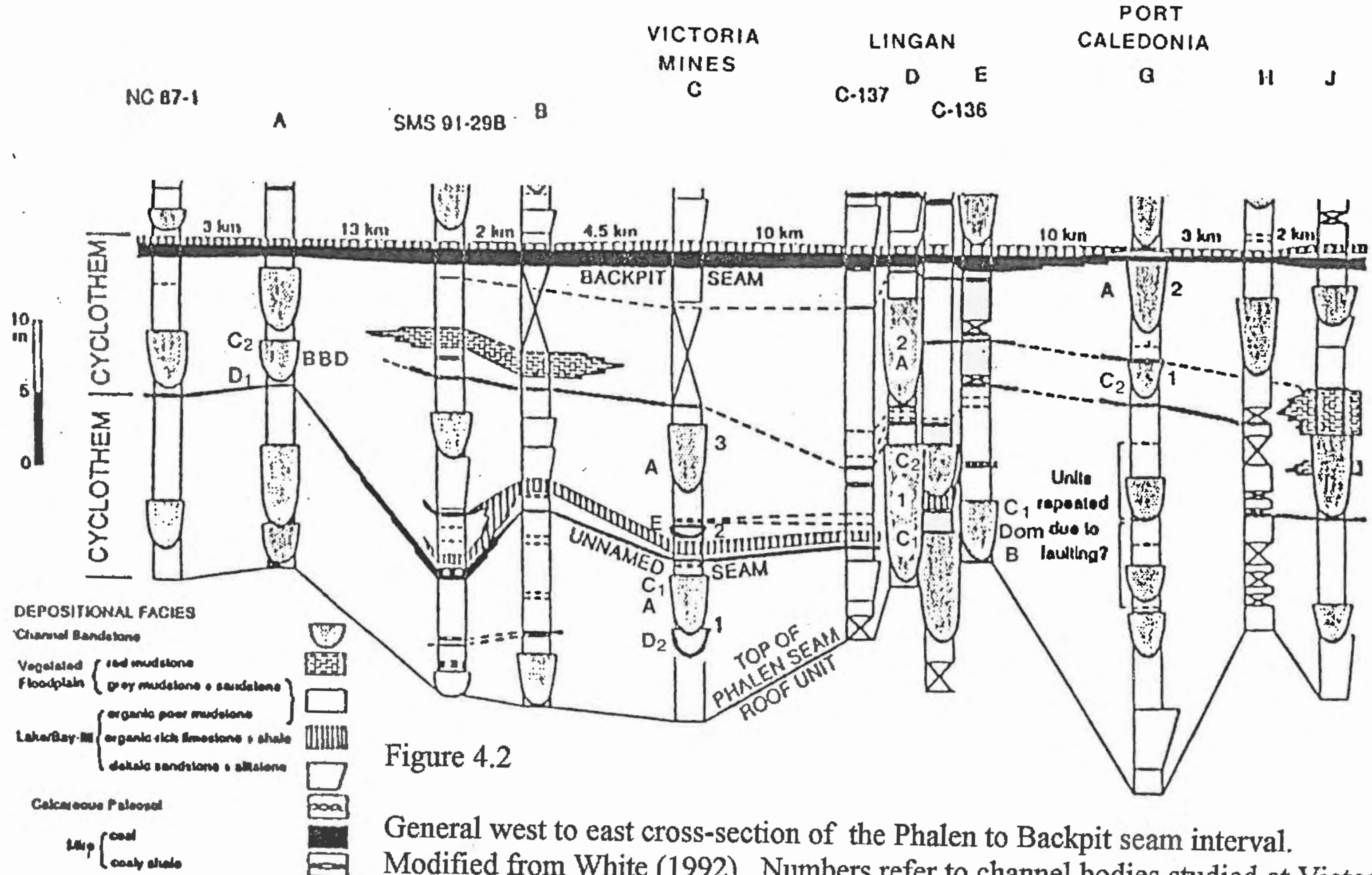

Figure 4.2

General west to east cross-section of the Phalen to Backpit seam interval. Modified from White (1992). Numbers refer to channel bodies studied at Victoria Mines, Lingan and Port Caledonia locations. BBD = Big Bras d'Or; Dom = Dominion. (A; B; C_1; C_2; D_1; D_2; E) refer to channel body Group.

event, possibly a maximum flooding surface, related to eustatic sea-level rise. Agglutinated foraminifera and freshwater thecamoebians from samples in this interval suggest marginal marine influence (Wightman *et al.*, 1994).

Channel-Body No. 1 at Lingan incises bayfill deposits and cuts down to and partly into the underlying Phalen Seam (Enclosure 3). All three storeys that form Unit A of this channel body have coarse basal lags and abundant fossil plant material. They have been classified as sinuous mixed load channels (Group C_1). Paleoflow is to the NE (Fig. 4.4, Table 4.2). Following temporary abandonment of this site, and reduction of sediment supply, a sequence of bayfills was deposited (Unit B). The site was reactivated by Storey # 4 which maintained the same NE paleoflow direction and same general morphology as the storeys within Unit A. It is a Group C_2 type (sinuous suspended load) channel body and incises through and amalagamates with the top of Unit A, becoming finer upwards. Channel abandonment was followed by a return to well drained floodplain deposits and dry conditions as indicated by a regional paleosol, "calcrete # 1", of Naylor *et al.* (1996), which marks a sequence boundary (Tandon and Gibling, in press).

The channel body at Dominion incises a limestone and shale sequence formed in a lake or bay at a maximum flooding stage. This sequence sits on a thin leaf of the Phalen Seam. The lower two storeys of the channel body have a NW paleoflow direction and form Group B type (low sinuosity sand flat) systems. They may have been supplying sediment to the Lingan area at this time. Prior to channel abandonment and drowning, the depositional style changed to a sinuous mixed load channel(Group C_1), and the paleoflow direction shifted to the NE.

During this interval, it would appear that two sites were prominent for channel development, the Bras d'Or site (not evaluated in this study) and the Lingan site. The Donkin area was bypassed and the channel systems shifted to the west.

This interval is significant from the standpoint of channel morphology in that it exhibits a change from a dominance of low sinuosity Group A and B type systems, with some minor C_1 type channels, to a more diverse set of channel systems with increased sinuosity . This implies an more base level influence promoting lateral migration and avulsion of channel bodies. It may also imply that the relative position of the outcrop site may be closer to a paleocoastline in a coastal plain setting.

Unnamed to Backpit Interval

This interval is represented in the study area by channel bodies at Big Bras d'Or, Victoria Mines, (Channel-Bodies # 2 and # 3) Lingan (Channel-Body No. 2) and Port Caledonia (Channel-Bodies #1 and # 2), (Table 4.2, Fig. 4.2). The channel body at Big Bras d'Or has been subdivided into two storeys. The lowermost storey incises bayfills and mouth-bars that immediately overlie the Unnamed Seam. It has been described as a distributary, bedload channel deposit (Group D_1) and was subsequently incised by a Group C_2 sinuous suspended load channel body (Storey # 2). The underlying bayfills and mouth-bars are interpreted to represent highstand deposits that represent a gradual seaward retreat following the maximum flooding stage above the Unnamed Seam. The subsequent channel development follows a similar depositional sequence of aggradation. The increased suspended load and sinuosity of this channel body and the capping of the unit by a thin coal following channel abandonment, indicates that this site had a low gradient and was incising a poorly drained floodplain shortly after maximum flood stage. The paleoflow is NE in the lower storey, shifting to SE in the upper storey (Table 4.2, Figure 4.4). The SE paleoflow direction within a generally northerly flow system is interpreted as a function of the position of outcrop and the sinuous nature of the channel body. A subsequent channel body below the

Backpit Seam was not evaluated in this study.

The Unnamed to Backpit interval at Victoria Mines is represented by two channel bodies. The lowermost, Channel-Body No. 2, is single storeyed and rather small compared to other channel bodies studied. It is unique in that it represents an ephemeral, rapid flood event, and it is considered to be a channel flood fill (Group E). The paleoflow is anomalous at 160° (Table 4.2, Fig. 4.4), a function of local topography or site of exposure. The channel body sits just above a limestone, possibly stratigraphically equivalent to the Phalen Limestone (Naylor *et al*., 1996), indicative of a maximum flooding zone. It cut through a forested mire, and was perhaps a side tributary to a larger channel body to the east. This type of channel body was not identified at other sites studied which may reflect its ephemeral nature. Another explanation for the perceived sparsity of preservation of this channel type may be that subsequent channel bodies have reoccupied earlier courses and either cut out or amalgamated with the previous channel body; giving the appearance of a multi-storeyed channel body with large intraformational basal woody fragments, represented by Se surfaces in multi-storey bodies. An erosional scour above the base, reworking of lower strata, change in grain size at the bounding surface and possible paleocurrent direction reorientation, may all be contributing criteria to the recognition of other such channel flood fill deposits. Channel-Body No. 2 is overlain by grey mud rocks formed in a poorly drained floodplain and capped by a bayfill fine sandstone. This, in turn, is incised by Channel-Body No. 3, described as a Group A type multi-storey bedload channel body, with a low sinuosity (braided) planform . The very coarse basal lag has mudstone intraclasts, fossil carbonaceous fragments and some limestone clasts, suggesting that the channel body had incised a nearby lake deposit. The channel body fines up, has a NW paleoflow direction (Table 4.2, Fig. 4.4) and is capped by a rooted, nodular, calcareous and ferruginous unit, which is one of the best developed calcrete units in the SMF. Siltstones with similar fabric to the calcrete overlie the channel body, suggesting a change in ground water level to a well drained floodplain, a drying period and a possible sequence boundary - the base of the Backpit sequence.

Channel-Body No. 2 at Lingan has a similar appearance to that of Channel-Body No. 3 at Victoria Mines and may be stratigraphically equivalent. Channel-Body No. 2 incises into a black limestone (the Phalen Limestone) and incorporates some of the limestone intraclasts in the lower very coarse basal 2 m. It also has been classified as a bedload (Group A) channel body. The channel body gradually fines up. Although a discrete storey boundary marking a transition to a channel abandonment fill sequence was not recognized, that boundary may exist approximately 4.5 m from the top where the grain size changes to fine sand with siltstone and mudstone interbeds. This upper unit may be individually classified as a sinuous suspended load (Group C_2) channel body. There are no paleoflow measurements from the upper unit to verify this, however. The channel body has a northerly paleoflow direction (Table 4.2, Fig. 4.4). Channel-Body No. 2 follows a maximum flood stage and may lie within a highstand systems tract. Alternatively, the base may mark a major basinward shift in facies and represent a sequence boundary and valley formation. It is a major channel body in the study area with considerable vertical aggradation. To reiterate an earlier statement in Chapter 3, this channel body may amalgamate with or cut out the underlying sequence above the Phalen Seam, offshore in the colliery area (Naylor *et al.*, 1996). The transition from channel abandonment to poorly drained floodplain to mire (Backpit Seam) to lake or bay (limestone) follows.

Channel-Body No. 1 at Port Caledonia commences just above a paleosol located in a wave cut platform. This marks a sequence boundary for the Backpit cyclothem. This channel body has been interpreted as a Group C_2 sinuous suspended load meandering channel. It is capped by bayfill sandstones and another paleosol, possibly part of a lowstand systems tract. Paleoflow measurements were not taken but the ridge-and-swale topography is clearly visible with IHS.

Channel-Body No. 2 at Port Caledonia has a NE paleoflow and is a multi-storey low sinuosity bedload system (Group A), (Table 4.2, Fig. 4.4). It is overlain by the Backpit Seam, so this channel body may be part of a transition to a poorly drained floodplain and mire within a transgressive systems tract. A maximum flooding surface lies within the limestone that sits directly on the Backpit Seam, and may indicate marine influence again (White *et al.*,). This pattern is similar to that seen at the coeval section at Lingan.

Backpit to Bouthillier Interval

This interval is represented by Channel-Body No. 3 at Lingan and Channel-Bodies # 3 and # 4 at Port Caledonia (Table 4.2, Fig. 4.3). Channel-Body No. 3 at Lingan makes a deep incision (6 m) into poorly drained floodplain deposits of a highstand systems tract. Vertical aggradation deposits overlap the incision. The basal erosional surface locally cuts into a thin limestone and rider seam above the limestone (Backpit maximum flooding surface). Inaccessibility did not permit measurements to be taken but the lower part of Storey # 1 appears to be of a bedload (Group A) type, making an upward transition to a Group B low sinuosity sand flat system. Storey # 2 maintains this channel morphology giving way to bayfills and well drained floodplain deposits (Unit B). These are capped by a paleosol, forming a sequence boundary (the base of the Bouthillier sequence) vertical aggradation deposits overlap the incision. Red and grey mudstones underlie the Bouthillier seam indicating a brief oxidation period resulting from subaerial exposure, followed by a reduction period producing grey strata then coal.

Channel-Body No. 3 at Port Caledonia incises into the maximum flooding

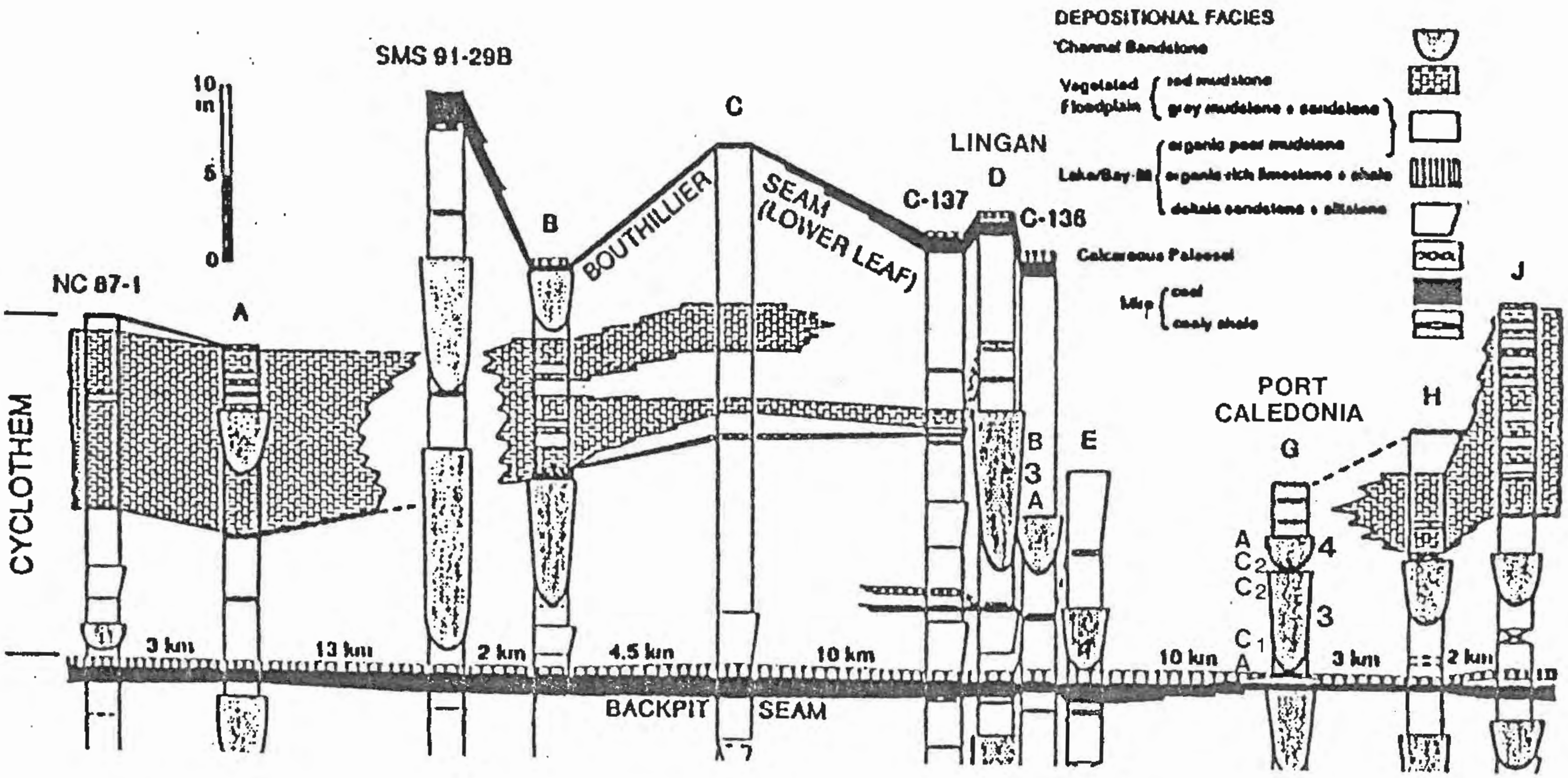

Figure 4.3

General west to east cross-section of the Backpit to Bouthillier seam (lower leaf). Modified from White (1992). Numbers refer to channel bodies studied at Lingan and Port Caledonia locations. (A; B; C_1; C_2) refer to channel body Group.

surface of the limestone above the Backpit Seam. The composite thickness of 18.6 m is quite significant in terms of channel fill accumulation. It is comparable in thickness and fluvial style to the amalgamated Channel-Body No. 1, in the Phalen to Unnamed interval at Lingan. The channel body has been classified into three types commencing with bedload (Group A) at the base, becoming more sinuous laterally and upward, and changing to sinuous mixed load (Group C_1) type. Bedload (Group A) type is reactivated following incision and infill by Storey # 6. A return to sinuous mixed load (Group C_1) is followed by suspended load (Group C_2) and channel abandonment. Paleoflow is quite variable (Table 4.2, Fig. 4.4) reflecting the fluctuation in channel morphology sediment supply and flow stage. Channel-Body No. 4 has a similar morphology to the upper part of Storey # 7 in the underlying channel body. An increase in sediment supply brought a return to the bedload channels (Group A) of Storey # 2. The channel body is overlain by well drained floodplain deposits that include paleosols (Fig. 4.3), possibly the Bouthillier sequence boundary and a lowstand systems tract.

In general, there is an upward change of fluvial style. The dominance of low sinuosity Groups A and B in the lower cyclothems is in accordance with the fluvial style of the underlying SBF. There is a relatively constant paleoflow direction throughout, consistent through the SBF and SMF (Gibling *et al*., 1992).

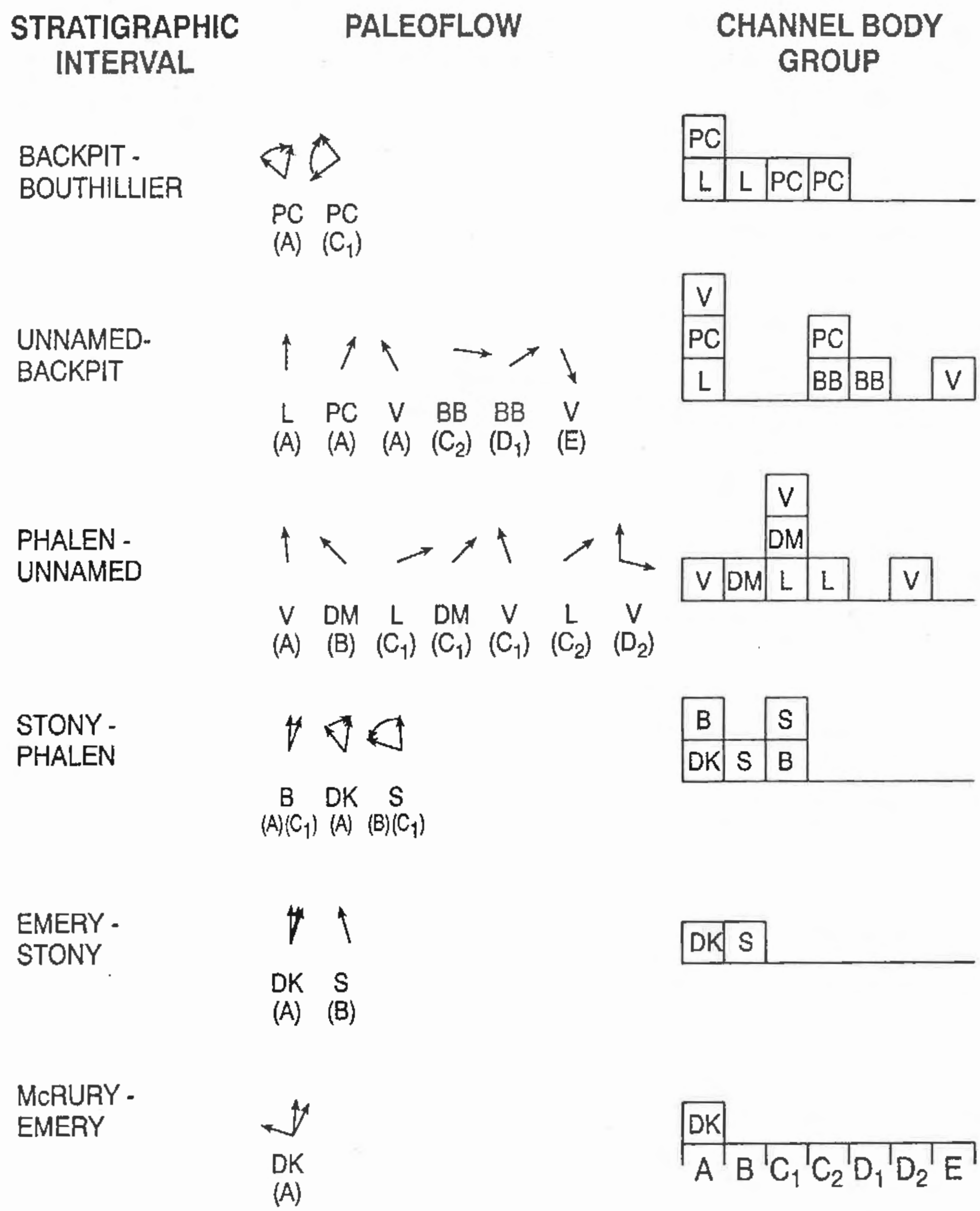

Figure 4.4

Stratigraphic distribution of paleoflow and channel body groups. Stratigraphic interval refers to cyclothems. Paleoflow is represented by arrows relative to north (top of page). Letters in brackets refer to classification of channel bodies A to E Group. B = Black Rock Point; BB = Big Bras d'Or; S = Sydney Mines; V = Victoria Mines; L = Lingan; DM = Dominion; PC = Port Caledonia; DK = Donkin.

4.3 DISCUSSION

Varying conditions during the deposition of channel bodies in the lower Sydney Mines Formation yielded a diversity of channel body and storey morphologies. In general, the diversity of channel body morphologies increases upward through the cyclothem intervals. Low sinuosity braided and sand sheet systems dominate in the McRury, Emery and Stony cyclothems. A transition to more sinuous bank attached barform systems in association with low sinuosity systems occurs within the Stony to Phalen interval. The Phalen to Unnamed seam interval cyclothem marks a change from low to high diversity of channel body geometries. This diversity continues through the Unnamed to Backpit and Backpit to Bouthillier cyclothems. It is important to note that the low sinuosity multi-storey bedload systems (braided) persist, however, throughout the entire section studied.

A number of controlling factors are inferred to have contributed to the diversity of channel body morphology, such as: depositional gradient; tectonism; relative sea-level (RSL), possibly influenced by glaciation in Gondwanaland (Crowell, 1978; Veevers and Powell,1987; Maynard and Leeder, 1992); climate; RSL and climate, in turn, may have been controlled by, or at least influenced by Milankovitch orbital cycles (Berger, 1977; Heckel, 1986; Leeder, 1988; Collier *et al.*, 1990; Gibling and Bird, 1994; Saunders, 1995); local topography; substrate erosional resistance; rate of sediment accommodation relative to sediment supply; proximity to source of sediment supply; configuration of receiving basin; and relative position of outcrop setting to paleocoastline. Different controlling factors could have been more significant at different stages of sequence development in the study area, or all factors could be considered. Relative position of outcrop setting to paleocoastline in concert with base-level change, climate and degree of substrate resistance to erosion could possibly have been the dominant controlling factors contributing to channel body diversity. The dominance of Group A and B channel bodies in the earlier cyclothems indicates that there not only was abundant sediment supply and accommodation, but that the depositional setting of the outcrops apparently were closer to an alluvial plain / braidplain than coastal plain environment. The fluvial systems maintained the course of the underlying South Bar and Waddens Cove Formations, filling paleovalleys defined by earlier bedrock structural controls, local topographic highs or lows and gradient adjustments. The dominance of alluvial braidplains restricted the development of thick peat accumulation in the study area. Thicker peat and therefore coal may have developed basinward away from the braidplain and more toward a coastal plain environment.

The well developed cyclothems of the Sydney Mines Formation commence in the Stony to Phalen interval. This may reflect a closer proximity of outcrop location to the coastal plain environment, as indicated by the sinuous fluvial style. As was previously mentioned, the inferred sequence boundary within a typical cyclothem commences on top of a nodular calcrete/palustrine limestone paleosol (Tandon and Gibling, in press). This surface implies a lowstand systems tract. Calcretes may be sequence boundaries, equivalent to some valleys, or may be local dryland facies capping abandoned channel belts. This has regional implications related to climatic controls on terrestrial depositional systems. These calcretes may be good marker horizons in the mine areas for regional or local correlation, as are limestones such as the Phalen Limestone.

At or near the sequence boundary, incipient channel body incision would have occurred, cutting down through underlying coastal plain bayfills, previously deposited in a highstand systems tract, to and occasionally through underlying limestone and coal, that mark a previous maximum flooding surface and cyclothem boundary. As RSL rose, a transgressive systems tract would have commenced. As sediment supply continued, channel and/or valley fill aggradation and clastic sediment accommodation occurred. Group A fluvial style may be common initially and may be associated with Group B and C_1 or C_2. The Group E channel body may have been a side tributary or the initial phase of aggradation on an incision surface. Only one example of this type of fluvial style was recognized in isolation. Other examples may exist, but may be amalgamated with other channel body systems and disguised as coarse basal lag deposits. Locally, well drained floodplain deposits would have prevailed until water levels had risen sufficiently to back up the fluvial system, change base-level, gradient and fluvial style. The resulting channel geometry would have transformed from low sinuosity systems to more sinuous systems in an upward succession. Group D channel bodies are more closely associated with sediment influx into standing bodies of water which are common in a coastal plain setting. The low gradient imposed by this setting would promote more sinuous fluvial style of a channel deposition. As sea-level rose, the climatic conditions may have become more humid also. Higher humidity could translate into more precipitation inland towards the headwaters of the river systems and thereby sustain sediment supply, possibly on a perennial basis, with seasonal fluctuations, resulting in variability in flow stage dynamics .

The Phalen cyclothem exhibits a marked diversification in fluvial style. There appears to be more allocyclic controls affecting the fluvial systems inferred to have been in the form of marine influences, due to the closer proximity of the coast. Thick economic coals like the Phalen and Backpit seams mark major flooding periods in close association with succeeding limestones. This flooding provided standing water which was filled with bayfill sediments of a highstand systems tract. A transition to regressive conditions followed, accompanied by progradation leading to a lowstand level, channel incision, then aggradation marking a readvance of a coastline or transgressive systems tract. In this way we not only see thick peat accumulation, but there is also a close association with incising channel bodies forming roof rock that is of concern in an underground mine. Above the Phalen seam, such incising channels are typically of Group A, C, D or E style, laterally discontinuous narrow bodies reflecting base-level influence. Because of the fibrous nature of the peat fabric there is a resistance to erosion, so rarely is there incision completely through the peat. Periodic autocyclic clastic influxes into adjacent floodplain and mire areas may have caused splits to develop in the coal seams, possibly encouraged by differential compaction of peat and floodplain sediments above pre-existing channel bodies. The incising channels commonly have very coarse to coarse basal lags and some are amalgamated with younger bodies.

Some possible valley fills may cut deeply and actually incise through coal (e.g. Phalen Colliery) - Group A. Without more comprehensive data, it is difficult to prove that these channel bodies are valley fills; if this is so, they may also represent sequence boundaries and lowstand systems tracts. A basinward equivalent may result in thick shallow marine reworked siliciclastic sequences. All would be potential hydrocarbon reservoirs, assuming the presence of a juxtaposed source rock. Channel sandstones on coals would also make excellent hydrocarbon reservoirs, trapped by overbank fines. Suitable porosity and permeability conditions would also be required. The adjacent mature coal and black organic-rich limestone and shale would potentially make good source rock for hydrocarbon generation.

Hydrocarbon exploration companies have successfully utilized 3-D seismic profiling to delineate traps in incised paleovalleys in the western Canada sedimentary basin. The same technology could be used for offshore exploration for hydrocarbons. This technique could also be applied by the mining industry to assist them in mapping underground economic coal seams and major associated channel bodies that form roof rock. Drill core and vertical seismic profiling could also be helpful in determining the velocity characterization related to the stratigraphy. This could then be integrated with the 3-D seismic to enhance the time to depth resolution.

CHAPTER 5: CONCLUSIONS

The lower Sydney Mines Formation (SMF) provides excellent examples of diversity of fluvial style of ancient channel body systems from outcrop exposures over a distance of 45 km along depositional strike. The channel body diversity was controlled by a number of factors, relative sea-level fluctuations, climate change and substrate variability of resistance to incision probably being the dominant ones. The following are the main points that summarize the principal conclusions of this thesis:

1. Of the twenty channel bodies studied, seven channel body groups were recognised. Group A comprises multi-storey bodies that were deposited from large sandy bedload systems with low sinuosity (braided) channel planforms which may be valley fills. Group B comprises planar sand sheets and within-channel bars formed in low sinuosity, sand-flat systems. Group C displays lateral accretion surfaces and ridge-and-swale topography, representing sinuous mixed-load (C_1) and suspended load (C_2) channel bodies. Group D comprises narrow channel bodies that cut bayfill and mouthbar deposits, and represent distributary bedload (D_1) and mixed-load (D_2) channel bodies. Group E represents thin, channel fills deposited during individual flood events. Some channel bodies may be single storey, while others may comprise several storeys that represent two or more groups.

2. The channel body groups are closely linked to stratigraphic level within cyclothems. This observation becomes more prevalent higher in the SMF. The typical well developed cyclothems fit into the context of the sequence stratigraphy model. The roof of the thick economic coal seams, in close association with black,

organic-rich, fossiliferous, well indurated limestone and shale which represent condensed sections, indicate maximum flooding surfaces. A subsequent highstand systems tract is represented by bayfill deposits that are cut by distributary channels (D_1, D_2). Both bayfills and distributary channels are commonly incised by the larger sinuous river systems of Group C. Relative sea-level then progressively dropped to a lowstand sequence boundary, represented by nodular calcretes and suggesting arid climatic conditions. Coincidental deep channel incision occurred (typically below low sinuosity channel bodies of Group A and B), bypassing the area and producing a forced regression. Gradual relative sea-level rise promoted channel body aggradation, localized subaerial exposure producing red beds, then eventual drowning and more bayfill deposition and peat formation. Humid climatic conditions are inferred for the latter phase.

3. The typical well developed cyclothem is not visible in outcrop until the Stony to Phalen stratigraphic interval, in which thick coal seams are developed. Within this interval the fluvial style makes a transition from a dominance of low sinuosity, braidplain and sheet sand channel systems (Group A and B respectively), also present in the underlying South Bar and Waddens Cove Formations, to more sinuous but variable fluvial systems of Groups C, D and E. The change in observed fluvial style may be a function of relative position of outcrop to paleocoastline in conjunction with fluctuation of base-level.

4. Some channel bodies have amalgamated to form thick, multi-storey units, on the order of 18 m in composite thickness. These multi-storey units may include Group E channel bodies in their bases. An understanding of the geometry of these large amalgamated channel body systems has important implications for underground coal mining operations. The utilization of 3-D reflection seismic

techniques, traditionally considered the domain of hydrocarbon explorationists, could also be applied to help understand the complexities of the relationships of the channel bodies in association with thick economic coal seams in underground mining operations. If good porosity and permeability is developed within these larger channel bodies, they would also have good potential for hydrocarbon accumulation.

REFERENCES

Allen, J.R.L., 1984. Sedimentary structures, their character and physical basis; unabridged one-volumn edition; Developments in Sedimentology 30, 663 p.

Berger, A.L., 1977. Support for the astronomical theory of climate change. Nature, 269: 44-45.

Bell, J.S. and Howie, R.D., 1990. Paleozoic geology. *In* Geology of the continental margin of eastern Canada. *Edited by* M.J. Keen and G.L. Williams. Geological Survey of Canada, Geology of Canada, 2: 141-165.

Bird, D.J., 1987. The depositional environment of the Late Carboniferous coal-bearing Sydney Mines Formation, Point Aconi area, Cape Breton Island, Nova Scotia. Unpublished M.Sc. thesis, Dalhousie University, Halifax, Nova Scotia, 343 p.

Boehner, R.C. and Giles, P.S., 1986. Geological map of the Sydney Basin: Nova Scotia Department of Mines and Energy, Map 86-1.

Bradley, D.C., 1982. Subsidence in Late Paleozoic basins in the northern Appalachians: Tectonics, 1: 107-123.

Brown, R., 1871. The coal fields and coal trade of the Island of Cape Breton. Geological Society of London Quarterly Journal, 7: 1-166.

Calder, J.H. and Gibling, M.R., 1994. The Euramerican Coal Province: controls on Late Paleozoic peat accumulation. Palaeogeography, Palaeoclimatology, Palaeoecology, 106: 1-21.

Calder, J.H., Gibling, M.R., Eble, C.F., Scott, A.C., MacNeil, D.J., 1996. The Westphalian D fossil lepidodendrid forest at Table Head, Sydney Basin, Nova Scotia: Sedimentology, paleoecology and floral response to changing edaphic conditions. International Journal of Coal Geology, 31: 277-313.

Cant, D.J. and Walker, R.G., 1978. Fluvial processes and facies sequences in the sandy braided South Saskatchewan River, Canada. Sedimentology 25: 625-648.

Collier, R.E.L., Leeder, M.R. and Maynard, J.R., 1990. Transgressions and regressions: a model for the influence of tectonic subsidence, deposition and eustasy, with application to Quaternary and Carboniferous examples. Geological Magazine, 127: 117-128.

Collinson, J.D. and Thompson, D.B., 1982. Sedimentary structures. Allen & Unwin, 194 p.

Crowell, J.C., 1978. Gonwanan glaciation, cyclothems, continental positioning, and climate change. American Journal of Science, 278: 1345-1372.

DiMichele, W.A. and Phillips, T.L., 1994. Paleobotanical and paleoecological constraints on models of peat formation in the Late Carboniferous of Euramerica. *In*: J.H. Calder and M.R. Gibling (Editors), The Euramerican Coal Province: Controls on Tropical Peat Accumulation in the Late Paleozoic. Palaeogeography, Palaeoclimatology, Palaeoecology, 106: 39-90.

Durling, P., and Marillier, J.Y., 1990. Structural trends and basement rock subdivisions in the western Gulf of St. Lawrence, northern Appalachians. Atlantic Geology, 26: 79-95.

Forgeron, S., MacKenzie, B. and MacPherson, K., 1986. The effects of geological features on coal mining, Sydney coalfield, Nova Scotia. Canadian Institute of Mining Bulletin, 79: 79-87.

Friend, P.F., Slater, M.J. and Williams, R.C., 1979. Vertical and lateral building of river sandstone bodies, Ebro Basin, Spain. Journal of the Geological Society of London, 136: 39-46.

Gibling, M.R., 1997. Unpublished data.

Gibling, M.R. and Bird, D.J., 1994. Late Carboniferous cyclothems and alluvial paleovalleys in the Sydney Basin, Nova Scotia. Bulletin of the Geological Society of America, 106: 105-117.

Gibling, M.R. and Kalkreuth, W.D., 1991. Petrology of selected carbonaceous limestones and shales in Late Carboniferous coal basins of Atlantic Canada. International Journal of Coal Geology, 17: 239-271.

Gibling, M.R. and Rust, B.R., 1990. Tectonic influence on alluvial sedimentation in the coal-bearing Sydney Basin, Nova Scotia, Canada. 13th International Sedimentology Congress, Nottingham, Abstract, p. 188.

Gibling, M.R. and Wightman, W.G. 1994. Paleovalleys and protozoan assemblages in a Late Carboniferous cyclothem, Sydney Basin, Nova Scotia. Sedimentology, 41: 699-719.

Gibling, M.R., Boehner, R.C. and Rust, B.R., 1987. The Sydney Basin of Atlantic Canada: an Upper Paleozoic strike-slip basin in a collisional setting. *In* Sedimentary basins and basin-forming mechanisms. *Edited by* C. Beaumont and A.J. Tankard, Canadian Society of Petroleum Geologists, Memoir 12, 269-285.

Gibling, M.R., Calder, J.H. and Naylor, R.D. 1992a. Carboniferous coal basins of Nova Scotia. Geological Association of Canada - Mineralogical Association of Canada Joint Annual Meeting 1992, Field Excursion C-1: Guidebook, 84p.

Gibling, M.R., Calder, J.H., Ryan, R., van de Poll, H.W. and Yeo, G.M., 1992. Late Carboniferous and Early Permian drainage Patterns in Atlantic Canada.Canadian Journal of Earth Sciences, 29: 338- 352.

Hacquebard, P.A., 1986. The Gulf of St. Lawrence Carboniferous Basin; the largest coalfield of Eastern Canada. Canadian Institute of Mining Bulletin, 79: 67-78.

Hacquebard, P.A. and Donaldson, J.R., 1969. Carboniferous coal deposition associated with floodplain and limnic environments in Nova Scotia. *In* Environments of Coal Deposition. *Edited by* E.C. Dapples and M.E. Hopkins. Geological Society of America, Special Paper 114: 143-191.

Haites, T.B., 1952. Conjectural shape and extent of the Sydney Coalfield. Canadian Institute of Mining and Metallurgy Transactions, LV: 202-212.

Hatcher Jr., R.D., Thomas, W.A., Geiser, P.A., Snoke, A.W., Mosher, S. and Wiltschko, D.V., 1989. Alleghenian Orogen. *In*: R.D. Hatcher Jr., W.A. Thomas and G.W. Viele (Editors), The Appalachian-Ouachita Orogen in the United States. Geological Society of America, Boulder, CO, F-2, pp. 288-318.

Heckel, P.H., 1986. Sea-level curve for Pennsylvanian eustatic marine transgressive-regressive depositional cycles along mid-continent outcrop belt, North America. Geology, 14: 330-334.

Hess, J.C. and Lippolt, H.J., 1986. $^{40}Ar/^{39}Ar$ ages of tonstein and tuff sanidines: new calibration points for the improvement of the Upper Carboniferous time scale. Chemical Geology, 59: 143-154.

Leeder, M.R., 1973. Fluviatile fining-upwards cycles and the magnitude of paleochannels. Geological Magazine, 110: 265-276.

Leeder, M.R., 1988. Recent developments in Carboniferous geology: a critical review with implications for the British Isles and N.W. Europe. Geological Association Proceedings, 99: 73-100.

Marillier, F., Keen, C.E., Stockmal, G.S., Quinlan, G., Williams, H., Colman-Sadd, S.P. and O'Brien, S.J., 1989. Crustal structure and surface zonation of the Canadian Appalachians: implications of deep seismic reflection data. Canadian Journal of Earth Sciences, 26: 305-321.

Maynard, J.R. and Leeder, M.R., 1992. On the periodicity and magnitude of Late Carboniferous glacio-eustatic sea-level changes. Journal of Geological Society of London, 149: 303-311.

McKee, E.D. and Weir, G.W., 1953. Terminology for stratification and cross-stratification in sedimentary rocks: Geological Society of America Bulletin, 64:381-389.

Miall, A.D., 1976. Palaeocurrent and palaeohydrologic analysis of some vertical profiles through a Cretaceous braided stream deposit, Banks Island, Arctic Canada. Sedimentology 23: 459-486.

Miall, A.D., 1978. Lithofacies types and vertical profile models in braided river deposits: a summary. *In* Fluvial Sedimentology. *Edited by* A.D. Miall. Canadian Society of Petroleum Geologists, Memoir 5, 597-604.

Miall, A.D., 1988. Reservoir Heterogeneities in Fluvial Sandstones: Lessons from Outcrop Studies. American Association of Petroleum Geologists Bulletin, 72: 682-697.

Naylor, R.D., MacNeil, D.J. and Kennedy, C.M., 1996. Stratigraphy, Sedimentology, and Depositional Environments of Roof Rock in the Phalen Colliery, Sydney Coalfield. *In* Nova Scotia Department of Natural Resources, Report of Activities, 1996, 1-11.

Nemec, W., 1988. The shape of the rose. Sedimentary Geology, 59: 149-152.

Paul, J., 1989. Unpublished data.

Rehill, T.A., 1996. Late Carboniferous nonmarine sequence stratigraphy and petroleum geology of the central Maritimes Basin, Eastern Canada. Ph.D. thesis. Dalhousie University, Halifax, Nova Scotia, 406 pp. (unpublished).

Robb, C., 1876. Report on exploration and surveys in Cape Breton Island, Nova Scotia. *In* Report of Progress for 1874-1875, Geological Survey of Canada, 166-266.

Rowley, D.B., Raymond, A., Parrish, J.T., Lottes, A.L., Scotese, C.R. and Ziegler, A.M., 1985. Carboniferous paleogeographic, phytogeographic and paleoclimatic reconstructions. *In* Paleoclimatic Controls on Coal Resources of the Pennsylvanian System of North America. *Edited by* T.L. Philips and C.B. Cecil. International Journal of Coal Geology, 5: 7-42.

Rust, B.R., Masson, A.G., Dilles, S.J. and Gibling, M.R., 1987. A sedimentological overview of the coal-bearing Morien Group (Pennsylvanian), Sydney Basin, Nova Scotia, Canada. Canadian Journal of Earth Sciences, 24: 1869-1885.

Saunders, K.I., 1995. Sedimentology and Depositional Environments of the Pennsylvanian Hub Cyclothem, Sydney Mines Formation, Cape Breton, Canada. M.Sc. thesis. Dalhousie University, Halifax, Nova Scotia, 171 pp. (unpublished).

Tandon, S.K. and Gibling, M.R. In press. Calcretes at sequence boundaries in Upper Carboniferous cyclothems of the Sydney Basin, Atlantic Canada. Sedimentary Geology.

Thomas, R.G., Smith, D.G., Wood, J.M., Visser, J., Calverley-Range, E.A. and Koster, E.H., 1987. Inclined heterolithic stratification - Terminology, description, interpretation and significance. Sedimentary Geology, 53: 123-179.

Stockmal, G.S., Colman-Sadd, S.P., Keen, C.E., Marillier, F., O'Brien, S.J. and Quinlan, G.M., 1990. Deep seismic structure and plate tectonic evolution of the Canadian Appalachians. Tectonics, 9: 45-62.

Van Wagoner, J.C., Posamentier, H.W., Mitchum, R.M., Vail, P.R., Sarg, J.F., Loutit, T.S. and Hardenbol, J., 1988. An overview of the fundamentals of sequence stratigraphy and key definitions. *In* Sea-Level Changes: An Integrated Approach. *Edited by* C.K. Wilgus, B.S. Hastings, C.A. Ross, H.W. Posamentier, J.C. van Wagoner and C.G. St. C. Kendall. Society of Economic Paleontologists and Mineralogists, Special Publication 42: 39-45.

Veevers, J.J. and Powell, C. McA., 1987. Late Paleozoic glacial episodes in Gondwanaland reflected in transgressive-regressive depositional sequences in Euramerica. Bulletin of the Geological Society of America, 98: 475-487.

White, J.C., 1992. Late Carboniferous cyclothems and organic facies in the Phalen-Backpit seam interval, Sydney Coalfield, Nova Scotia. M.Sc. thesis. Dalhousie University, Halifax, Nova Scotia, 287 pp. (unpublished).

White, J.C., Gibling, M.R. and Kalkreuth, W.D., 1994. The Backpit seam, Sydney Mines Formation, Nova Scotia: A record of peat accumulation and drowning in a Westphalian coastal mire. Palaeogeography, Palaeoclimatology, Palaeoecology, 106: 223-239.

Wightman,W.G., Scott, D.B., Medioli, F.S. and Gibling, M.R., 1994. Agglutinated foraminifera and thecamoebians from the Late Carboniferous Sydney coalfield, Nova Scotia: paleoecology, paleoenvironments and paleogeographical implications. Palaeogeography, Palaeoclimatology, Palaeoecology, 106: 187-202.

ENCLOSURE 1

BLACK ROCK POINT CHANNEL BODY

LEGEND

Grain Size

CS = coarse sand
MS = medium sand
FS = fine sand
VFS = very fine sand
ST = siltstone
MST = mudstone

Architectural Elements

SB = sandy bedform
OF = overbank fines
LA = lateral-accretion macroform
LS = laminated sand sheet
DA = downstream accretion macroforms

Colours

PALEOSOL
SOIL, GRAVEL
SHALE
OCEAN
REDBEDS
MST
SST (ch. body)
SST (overbank)
COAL
LIMESTONE

Numbers = bounding surfaces (Miall)

Sedimentary Structures

St = solitary or grouped trough cross beds
Sr = ripple cross lamination
PCL = primary current lineation
Sp = solitary or grouped planer cross beds
Se = erosional scours with intraclasts
IS = inclined stratification
IHS = inclined heterolithic stratification
RST = ridge-and-swale topography
S = slump block
Sh = horizontal lamination parting or streaming lineation

Symbols

roots
channel scour
nodules
woody material
stratal surfaces
plant fragments

BIG BRAS D'OR CHANNEL BODY

ENCLOSURE 2


SYDNEY MINES
CHANNEL BODY NO. 1
010
CLIFF TOP
STOREY #1
STOREY #2
STOREY #3
STOREY #4
STOREY #5
STOREY #6
Weathered Rock and Coal
EMERY SEAM
Siderite Nodules
Plant Fragments
Calamites
Correlation of outlier uncertain
- STOREY #4-6 ?
Weathered Rock
0m
25m
50m
5m
CHANNEL BODY NO. 2
025
CLIFF TOP
Concrete
STONY SEAM
MST Rubble
Interbedded Sideritic + Carbonaceous Layers
Riprap, rock falls, and talus in 60 m gap between Channel Bodies 1 and 2
10m
125m
150m
025
CLIFF TOP
REDBEDS
PALEOSOL (Weathered)
REDBEDS (Weathered)
PALEOSOL
MST Rubble
Siderite Nodules
ST/MST Rubble
Wave Cut Platform
Concrete
175m
200m
LEGEND
Grain Size
CS = coarse sand
MS = medium sand
FS = fine sand
VFS = very fine sand
ST = siltstone
MST = mudstone
Numbers = bounding surfaces (Miall)
Sedimentary Structures
St = solitary or grouped trough cross beds
Sr = ripple cross lamination
PCL = primary current lineation
Sp = solitary or grouped planer cross beds
Se = erosional scours with intraclasts
IS = inclined stratification
IHS = inclined heterolithic stratification
RST = ridge-and-swale topography
S = slump block
Sh = horizontal lamination parting or streaming lineation
Architectural Elements
SB = sandy bedform
OF = overbank fines
LA = lateral-accretion macroform
LS = laminated sand sheet
DA = downstream accretion macroforms
Symbols
roots
channel scour
nodules
woody material
stratal surfaces
plant fragments
Colours
PALEOSOL
SOIL, GRAVEL
SHALE
OCEAN
REDBEDS
MST
SST (ch. body)
SST (overbank)
COAL
LIMESTONE

ENCLOSURE 3


LINGAN
SYDNEY MINES FORMATION
SOUTH BAR FORMATION
EMERY SEAM
STONY SEAM
PHALEN SEAM
CHANNEL BODY NO. 1
CLIFF TOP
Wave Cut Platform
CHANNEL BODY NO. 2
BACKPIT SEAM
NORTH HEAD
UNIT A
UNIT B
TOP OF UNIT A
STOREY #1
STOREY #2
STOREY #3
STOREY #4
CHANNEL BODY NO. 3
SCALE CHANGE
(~7m Missing Between Sections)
DOMINION
abandoned channel fill
Siderite
Coal and Shale (covered)
LEGEND
Grain Size
CS = coarse sand
MS = medium sand
FS = fine sand
VFS = very fine sand
ST = siltstone
MST = mudstone
Architectural Elements
SB = sandy bedform
OF = overbank fines
LA = lateral-accretion macroform
LS = laminated sand sheet
DA = downstream accretion macroforms
Colours
PALEOSOL
SOIL, GRAVEL
SHALE
OCEAN
REDBEDS
MST
SST (ch. body)
SST (overbank)
COAL
LIMESTONE
Numbers = bounding surfaces (Miall)
Sedimentary Structures
St = solitary or grouped trough cross beds
Sr = ripple cross lamination
PCL = primary current lineation
Sp = solitary or grouped planer cross beds
Se = erosional scours with intraclasts
IS = inclined stratification
IHS = inclined heterolithic stratification
RST = ridge-and-swale topography
S = slump block
Sh = horizontal lamination parting or streaming lineation
Symbols
roots
channel scour
nodules
woody material
stratal surfaces
plant fragments

ENCLOSURE 4

PORT CALEDONIA
CHANNEL BODY NO. 3
BACKPIT SEAM
CHANNEL BODY NO. 2
CHANNEL BODY NO. 1
CHANNEL BODY NO. 4
CLIFF TOP
Wave Cut Platform
LEGEND
Grain Size
CS = coarse sand
MS = medium sand
FS = fine sand
VFS = very fine sand
ST = siltstone
MST = mudstone
Architectural Elements
SB = sandy bedform
OF = overbank fines
LA = lateral-accretion macroform
LS = laminated sand sheet
DA = downstream accretion macroforms
Colours
PALEOSOL
SOIL, GRAVEL
SHALE
OCEAN
REDBEDS
MST
SST (ch. body)
SST (overbank)
COAL
LIMESTONE
Numbers = bounding surfaces (Miall)
Sedimentary Structures
St = solitary or grouped trough cross beds
Sr = ripple cross lamination
PCL = primary current lineation
Sp = solitary or grouped planer cross beds
Se = erosional scours with intraclasts
IS = inclined stratification
IHS = inclined heterolithic stratification
RST = ridge-and-swale topography
S = slump block
Sh = horizontal lamination parting or streaming lineation
Symbols
roots
channel scour
nodules
woody material
stratal surfaces
plant fragments
DONKIN
McRURY COAL SEAM ?
EMERY SEAM ?
CHANNEL BODY NO.1
CHANNEL BODY NO.2
STONY SEAM ?
CHANNEL BODY NO.3
CHANNEL BODY NO.4
WATER
BEACH GRAVEL
WAVE CUT PLATFORM