GEOMETRY AND DEPOSITIONAL SETTING OF THE LATE CARBONIFEROUS MULLINS COAL IN THE SOUTH BAR FORMATION, SYDNEY BASIN, NOVA SCOTIA

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Abstract

The three-dimensional geometry of the Mullins Coal (Westphalian C) provides information about its origin and potential for commercial exploitation. Controls for peat accumulation are allogenic in contrast to a previous autogenic model. Sedimentary structures, observable in drill core and coastal outcrop, define four facies assemblages: *fluvial channel deposits* comprising trough cross-bedded sandstone and conglomerate; *bayfill deposits* comprising fine cross-laminated sandstone, laminated siltstone, and paleosols; *coal deposits* comprising bituminous A coal and shaly coal; and *well-drained floodplain deposits* comprising oxidized fine sandstone and mudstone. The coal ranges from 0.56-2.13 meters thick and extends for 15 km. The seam is thickest overlying fluvial sandstone deposits west of the Bridgeport Anticline near Victoria Mines. Thinning and splitting of the seam, associated with bayfill deposits, increase eastward towards the Glace Bay Syncline. Flooding of a distal braidplain caused brackish water to accumulate in a topographic low forming a protected inland bay. The presence of agglutinated foraminifera in bayfill shales testifies to marine influence. Ponding of freshwater near maximum marine transgression stage resulted in the accumulation of unusually thick paralic peat. The Mullins coal seam is favourable for an open cast pit as it overlies fluvial sandstone and is less than 50 meters below the surface where the coal is thickest.

Key Words: coal geometry, inner bay, braided fluvial, marine transgression

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CHAPTER 1 INTRODUCTION

1.1 Introduction

The South Bar Formation is the basal stratigraphic unit of the Upper Carboniferous coal-bearing Morien Group in the Sydney Basin, Nova Scotia (Fig. 1.1). The formation contains the Mullins Coal Seam which extends across part of the onshore area of the basin but has received little detailed study. The location of the coastal outcrop is 10 km north of the city of Sydney (Fig. 1.1) and is accessible via paths from the highway to the wave-cut platform. Low cliffs range from 1-5 m in height and bedding surfaces dip 24° northward. The data for this study originates from sixteen cores from the former Nova Scotia Department of Mines and Energy (NSDME)(now the Nova Scotia Department of Natural Resources), field observations from the coastal section at Sydney Harbour, and additional core data from a former mine location at North Sydney (Fig. 1.2). A complete record of the sedimentary structures in the cores allows an accurate interpretation of the depositional environment. The 16 NSDME cores (NW1-NW16) and coastal outcrop observations provide the bulk of the sedimentological information for this study. The mine data at North Sydney and Devco cores provide additional data on seam thickness (Chapter 5).

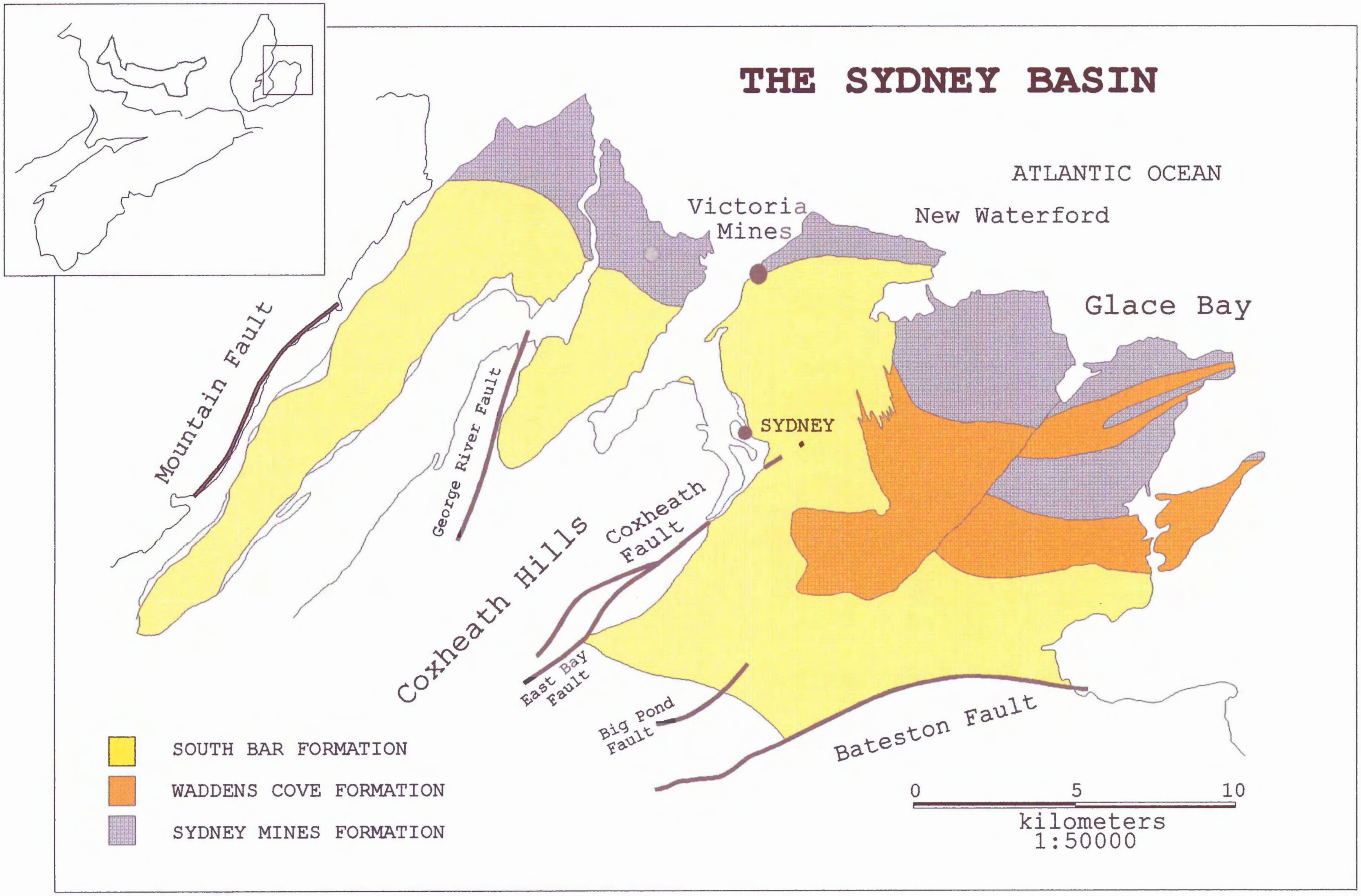

Figure 1.1 The Morien Group of the Sydney Basin (after Boehner and Giles 1986).

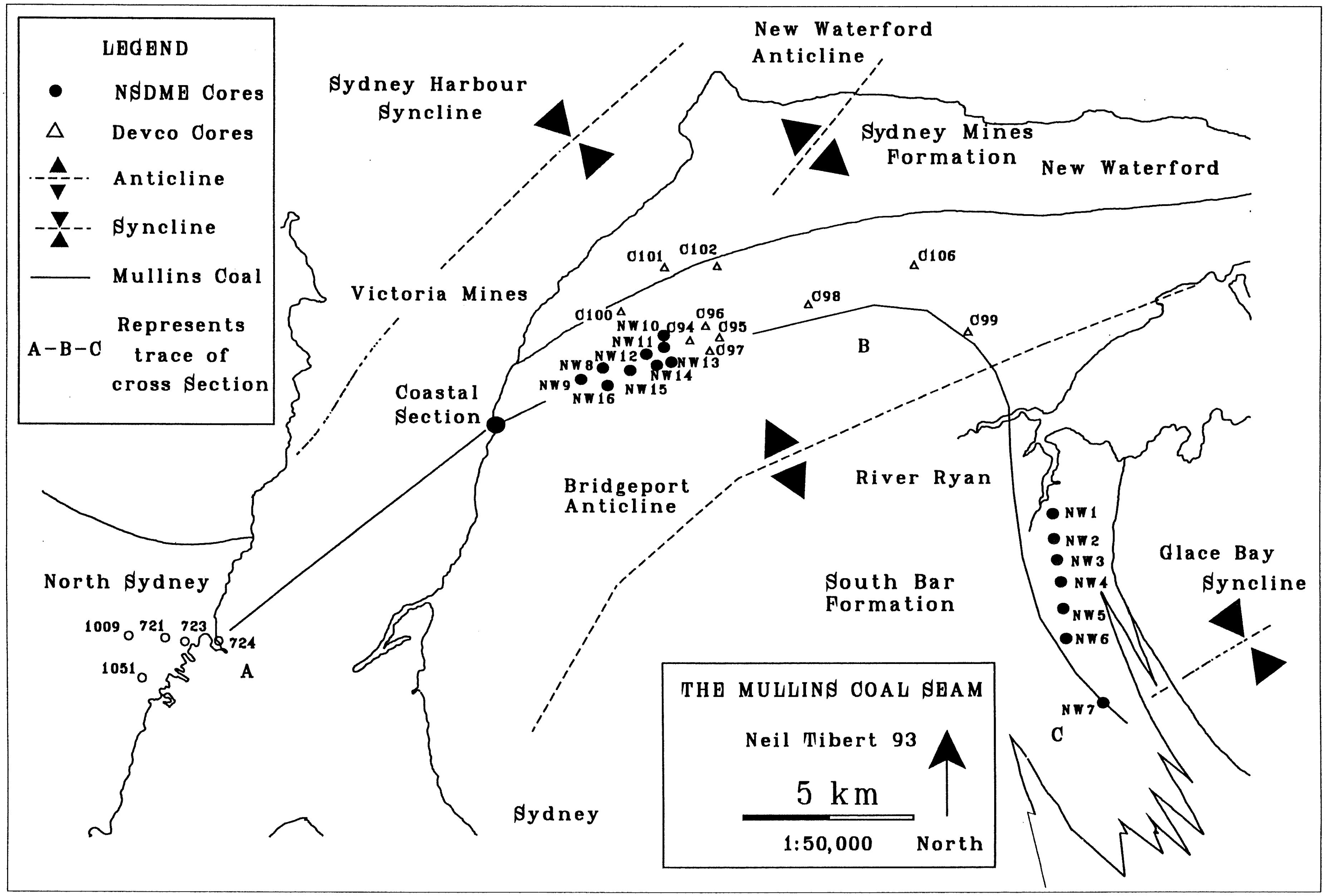

Figure 1.2 The location of cores and coastal outcrop. Note the position of the major anticlines and synclines.

1.2 Purpose

The purpose of this thesis is two-fold:

1. An interpretation for the South Bar Formations braided fluvial coal bearing unit was an autogenic peat deposit that formed on local bar tops or in alluvial backswamps (Rust and Gibling 1990). In modern depositional settings where braided fluvial systems build directly into the sea, such as the California coast or the Canterbury Plains of New Zealand, coastal processes make conditions unfavourable for the accumulation of high quality peat (Hicks and Inman 1987). An allogenic control for peat accumulation, such as a rise in sea level or tectonic subsidence, provides a better explanation for the formation of the laterally extensive Mullins Coal. Workers elsewhere have suggested that a radical change of depositional environment is necessary for peat to accumulate in the braided fluvial environment (Haszeldine and Anderton 1980; Nemec 1992). The Mullins Coal Interval does not fit the braided fluvial models, making this study of interest to the scientific community.

2. A recent evaluation of the Cape Breton Coal field suggests the Mullins Coal Seam is potentially economic for an open cast pit (Gillis 1981). This thesis provides information on the depth of the coal, the overlying roof rocks, and the lateral extent of the seam in the subsurface.

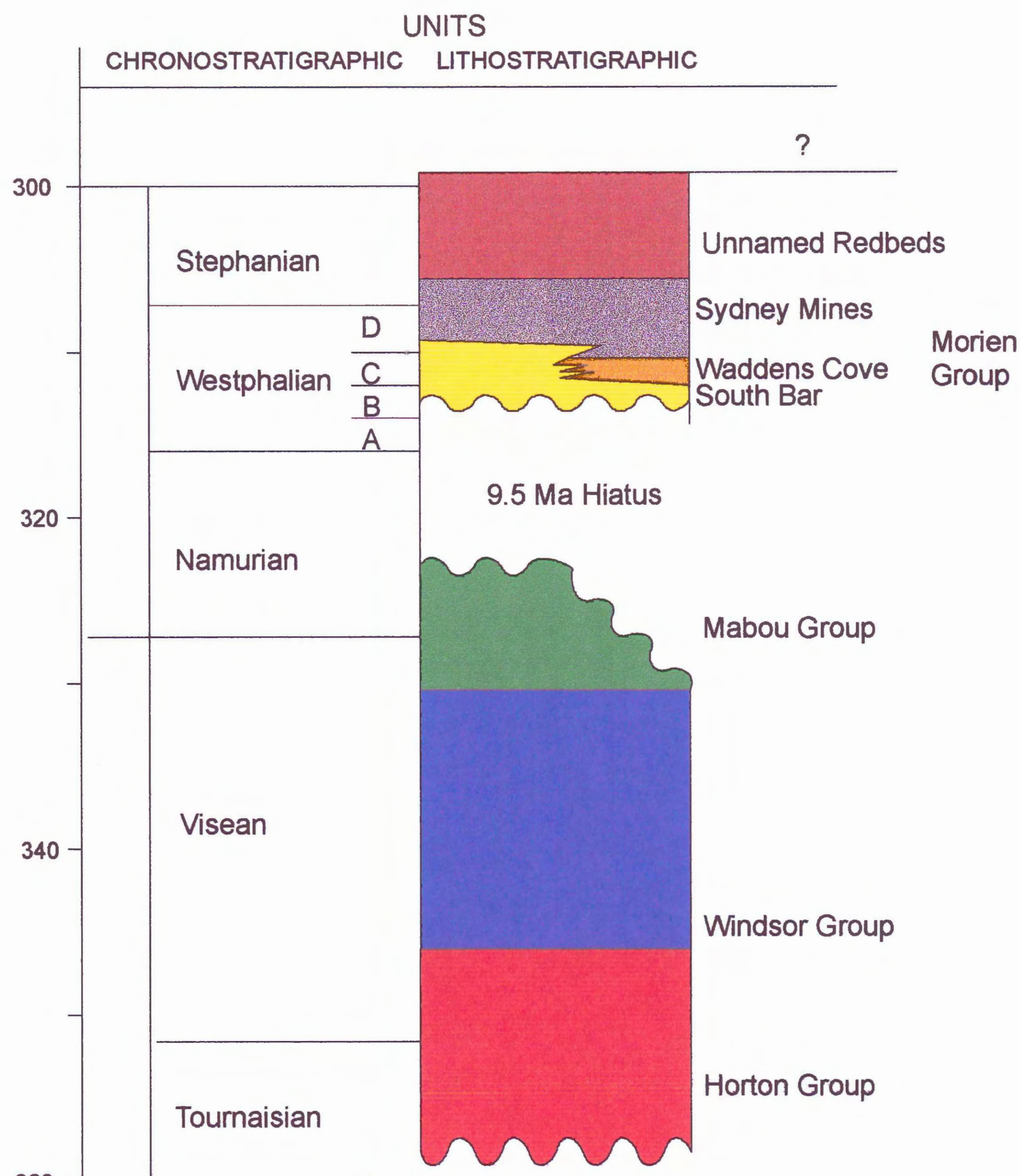

Figure 1.3 The stratigraphy of the Sydney Basin (after Gibling et al. 1987).

1.3 Basin Setting

The Sydney Basin, 350 km by 150 km, extends offshore from Cape Breton Island almost to Newfoundland. Deposition in the basin occurred from Devonian to Permian times in two mega-sequences (Fig 1.3)(Gibling et al. 1987). The first megasequence comprises the Horton, Windsor, and Mabou Groups that overlie Hadrynian to Devonian rocks (Boehner and Giles 1986). The Horton Group consists of red conglomerate, sandstone, and pedogenic limestone exposed on the western margin of the basin where it overlies granitic basement. The Windsor Group consists of limestone, dolostone, grey shale, and evaporites deposited under hypersaline conditions in a marine embayment. The Mabou Group consists of red and grey mudstone with minor stromatolitic units indicative of a lacustrine deposit (Rust et al. 1987). An erosional vacuity separates the first mega-sequence from the second. The Morien Group (Fig 1.1 and 1.3), the second mega-sequence, comprises approximately 2 km of fluvial to coastal plain strata (Bell 1938; Hacquebard 1983) of Westphalian B to Stephanian age (approximately 310-315 Ma: Hess and Lippolt 1986). The South Bar Formation unconformably overlies the Windsor and Mabou Groups at Cape Dauphin on Boularderie Island. The Bateston Fault truncates the South Bar Formation along the southeastern margin of the basin (Fig. 1.1). South Bar strata demonstrate an overall upward fining trend with coarse conglomeratic sandstones in basal units grading into predominantly medium-grained trough cross-bedded sandstone evident only in eastern localities (Fig.

1.1). The Sydney Mines Formation conformably overlies South Bar strata at Victoria Mines (Fig. 1.1) and consists of alternating successions of sandstone, mudstone, limestone, and coal. Rust et al. (1987) interpreted the formation as a meandering fluvial deposit. At more easterly localities, the Waddens Cove Formation is laterally equivalent to the South Bar Formation. The Waddens Cove Formation consists of sinuous channel deposits incised into hard, contemporaneously calcified sandstone (Rust et al. 1987). The change from braided fluvial to meandering fluvial conditions probably represents a change in environment relative to base-level conditions.

The paleogeographical position of the Sydney Basin during deposition was 10-20° latitude south of the equator (Scotese and McKerrow 1990). The climate of the Late Carboniferous at this latitude was tropical (warm and wet with seasonal fluctuations) appropriate for abundant plant growth (Rowley et al. 1985). Tectonic events of this period (Westphalian) were late-stage phases of the Hercynian/Variscan orogeny. The resulting structural deformation in the Sydney Basin generated gentle folds with beds dipping less than 30° and trending northeast (Boehner and Giles 1986).

1.4 Scope

Geographically this study concentrates on the New Waterford area in the Sydney Basin (Fig. 1.1). Stratigraphically the upper

South Bar strata, approximately 50 m above and below the Mullins Coal Seam, are the focus of this study (defined as the Mullins Coal Interval throughout this thesis (MCI)). The examination of the sedimentary structures and the correlation of 16 NSDME drill cores provide the means of interpreting the depositional history.

1.5 Organization

The evaluation of an extensive study area incorporating 16 cores and coastal observations requires classification of the sedimentary rocks into correlatable packages. Chapter 2 defines the facies and facies assemblages and presents hydrodynamic and depositional interpretations on a local scale. Chapter 3 describes the lateral distribution of the facies and facies assemblages using a detailed cross section. Chapter 4 addresses broader issues associated with the geometry of strata, their depositional history, and fundamental controls on sedimentation and peat accumulation. An economic evaluation (Chapter 5) provides information on the geometry and properties of the coal for future mining interests. The last chapter (6) summarizes the results of this study. Appendix A contains detailed visual logs of cores NW1-NW16. Appendix B contains a thin section description and Appendix C is a report on foraminiferal results prepared by Dr. Winton Wightman.

CHAPTER 2 FACIES AND FACIES ASSEMBLAGES

2.1 Introduction

The essential elements in the determination of individual facies are the lithologic, structural, and organic aspects of sedimentary rocks that are identifiable in the field (de Raaf et al. 1965). The MCI is divided into 5 facies types based on the lithologies. Each lithology is divided into specific units with an interpretation provided for the hydrodynamic, pedogenic, and organic characteristics. The facies occur in packages (facies assemblages) indicative of depositional environments. This section includes descriptions of the facies and facies assemblages followed by a brief interpretation of the hydraulic and depositional setting.

2.2 Facies Descriptions

2.2.1 Type 1: Conglomerate

1. a. Intraformational Conglomerate (Gmi): This facies occurs in the base of trough crossbedded sandstone usually associated with poorly sorted coarse sandstone units 0.35-0.85 m thick. The subangular clasts range from 1-5 cm long commonly displaying a reddish color.

Table 2.1 The facies descriptions for the Mullins coal-bearing strata (after Miall 1978).

Type Facies	Lithofacies	Sedimentary Features	Interpretation
1. a. Gmi	massive intraform-ational cgl	mudclasts 1-5 cm; cross-beds; organic detritus	lags on channel bases and erosional scours
b. Gt	extraform-ational granule cgl	rounded granules; cross-beds	dunes within channels
2. a. Sm	massive grey sandstone	appears structureless	dewatered dunes
b. St	medium-grained grey sandstone	trough cross-beds; load casts; burrows; organic partings	dunes within channels and bays
c. Sr	fine-grained cross-laminated heterolithic grey sandstone	cross- laminae; convolute laminae; inter-stratified mud; flasers	ripples in channels and bays
3. Fl	fine grey or red siltstone with clay partings	planar and ripple cross-laminae; root traces; organic partings; convolute lamination	traction/suspen-sion deposition in bays
4. a. Fm	grey mudstone	root traces; slickensides; bioturbation	hydromorphic paleosol or seat earth
b. Fmr	mottled red to grey mudstone; rare sandstone interbeds	slickensides; bioturbation; no organics	well drained paleosol
5. a. C	bituminous coal	pyrite crystals	mire
b. Ch	shaly coal	thin laminae; plant rich	clastic swamp

Interpretation: The inferred hydraulic setting is a shallow fluvial channel that has moderate to strong current velocities. Cant and Walker (1978) described similar facies in the Saskatchewan River which they interpreted as lag deposits in channels and erosional scours. The red color and subangular nature of the clasts suggests episodic scouring on a well-drained floodplain (Turner 1980).

b. Granule Trough Cross-bedded Conglomerate (Gt): The beds range from 10-47 cm in thickness and commonly display fining upward trends (Fig. 2.1). Trough cross-bed sets occur at Victoria Mines and range in size from 1.0-2.0 m wide by 0.15-2.0 m thick (Fig 2.8). Coal mats a few centimeters thick and up to 1 meter long, large carbonaceous fossilized tree trunks, and abundant plant detritus are features associated with this facies. The granule sized grains have a predominant quartz and minor feldspar composition. The granules and pebbles occur locally in the basal regions of the trough cross-beds (Fig. 2.9).

Interpretation: The coarse grains, abundant trough cross-beds, coal mats, and plant remains suggest a channel base deposit in proximity either to a vegetated bar-top or a back-swamp (Rust and Gibling 1990).

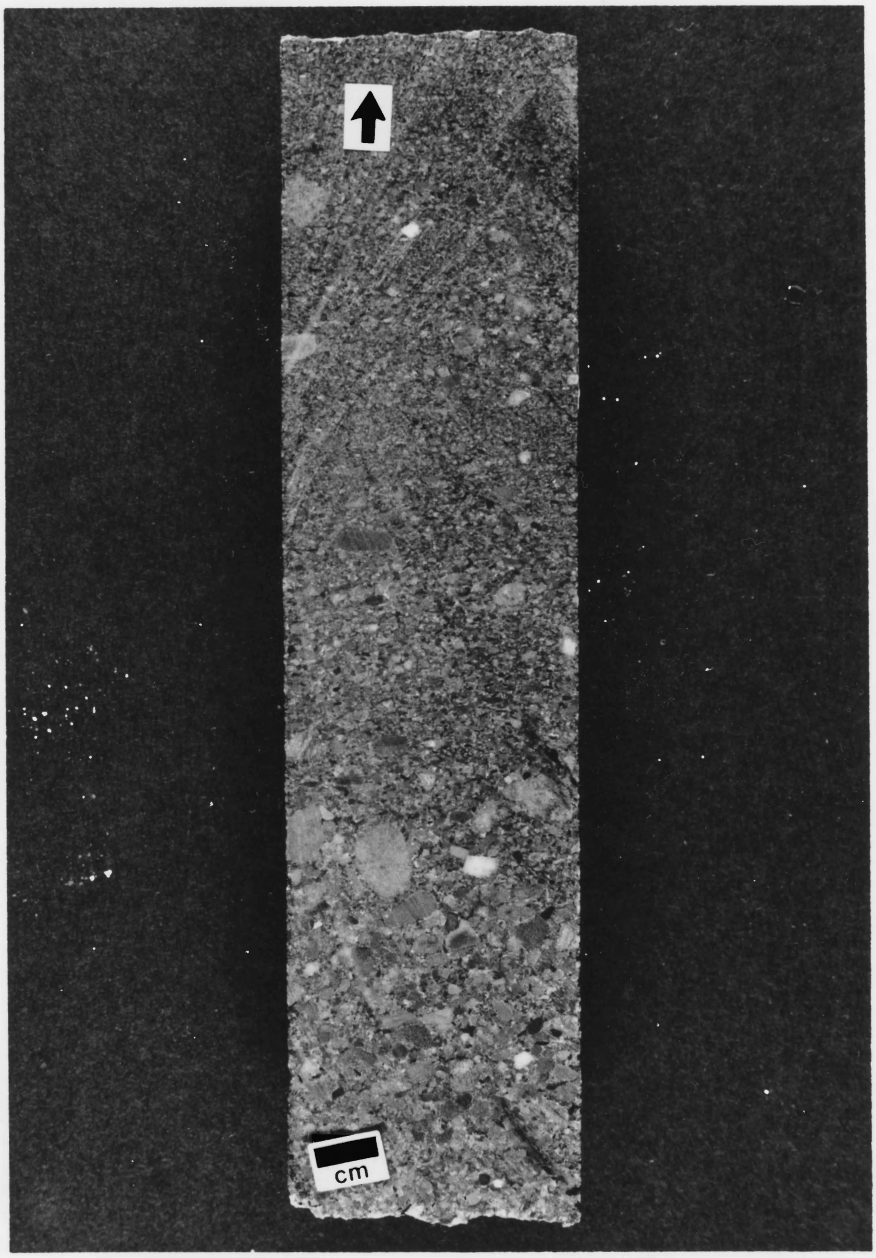

Figure 2.1 Extraformational conglomerate facies (Gt). Note the granule to pebble sized grains at the base fining up to coarse sandstone. Arrow in this and subsequent photos points to top of core.

2.2.2 Type 2: Sandstone

2. a. Massive Sandstone (Sm): This is the most abundant facies in the studied strata of the South Bar Formation. The units range from 0.83-6.55 m in thickness with an average of 2-3 m. The average grain size is 0.25-1.0 mm (Fig. 2.2). Plant matter commonly occurs either in the form of wispy bands between beds or as small "coffee grounds" within the unit itself. Figure 2.2 shows faint planar bedding, and Figure 2.3 shows a small coalified tree fragment.

Interpretation: Dewatering destroys the syndepositional features shortly after deposition (Cant and Walker 1978) and would explain the apparently structureless nature of this facies. Crevasse splay and fluvial channel deposits commonly contain significant accumulations of massive sandstone (Coleman 1980; Miall 1992).

2 b. Trough Cross-bedded Sandstone (St): The beds containing this facies range from 0.33-5.0 m thick. The trough cross-sets at the coastal outcrop are approximately 1 m deep by 3 m wide. Abundant fossilized plant detritus comprise thin wispy bands separating the beds. Local granule-rich horizons are common, indicating periodic increases of current velocity. This facies is similar to the trough cross-bedded extra-formational conglomerate facies discussed above, but is distinguishable by a finer grain size.

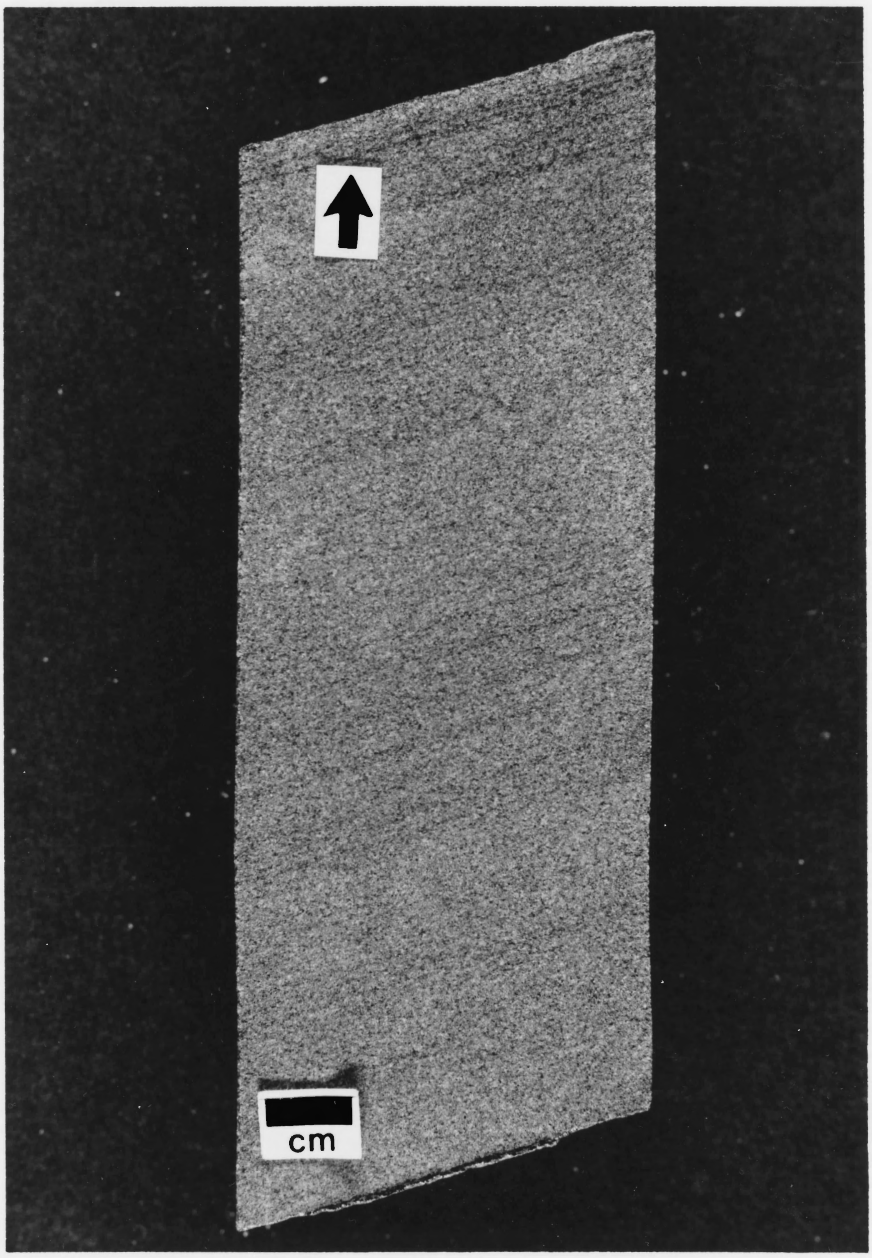

Figure 2.2 Massive sandstone facies (Sm). Note the faint planar stratification and the thin organic partings.

Figure 2.3 Massive sandstone facies (Sm) showing fossilized organic material and a small tree fragment (near arrow).

Interpretation: Trough cross-beds indicate dune formation in the lower flow regime (Allen 1984). They are abundant in many fluvial channel deposits (Cant and Walker 1978; Coleman and Prior 1980).

2 c. Ripple Cross-laminated Sandstone (Sr): The beds comprising this facies range in thickness from 0.03-1.07 m. The common diagnostic features of this facies are ripple cross-lamination, planar lamination, convolute lamination, interstratified mudstone in flaser and lenticular beds (Figs. 2.4-2.6), and rare trace fossils (burrows). The ripple cross-laminae comprise sets ranging from 1-2 cm and commonly display climbing ripple forms (Figs. 2.4 and 2.5).

Interpretation: Climbing ripple forms (Fig. 2.5) suggest rapid deposition under unidirectional flow in low-energy channels, crevasse splays, and shallow bays. The convolute laminae and loading structures represent features similar to crevasse splay, distributary channel, and mouth bar deposits described in the Mississippi Delta region (Figs. 2.5 and 2.6)(Coleman and Prior 1980; Tye and Kosters 1986; Tye and Coleman 1989).

2.2.3 Type 3: Siltstone

3. Laminated Siltstone (Fl): Beds of this facies range from 0.13-3.72 m in thickness, averaging approximately 1.5 m. The color is predominantly light grey (Fig. 2.6) but in some places shows red

Figure 2.4 Cross-laminated sandstone facies (Sr). Note the clay partings, small cross-laminae 1-2 cm thick, and climbing ripple forms.

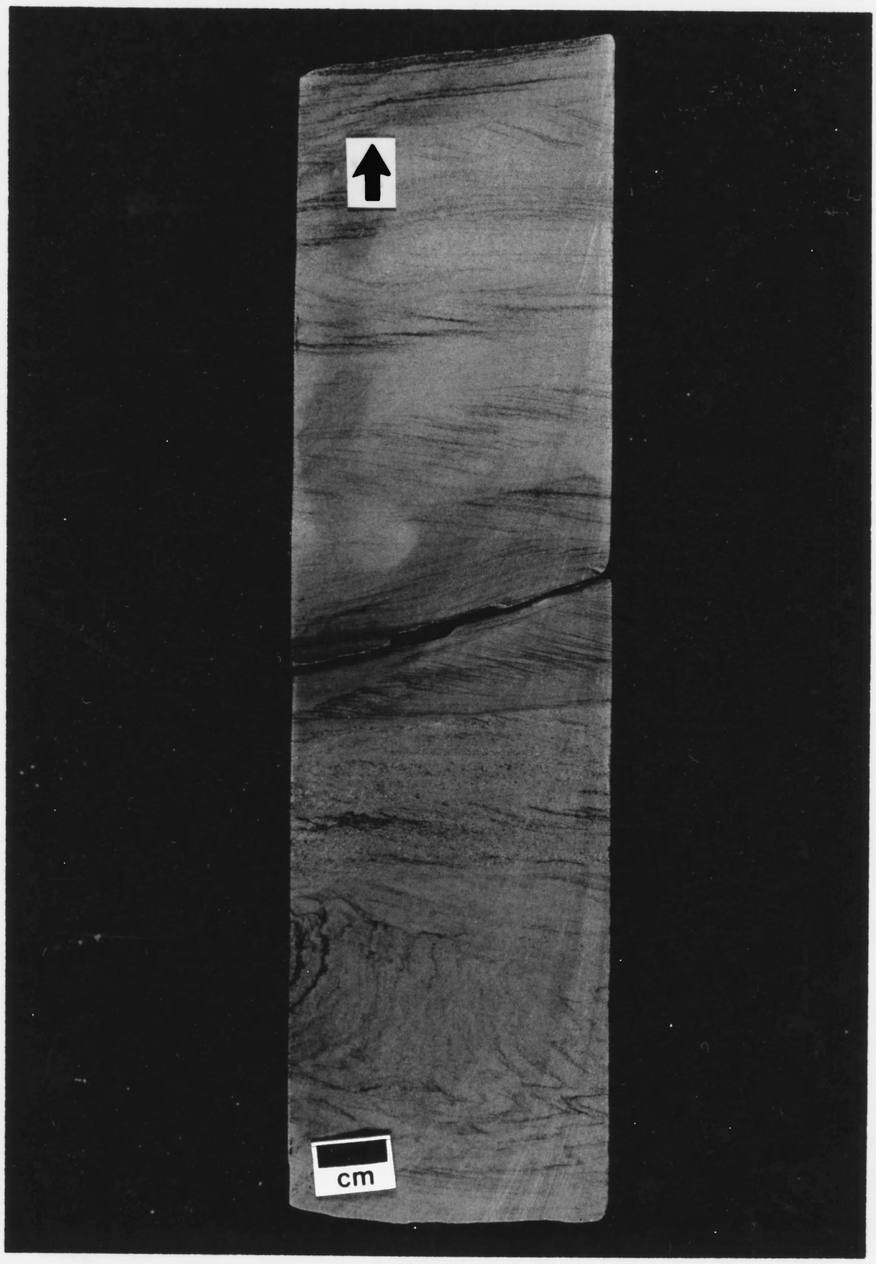

Figure 2.5 Cross-laminated sandstone facies (Sr). Note the climbing ripple forms, organic and clay partings, and the load cast structures at the base of the photo.

Figure 2.6 The contact between the cross-laminated sandstone facies (Sr, below) and the laminated siltstone facies (Fl, above). Note the well developed loading structures.

mottling (Fig. 2.7). The dominant features are fine wavy and planar laminae, plant detritus, load casts, and convolute structures (Fig. 2.6 and 2.7). Figure 2.6 shows an occurrence of this facies in contact with cross-laminated sandstone (Sr).

Interpretation: Deposition of finely laminated sediment occurs when sediment leaves the confines of a channel and settles from suspension in a standing-water body. Coleman and Prior (1980), Tye and Kosters (1986), and Tye and Coleman (1989) observed the association of siltstone and fine sandstone in distal bar deposits of lacustrine deltas and crevasse splays. Staub and Cohen (1978) and Breyers and McCabe (1987) also noted similar sediment associations in tidal deposits.

2.2.4 Type 4: Mudstone

4 a. Grey Mudstone (Fm): Grey mudstones form beds ranging from 0.05-2.05 m (averaging 0.75 m) thick. Accumulations of this facies are relatively minor in contrast with the coarser lithologies. Grey color, bioturbation, slickensides, and root traces characterize this facies. The mudstone commonly has interstratified cross-laminated sandstone (Sr).

Interpretation: Wet conditions prevailed with periodic plant accumulation in a marsh environment. Root traces and slickensides indicate compaction and disruption of an original hydromorphic

Figure 2.7 Laminated siltstone facies (Fl). Note the red color, fine lamination with minor convolute structure, and cross-lamination.

paleosol. The association of interstratified sandstone suggests periodic flooding of the area.

4 b. Red Mudstone (Fmr): This facies occurs in beds 27-85 cm thick with the greatest aggregate accumulations (approximately 2 m) occurring in cores NW4 and NW5 (Fig. 3.2c). The characteristics of this facies observable in the cores are the red color, slickensides, fractures, and minor root traces. Petrographic information provided from a thin section (Appendix B) shows an isotropic ferruginous fabric (40%), microcrystalline quartz (chert) and subangular quartz (20%), and ferruginous and calcareous glaebules (25%). The opaque ferruginous glaebules occur as 0.25-0.33 mm subangular nodules. The carbonate glaebules show layers of carbonate surrounding a quartz microfragment. Polycrystalline quartz and carbonate glaebules fill in voids and root traces common in the rock.

Interpretation: The red color, the scarcity of roots and a low percentage of sandy detritus in the beds indicate low ground and surface water levels typical in a well-drained paleosol (Gibling and Bird 1994; Schutter and Heckel 1985). Climatic seasonality causes wetting and drying in soils. This results in the swelling and shrinkage of clay minerals causing fracturing, the formation of carbonate nodules, and the development of the red color when a lack of organic detritus causes iron to go into the oxides (Schutter and Heckel 1985). The ferric minerals comprise an opaque fabric indicating acidic and oxidizing conditions. The presence of ferruginous and calcareous minerals suggests formation in a semi-arid climate (Retallack 1990; Schutter and Heckel 1985).

2.2.5 Type 5: Coal and Shale

5 a. Bituminous Coal (C): Thickness of the seam ranges from 0.55-2.13 m. The coal contains minor banding, and shows a vitrinite reflectance in the 0.80-0.85 range (Hacquebard and Cameron 1989). Chapter 5 provides a detailed description of coal quality and seam geometry.

Interpretation: This facies is well documented. It commonly forms on vegetated bar tops in fluvial systems, in low lying mires, and as paralic peat on landward margins of barrier lagoons and bays (Section 4.2) (Staub and Cohen 1978; Fielding 1987; Nemec 1992; Kosters et al. 1987).

5 b. Shaly Coal (Ch): Thin horizontal laminations and abundant organic detritus characterize this facies occurring in units 0.16-5.06 m thick. Many of the coal splits contain interstratified cross-laminated siltstone and grey rooted paleosol associated with carbonaceous shale. Abundant plant fossils occur in the thin 1-2 mm thick beds. Wightman (pers comm 1994) identified a rich assemblage of agglutinated foraminifera including the genera *Ammotium, Ammobaculites,* and *Trochammina* (see Sect. 3.3 and Appendix C).

Interpretation: The flooding of a marsh causes an increase in clastic deposition that is unfavourable for peat accumulation (Coleman and Prior 1980; Kosters et al. 1987; Robinson Roberts and McCabe 1992). Occurrences of this nature are common in interdistributary basins (Tye and Coleman 1989), lagoons, and in coal splits associated with braided fluvial deposits (Staub and Cohen 1978; Nemec 1992).

2.3 Facies Assemblages

2.3.1 Fluvial Channel Facies assemblage (CH)

Description: The fluvial channel (Table 2.2) is the most common facies assemblage in the South Bar Formation. It includes the following facies: extraformational and intraformational trough cross-bedded conglomerate facies (Gt and Gmi); massive trough cross-bedded and fine cross-laminated sandstone facies (Sm and Sr); and rare grey mudstone (Fm) (Figs. 2.8-2.10). Occurrences of the assemblage range in thickness from 3.0 m to more than 47.33 m (core NW15), but are typically 5-10 m thick. The massive and trough cross-bedded sandstone facies are the most common comprising over 84% of aggregate thickness (Fig. 2.13a). Some stratal units show a fining upwards trend, beginning with a

Table 2.2 Facies assemblages for the Mullins Coal interval.

TYPE	SEDIMENT TYPE	FACIES	FEATURES	DEPOSITIONAL ENVIRONMENT
A. Fluvial Channel (CH)	Cgl, medium Ss, fine Ss, Slt, rare mudstone and coal	Gmi, Gt, Sm and St	Rest on erosional surfaces; organized in stacks of crude fining upwards sequences	Braided channel formed on the distal braidplain
B. Bayfill Deposits (BF)	fine Ss, fine to very fine red-grey Slt, grey Slt, and grey mudstone	Sr, Fl, and Fm	Coarsening-up units (1-3 m) that may form stacked (5-10 m) sequences. They are usually capped with hydromorphic paleosols (Fm). Convolute and de-watering structures prominent	Subaqueous to subaerial deposits that represent the infilling of topographic lows on a coastal plain. ie: inter-distributary bay fills or crevasse splays
C. Coal (CS)	Bituminous coal, black shaly coal and minor grey mudstone	C, Ch, and Fm	Range from 2.08 m thick to <1 m thick. Overlie hydromorphic paleosols (Fm) commonly associated with bayfill deposits. Sulphur and ash contents are high.	Paralic (marine) peat formed in reed moor telmatic zone; Shale horizons represent flooding of coastal plain.
D. Well-Drained Floodplain (WF)	Red mudstone, red Slt, and red- grey mottled Slt, and rare fine-medium Ss.	Fmr, Fl and rare Sr, Sm	Red units range from 0.5 to 2 m in thickness. Usually lacks sedimentary features	Well drained paleosols that reflect periodic drying conditions or low relative base levels on the coastal plain

Figure 2.8 The fluvial channel facies assemblage (CH) above the Mullins seam at coastal outcrop. Note the crossbedding.

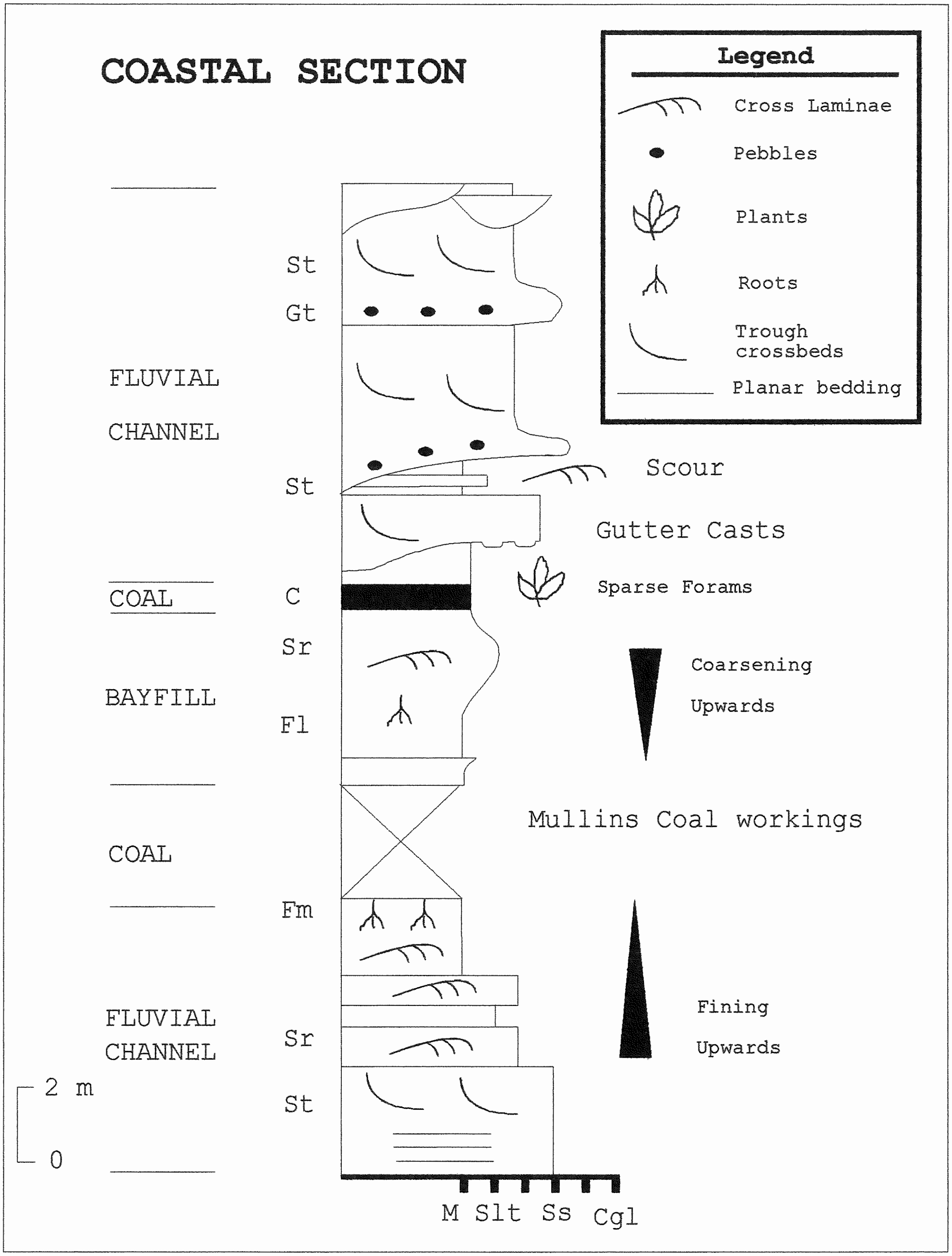

Figure 2.9 The coastal section at Victoria Mines. Left of the column are the locations of the facies and facies assemblages.

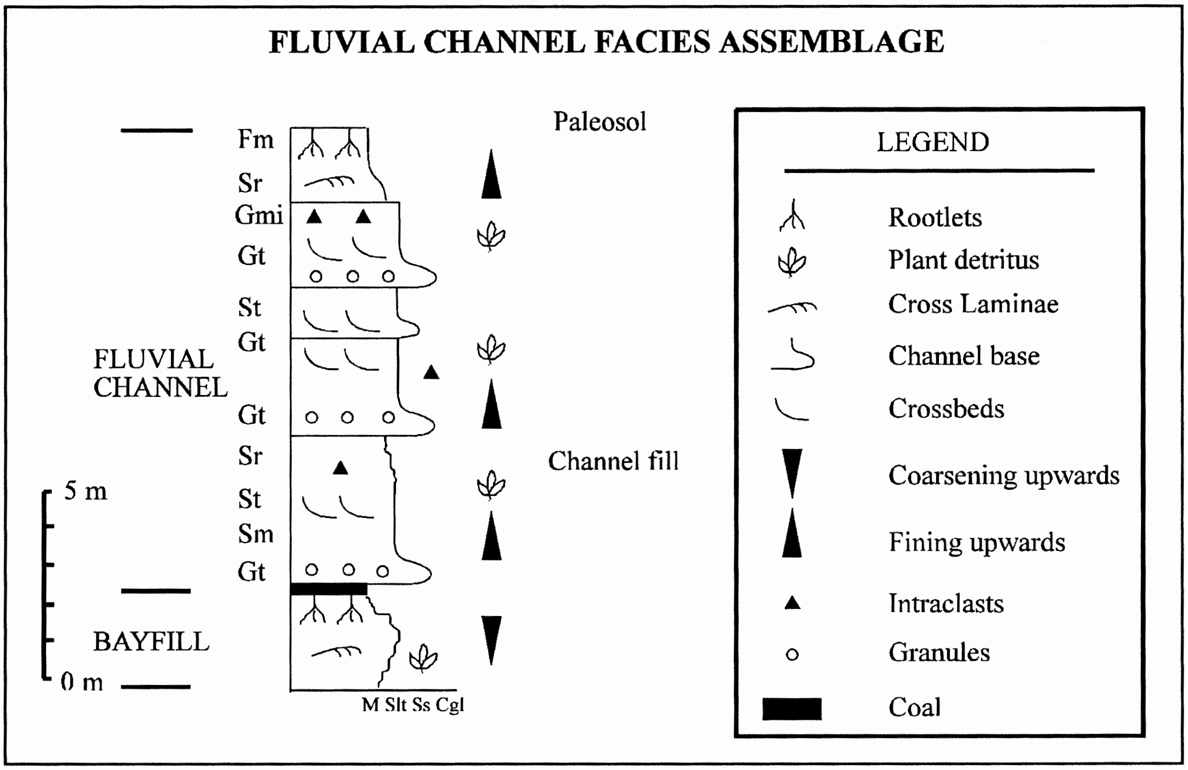

Figure 2.10 The fluvial channel facies assemblage from NW1 at 30 m depth in core.

pebble-granule basal unit (Gmi) grading into medium-to coarse-grained cross-bedded sandstone (St and Sm). The top of the package is fine-grained cross-laminated sandstone (Sr), usually capped by grey rooted mudstone (Fm) (Figs 2.9 and 2.10). Observations from the coastal section at Victoria Mines reveal coal mats, fossilized tree fragments, slump structures, and scours characterized by intraformational mudclasts (Gmi). The coastal section and a type section from core NW1 show all of the characteristic elements (Figs. 2.9 and 2.10).

Interpretation: Braided river systems generate alluvial sedimentary deposits that fill low-lying areas with detrital clastic sediment transported from higher elevations. A medium to high gradient on an alluvial plain typically results in the formation of low sinuosity channels containing multiple braid bars. The abundant cross-bedded sandstone, stacked and erosively based units with poorly developed fining upward trends, channel lags, and a high sandstone to mudstone ratio (Fig. 2.13a) suggest a distal braidplain depositional setting (Cant and Walker 1978; Rust 1978; Rust and Jones 1986; Rust and Gibling 1990). The presence of fossilized plant detritus, coalified tree fragments, and coal mats indicate proximity to vegetated land surfaces (Fig. 2.3) (Rust 1978). Rust and Gibling (1990) interpreted the South Bar Formation as a proximal braided fluvial deposit that fines up into a distal braidplain deposit in the stratal interval containing the Mullins Seam.

2.3.2 Bayfill Facies Assemblage (BF)

Description: This assemblage consists of coarsening-up packages of sediment indicative of the infilling of standing water bodies. The most common facies are the laminated siltstone (Fl), trough cross-bedded sandstone (St), and cross-laminated sandstone (Sr), comprising 69%, 17%, and 9% of the sequence, respectively (Fig. 2.13b). The basal regions of the coarsening-up packages contain silty sediments showing wavy and planar laminae separated by plant fossils. Following the silty sediments is an upward progression into cross-laminated sandstone with convolute structures, load casts, minor occurrences of flaser and lenticular bedding, and rare burrows. Grey rooted paleosols (Fm) cap the coarsening-up packages in beds less than 1 m thick displaying bioturbation and abundant root traces (Fig. 2.11). The assemblage thicknesses range from approximately 3.0-6.0 m (Fig. 2.12) commonly forming stacked sequences of three or four packages (Fig. 2.11). *Ammobaculites* and *Trochammina* are high marsh foraminifera indicative of a paralic peat-forming environment (Wightman 1993). Wightman (pers comm 1994) identified these genera within 1-10 m below the base of the Mullins Seam in the laminated siltstones (See Sect. 3.3 and Appendix C).

Interpretation: The bayfill facies assemblage resembles modern interdistributary basin fills and crevasse splays (Coleman and Prior 1980; Tye and Kosters 1986; Tye and Coleman 1989), tidal-

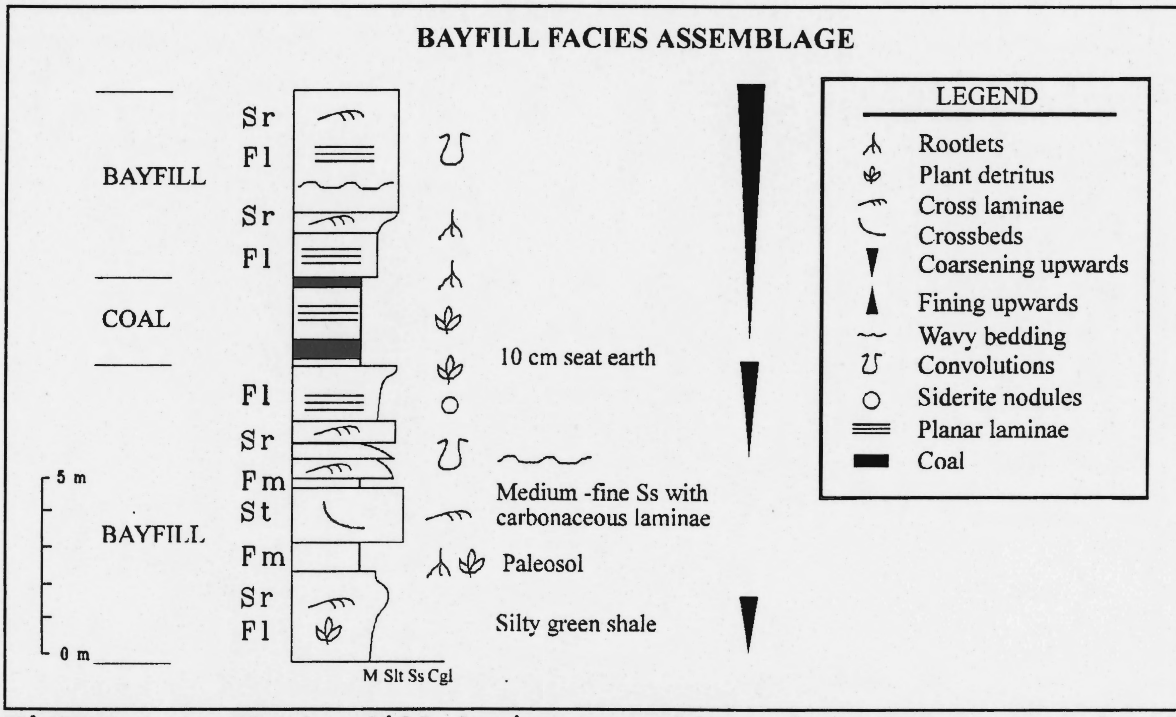

Figure 2.11 The bayfill facies assemblage from NW5 at 40 m depth in core.

Figure 2.12 Bayfill facies assemblage from the coastal section at Victoria Mines.

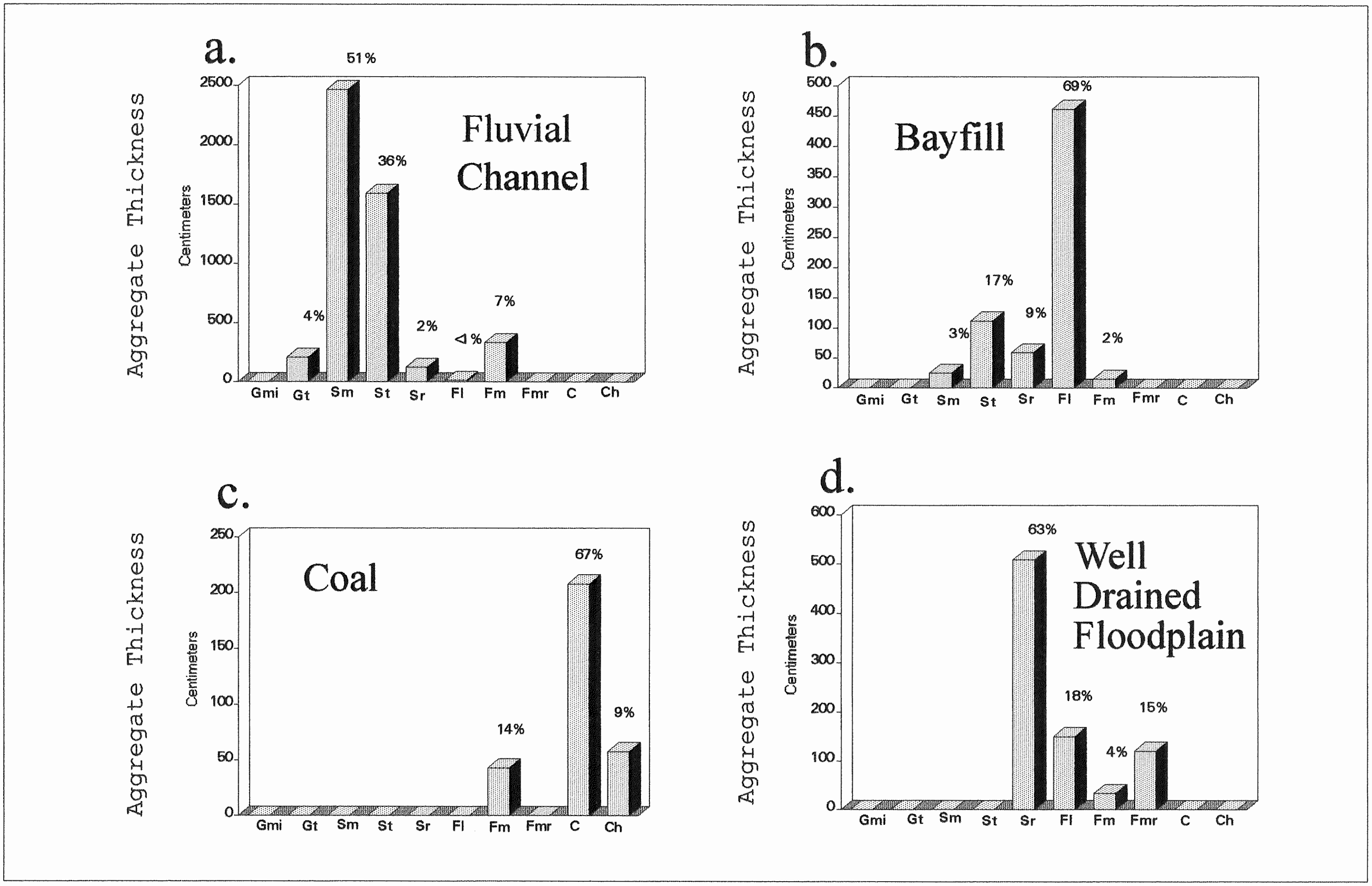

Figure 2.13 The thickness distribution of facies in the four facies assemblages. a. CH from NW15 (17m) b. BF from NW4 (61.3 m) c. C from NW13 (16.45 m) d. WF from NW5 (34m).

estuarine deposits, backbarrier lagoonal deposits, and fluvial-lacustrine systems (Breyer 1987; Nemec 1992; Staub and Cohen 1978; Fielding 1984; Haszeldine 1984). All of these inland basins occupy large portions of the lower alluvial valley and upper deltaic plain. They can range in width from a few tens of meters to 15-20 km. The basins are shallow, with water depths ranging from 7-10 m, and are often brackish to marine (Coleman and Prior 1980; Nemec 1993; Breyer 1987; Breyer and Mcabe 1986; Kosters et al. 1987; Tye and Coleman 1989). Inland bays may have marine connections (Section 4.3) by way of tidal channels or open bay mouths (Coleman and Prior 1980; Breyers 1987). The agglutinated foraminiferal assemblages found in the bayfills suggests a middle to lower estuarine paleoenvironment (Wightman pers comm 1994). Infilling results when crevasse breaks in the channel banks cause sediment to prograde out into the standing water body.

A recent analogue is the Mississippi delta which contains coarsening-up packages. They begin with a prodelta clay deposit rich in organic matter that accumulates during waning periods of episodic flooding events and extreme high tides (Coleman and Prior 1980). Following the prodelta clays are ripple-laminated silt and cross-laminated fine sandstone (equivalent to facies Fl and Sr in this study) usually deposited at the delta-front as hydraulic energy decreases. Distributary mouth bar deposits contain medium-grained well-sorted sand in convolute beds grading upwards into coarser cross-bedded sand (Sm and St) as water depths decrease. The final stratum is commonly a subaerial marsh deposit that contains soil horizons (Fm) that predate the accumulation of peat. Eventually either channel switching, or a rise in downstream base level (sealevel), causes the capacity of the stream to diminish. Subsidence then overtakes deposition and the area becomes flooded starting the cycle once again. Usually bayfill deposits of this nature will form multiple stacks of 3-5 m thick individual coarsening-up packages (Staub and Cohen 1978; Coleman and Prior 1980).

2.3.3 The Coal Facies Assemblage

Description: This assemblage consists of the coal (C) and shaly coal (Ch) facies (Fig. 2.14). An example from NW13 shows the thickness distribution of facies in this assemblage (Fig. 2.13c). The coal thickness averages approximately 2 m and the carbonaceous shales range in thickness from 0.39-5.06 m (Table 6.1 and Fig. 3.1). The split contains thin interbeds (10-20 cm) of grey mudstone (Fm) and cross-laminated sandstone (Sr).

Interpretation: Hacquebard and Donaldson (1969) distinguished three coal-forming environments in the Sydney Basin based on microlithotype analysis:

(i) a Forest Moor or a relatively dry terrestrial zone;

(ii) a Reed Moor with wetting and drying conditions within the telmatic zone; and

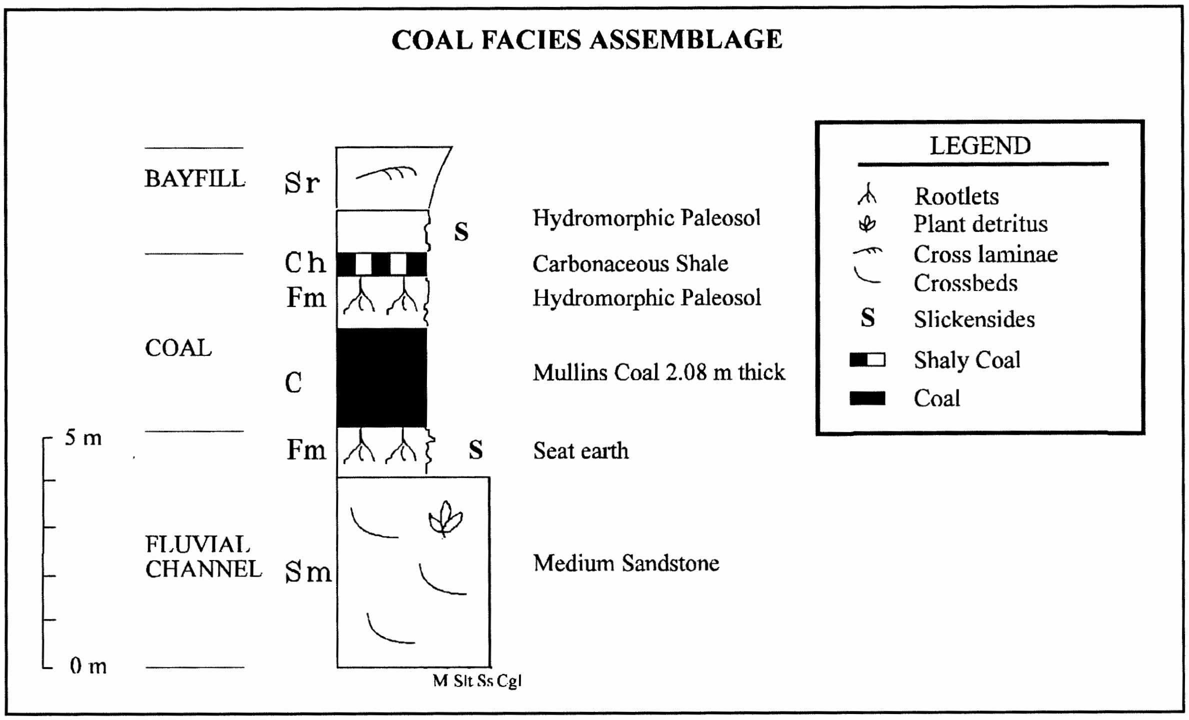

Figure 2.14 The coal facies assemblage from NW13 at 16.45 m depth in core.

(iii) an Open Moor under subaqueous conditions of the limno-telmatic zone.

Hacquebard and Donaldson (1969) classified the Mullins Coal as a predominantly reed moor deposit of the telmatic zone, implying a relatively poorly drained peat-forming ecosystem. The impure coal units suggest elevated water levels in the peat bog, allowing an increased clastic supply (Kosters et al. 1987). The foraminiferal assemblages in the coal-bearing strata indicate a paralic peat-forming environment (Wightman 1993; Wightman pers comm 1994).

2.3.4 The Well-Drained Floodplain Facies Assemblage (WF)

Description: This facies assemblage contains cross-laminated sandstone (Sr), laminated siltstone (Fl), red mudstone (Fmr), and grey mudstone (Fm)(Fig. 2.15). Figure 2.13d illustrates the abundance of these finer lithologies. This assemblage usually overlies bayfill deposits, beginning with a red paleosol (Fmr) grading into a grey mudstone (Fm). Red siltstone and cross-laminated sandstone commonly cap the muddy sequences (Fig. 2.15).

Interpretation: The paleoenvironment was a well-drained floodplain where periodic fluctuations in water levels, both surface and subsurface, allow reduction of the sediments. The packages overlie bayfill assemblages, suggesting that periods of good drainage succeed the infilling of the standing water body.

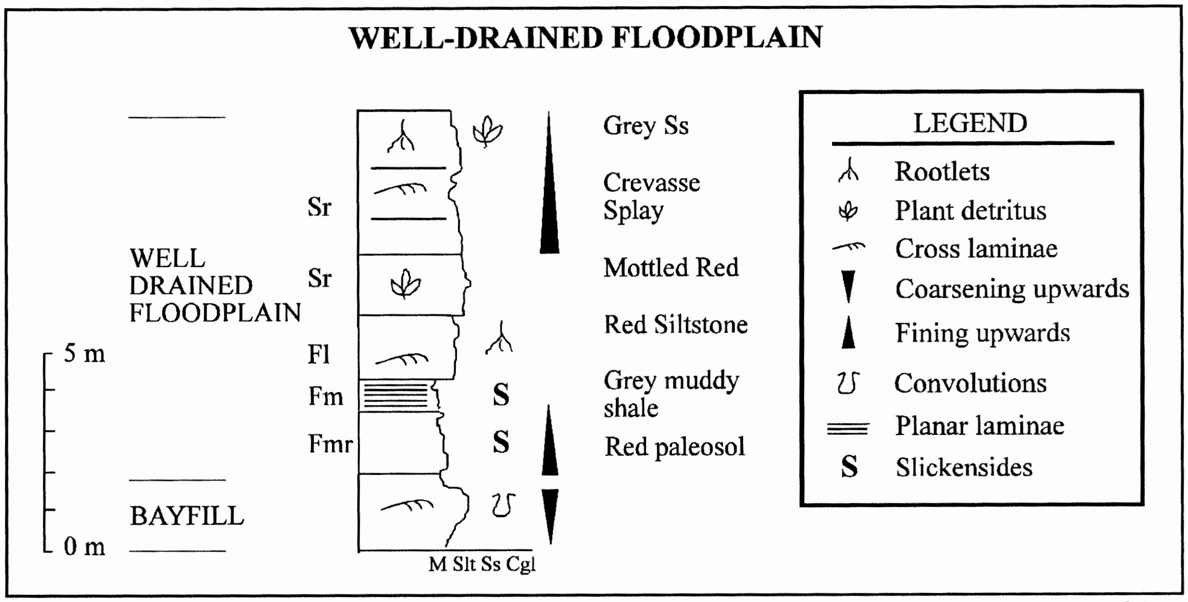

Figure 2.15 The well-drained floodplain facies assemblage from NW5 at 34 m depth in core.

2.4 Summary

Ten facies indicate hydrodynamic, pedogenic, and organic characteristics in the MCI. The facies occur in packages indicative of the depositional environment. A correlation of the four facies assemblages follows in the next chapter allowing a regional interpretation.

CHAPTER 3 CORRELATION

3.1 Introduction

The Mullins Coal extends from North Sydney to River Ryan, a distance of approximately 15 km (Fig. 1.2). Data derived from the NSDME cores NW series 1-7 at River Ryan, NW series 9-16 at Victoria Mines, and cores 721, 723, 724, 1009, and 1051 at North Sydney (Fig. 1.2) provide the necessary information for a stratigraphic cross-section of the MCI (Figs. 3.1 and 5.1). Using the facies and facies assemblages (Chapter 2), a regionally extensive correlation is possible. The following three sections describe the distribution of the facies, facies assemblages (including paleocurrent data), and foraminiferal assemblages.

3.2 Distribution of Facies

Figure 3.2 shows the distribution of facies from four representative cores. The most obvious feature of these cores is the predominance of massive and trough cross-bedded sandstone (Figs. 3.1 and 3.2a,b). Core NW12 has accumulations of the coarser lithologies (Gt, Sm, and St) totalling 15 m. Cores NW4 and NW7 show a significant difference in the distribution of the facies aggregate accumulations (Fig 3.2c,d). The finer lithologies (Sr, Fl, Fm,and Fmr) total 25 m in aggregate thickness in core NW4 (Fig. 3.2 b) comprising mainly bayfill deposits. The massive sandstone facies (Sm) is abundant in these cores, representing the upper parts of coarsening-up bayfill deposits (Section 2.3.2).

3.3 Distribution of Facies Assemblages

3.3.1 Fluvial Channel

The correlation diagram (Fig 3.1) shows the predominance of the fluvial channel facies assemblage in cores NW8-NW16. The location of these cores also corresponds to the position of the major anticlines (Figs. 1.1 and 3.1). Core NW10 shows the relative abundance of fluvial channel deposits above the Mullins Seam (an approximate 50 m interval) and NW15 shows the thick accumulation below the Mullins Coal (an approximate 42 m interval). The coastal outcrop at Victoria Mines shows a similar channel sandstone distribution (Fig. 2.9). The eastern side of the basin shows a decrease in the proportion of the fluvial channel facies assemblage occurring in stacked 3-5 m packages with erosional basal contacts. The lags above the basal erosional contacts contain a higher proportion of the intraformational conglomerate facies (Gmi) (Fig. 3.2a,b). The subangular clasts are commonly red, suggesting episodic erosion of the well-drained floodplain.

Trough crossbeds, primary current lineation, ripple cross-laminae, and flute casts measured from the coastal section are paleocurrent indicators. Figure 3.3 shows a consistent NNW fluvial trend below the base of the Mullins Seam. The crossbeds and primary current lineations above the Mullins display a similar NNW trend (Fig 3.3b). The ripple cross laminae, gutter casts, and flute casts show a more NNE paleoflow direction (Fig. 3.3a,b). Paleoflow readings show a general northerly, trend perpendicular to the strike of the cross-section (Fig. 3.1).

3.3.2 Bayfills

The River Ryan area shows the greatest accumulations of the bayfill facies assemblage (Fig. 3.1). They increase in thickness both above and below the Mullins Seam, ranging from approximately 1-2 m in core NW10 to 8-10 m in core NW7. At Victoria Mines and North Sydney this facies assemblage is uncommon. The bayfill deposits are less than 1 m thick below the Mullins Seam in cores NW9-NW15 (Fig. 3.1). Similarly, the bayfill deposits above the Mullins in the eastern localities are less than 2 m thick.

A notable feature in core NW7 is the 2 m thick massive sandstone deposit that resembles a sand washover located in the middle of a 10-15 m coarsening-up package (Fig. 3.1). The sandstone does not have either an erosional base or trough crossbedding, indicative of a fluvial channel, but contains subangular mudstone pebbles (10-15 cm) and abundant woody-plant detritus. Staub and Cohen (1978) and Reinson (1992) observed similar sand sheets in modern back-barrier deposits.

3.3.3 Coal Facies Assemblage

Tables 5.1, 5.2, and 5.3 show coal-seam thickness from all the cores shown in Figure 1.2. The seam is continuous from North Sydney to River Ryan and ranges in thickness from 1.97-2.13 m (Fig. 3.1). Cores NW1-NW7 show a split that increases in thickness eastward from 0.39-5.06 m (Fig 3.1) suggesting an increase in detrital supply into the peat-forming swamp. The first appearance of this split corresponds to the position of the Glace Bay Syncline and the Coxheath Fault (Figs. 1.1, 1.2, and 3.1). Gibling and Rust (1990) suggested a predominantly "wetter" period of deposition in this locality. The minor coal stringers (impure coal seams less than 1 m thick), above the Mullins Seam, cap the coarsening-up bayfill deposits. South of River Ryan three stringers occur above the Mullins separating the bayfill deposits. The unit directly above the Mullins extends from cores NW1-NW7 (Fig. 3.1). The other two impure coals form small lenses capping well-drained floodplain bayfill successions.

3.3.4 Well-Drained Floodplain

This minor component in the MCI occurs in the River Ryan-Glace Bay Syncline locality. The assemblage comprises finer lithologies, namely Sr, Fl, Fm, and Fmr (Fig. 2.13d). The most notable feature is the westward pinching out of the two occurrences, which lie 12 m and 30 m above the Mullins Seam

(Fig. 3.1). These occurrences represent periods of low baselevel and brief subaerial exposure. Minor coarsening-up units 2-3 m thick, and small lensoid fluvial scours, separate the well-drained facies assemblages indicating periodic flooding (Fig. 3.1).

3.4 Distribution of Agglutinated Foraminifera

The richest assemblages of agglutinated foraminifera occur in localities associated with the bayfill and coal facies assemblages (Appendix C)(Wightman pers comm 1994). Core NW4 contains specimens both directly below and 20 m above the Mullins Seam (Fig 3.1). Core NW5 contains a rich assemblage in an impure coal unit directly above the Mullins (Fig. 3.1). Core NW15 is interesting because a relatively rich assemblage occurs 13 m below the Mullins within mudstone capping a fluvial channel deposit (Fig. 3.1). The coastal outcrop shows only a sparse assemblage occurring 2 m above the Mullins workings (Fig. 2.9).

3.5 Summary

The distribution of the facies assemblages indicate fluvial domination in western, more proximal regions associated with well-developed coal. The more eastern localities display wetter conditions with periodic subaerial exposure.

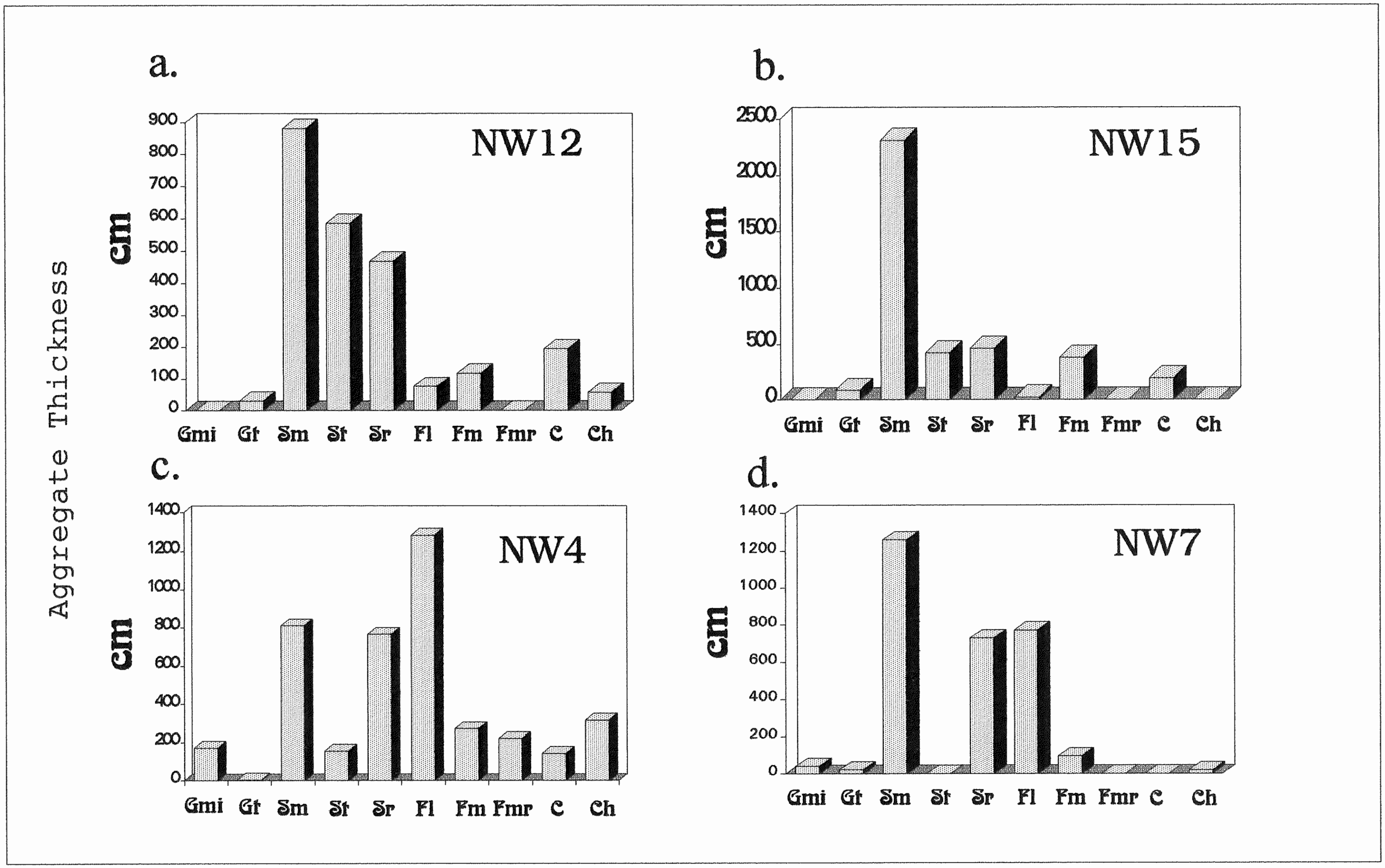

Figure 3.2 Facies aggregate thickness distribution from four representative NSDME cores.

PALEOFLOW MEASUREMENTS FROM THE SOUTH BAR FORMATION

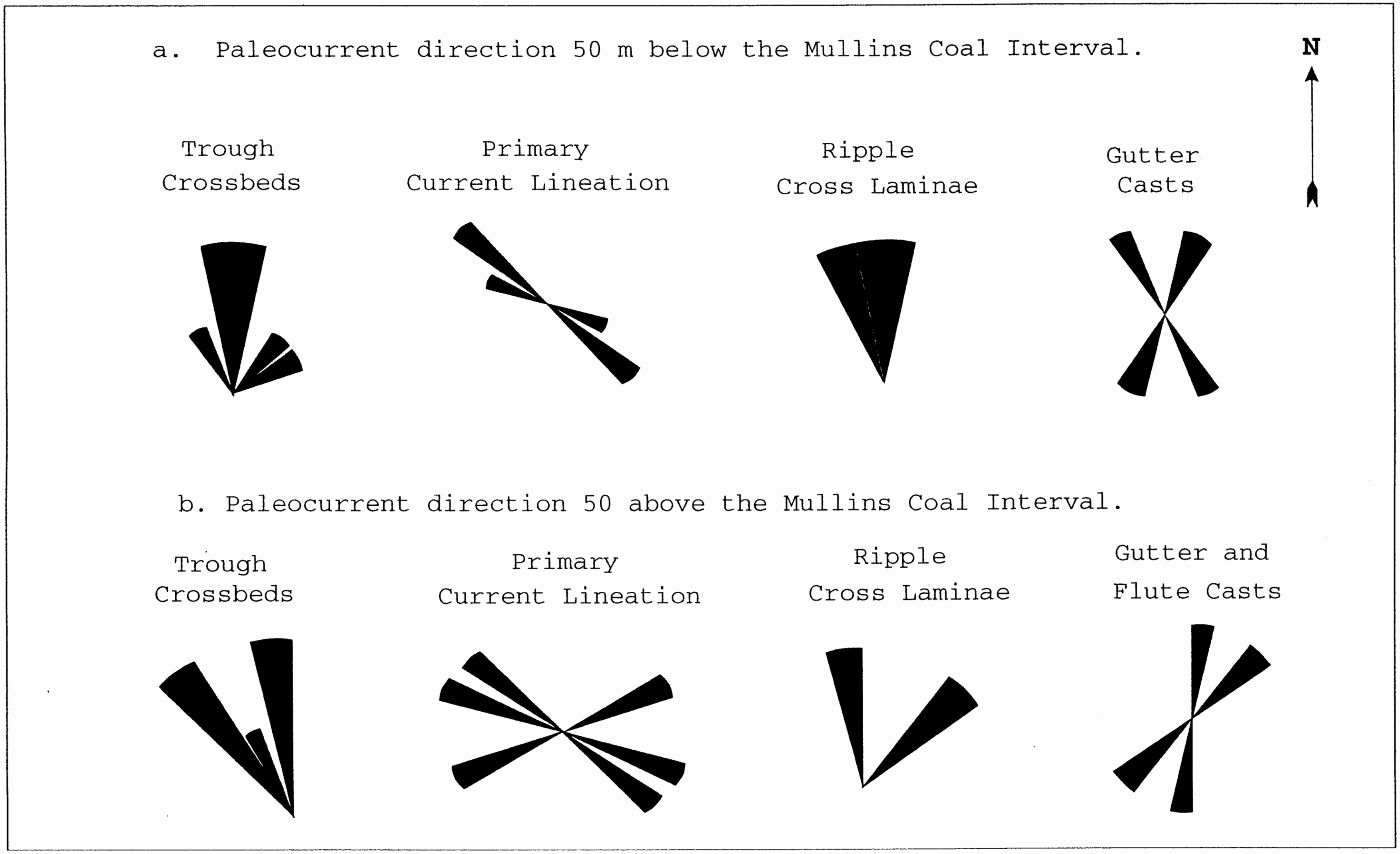

Figure 3.3 Paleocurrent data from the South Bar Formation. a. 82 m to 132 m above base of Formation. b. Data from 132 m to 182 m above Mullins seam.

CHAPTER 4 CONTROLS ON COAL GEOMETRY

4.1 Introduction

The geometry and characteristics of the Mullins Coal Seam relate directly to the depositional environment in which the peat formed. Controls on peat accumulation include a requirement for substantial plant growth and vegetative cover, sufficiently elevated water levels to inhibit oxidation and bacterial reduction, and a reduction of clastic input during peat accumulation (Fielding 1987). To accumulate substantial thicknesses of peat, rates of accretion and subsidence must balance (Coleman and Prior 1980; Fielding 1987; Kosters et al. 1987; Tye and Kosters 1989; McCabe 1990; Nemec 1992). The MCI reflects changing conditions within the Sydney Basin during Westphalian time. The first section of this discussion relates the significance of the coal to the fluvial channel and the bayfill deposits. The second section deals with issues related to a possible marine incursion. Next is a discussion on the structural nature of the study area followed by an interpretation of the depositional history. A brief summary concludes the chapter.

4.2 Coal-Forming Environments

4.2.1 Fluvial

Characteristics of the fluvial channel deposits indicate deposition on a distal braidplain comparable to the modern South Saskatchewan River (Rust and Gibling 1990). Coal associated with these deposit types are usually autochthonous, forming as peat on distal braid-bar tops or in alluvial backswamps. Much of the strata above and below the MCI in the coastal section (Section 2.4) undoubtedly display characteristics of a stacked distal braidplain deposit (Rust 1978; Cant and Walker). The coal, however, is laterally extensive (15 km) and relatively thick (0.5-2.13 m). The geometry of the Mullins Coal does not fit the braided coal model. Coal seams associated with braided fluvial deposits are typically no more than a few hundred meters wide and less than 1 m thick (Fielding 1987).

Nemec (1993) discussed coal deposits of the Helvetiafjellet Formation (Svalbard, Norway) where accumulations of peat occurred as a result of channel switching and subsequent infilling. He showed that coal and seat earth accumulations are thickest directly overlying fluvial sand bodies and tend to split, becoming shalier towards sand body margins. The MCI shows similar relationships. The thickest accumulations of coal overlie fluvial channel sandstone at Victoria Mines and split towards River Ryan (Chap. 3). Coals associated with braided river deposits of the

Helvetiafjellet Formation are approximately 60 cm thick and 100 m wide (Nemec 1992). The Mullins differs in that it is thicker and has a greater lateral extent, suggesting an allogenic control for peat accumulation. However, Nemec also suggested that thick accumulations of fine sediments (similar to the bayfill deposits in the MCI), associated with braided fluvial deposits, reflect far reaching incursions of marine to brackish waters. An event of this nature raises base levels and reduces the gradient on a distal braidplain. A standing water body forms in topographic lows and subsequently fills by the progradation of minor deltas. This terrestrialization of the standing water body allows peat-forming ecosystems to develop on the newly formed subaerial surface, with thicker accumulations occurring at the basin margins on the topographically higher fluvial sandbodies (Fig. 4.1). Subsidence outpaces peat accumulation, resulting in the development of impure coal towards the basin center (Fielding 1987; Kosters et al. 1987; Nemec 1992).

4.2.2 Bayfills

Coal associated with the coarsening-up packages of the MCI may have formed in fresh-water lacustrine environments, tidally influenced lagoonal-estuarine environments, or interdistributary basins connected to a marine embayment.

The bayfill deposits of this study closely resemble modern and ancient lacustrine deposits documented in the literature.

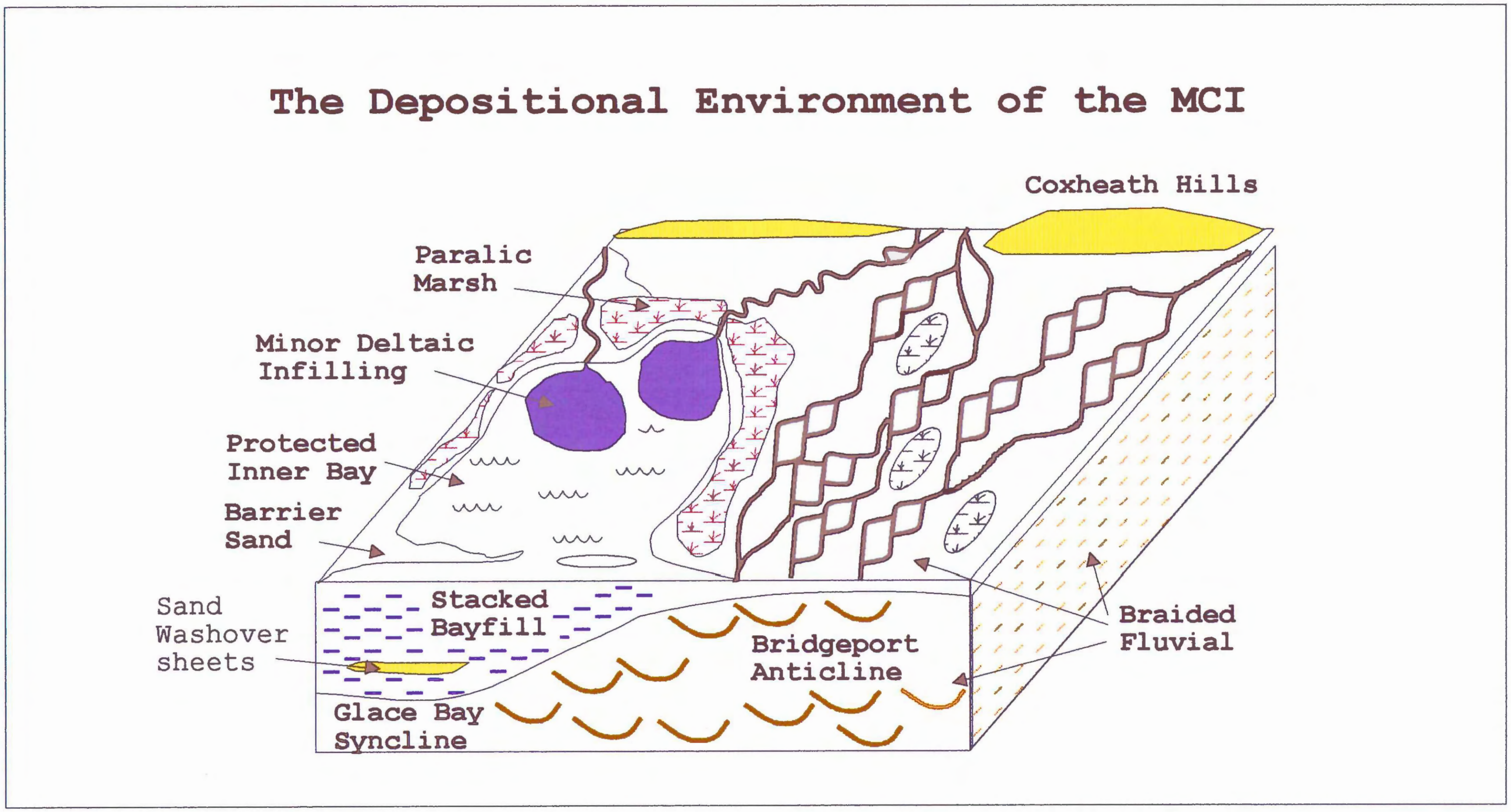

Figure 4.1

A visual representation of the depositional setting of the MCI. Continued sea-level rise and a subsequent highstand allowed thick high quality peat to develop over fluvial bodies. When sedimentation rates kept pace with subsidence and sealevel rise, peat spread over the bayfill surface, explaining the splitting of the Mullins Coal. An increase in subsidence or sea-level resulted in the flooding of the paralic peat, indicated by the coarsening-up units overlying the Mullins.

Fielding (1984) described Westphalian fluvio-lacustrine deposits from the Durham Coal Measures. The coarsening-up packages contain cross-laminated to wavy bedding in the siltstones and load structures in the fine cross-laminated sandstones. These are indicative of distal crevasse splays or minor deltas. However, fresh-water pelecypods and vertical burrows, abundant in the Durham Coal Measures, are absent in the MCI. Haszeldine (1984) provided a similar description for the Lower Westphalian coal measures in Northern England that contain a diverse bivalve fauna and seasonal varve-like rhythmites typical of a fresh water lacustrine environment. Finely laminated anoxic lacustrine muds do not occur in the Mullins strata, but are abundant in the Westphalian coal measures of northern England (Fielding 1984; Haszeldine 1984). The lack of prodeltaic mud and fresh water fauna in the coarsening-up packages in the MCI suggest that deposition did not occur exclusively in a fresh-water environment.

Tidally influenced coal measures of the Wilcox Group in East Texas display coarsening-up packages similar to those of the MCI. Breyer (1987) interpreted the East Texas deposit as a tidal channel complex on an embayed shoreline where peat formed on landward margins. The Paleogene tidal sediments contain wavy, lenticular, and flaser bedding types observable in the Mullins strata. Comparable also is the lack of rooting, the lack of desiccation cracks, bands of siderite nodules, and mud drapes in the cross-beds. The strata of this study are similar to the East

Texas Paleogene tidal sediments but lenticular and rhythmic bedding is much less common. Breyer and McCabe (1986) compared the East Texas deposit to the Snuggedy Swamp Deposit (Staub and Cohen 1978).

The Snuggedy Swamp of South Carolina, a modern peat-forming ecosystem, is a tidal deposit associated with a protective barrier island (Staub and Cohen 1978). The development of the deposit is as follows. A Salt marsh formed landward of the embayment as a result of sea-level rise. A barrier island formed at the bay mouth restricting wave and tidal influence. Fresh water recharge was greater than saline recharge in the protected bay and resulted in thick fresh-water peat extending over the salt marsh. Peat deposits associated with the salt marsh are thin and discontinuous while the fresh water peat deposits are thick and laterally extensive. The deposit consists of stacked 5-10 m coarsening upwards deposits each capped by thin seat earths and substantial accumulations of peat. Storm washovers usually form thin sand sheets inter-bedded with peat (Cohen and Staub 1978; Reinson 1992).

The East Texas sediments (discussed above) do not show evidence for an ancient shoreline deposit containing sand washover sheets. However, Breyer and McCabe (1986) suggest that the lack of tidally influenced structures in the Wilcox Group indicate a protected lagoonal embayment similar to the Snuggedy Swamp. The MCI best fits the Snuggedy model as it consists of stacked coarsening-up units containing marine faunal assemblages, sand washover sheets (Section 3.3.2), and minor lenticular bedding. The thick coals associated with bay margins thinning towards the basin center also resemble the lagoonal environment of the Snuggedy Swamp.

4.3 The Marine Connection

Barrier islands form on coastal plains in response to marine transgressions. A transgression increases coastal current activity causing fluvial sediments to stockpile at the head of a river or coastal embayment (Penland et al. 1988). This results in the formation of an extensive barrier island that protects inner bays and lagoons from wave and tidal energy (Penland et al. 1988). Minor deltaic sedimentary processes comparable to the Atchafalaya Basin and the Barataria Basin interdistributary bay and crevasse splay deposits (See Section 2.32) cause the lagoon or bay to infill with coarsening-up packages of sediment (Coleman and Prior 1980; Nemec 1992). In all of the coal deposits discussed above, peat accumulates on the landward margin of these protected bays approximately 20 km inland from open marine conditions. The influx of saline water either episodically by storm events or daily in response to tidal cycles is of great importance. A small change in pH and salinity greatly increases the environmental stress on organisms, explaining the lack of fresh-water fauna observable in the Mullins cores (Bustin et al. 1983).

Agglutinated foraminiferal assemblages identified in the MCI are: high marsh fauna located in the coal facies assemblage and lower to middle estuarine assemblages occurring in the bayfill deposits (Wightman et al. 1993; Wightman pers comm 1994).

Sulfur and ash values are high in the Mullins coal (Section 5.3). If the Mullins formed in a fresh-water peat swamp, sulfur values of approximately 0.2-1.0% would be normal (Bustin et al. 1983). The Mullins has a sulfur content of 5.93% comparable to brackish marine bays (Bustin et al. 1983). The higher sulfur values in the South Bar Formation may reflect sulfur recycling from underlying sulphates of the Windsor Group (Section 1.3) (Rust et al. 1987; Gibling et al 1989; Rust and Gibling 1990). However, this theory is not consistent with the relatively even distribution of sulphur values within the Morien Group, but may explain the slightly higher sulfur values in the Mullins Coal which lies relatively close to the underlying Windsor bedrock (Section 5.3). The ash values within the South Bar Formation are high, reflecting a high clastic input at the time of peat formation, typical of a low lying mire (Robinson Roberts and Mcabe 1992).

4.4 Basin Structure

The Westphalian Morien Group shows little structural deformation. Gentle NE-trending folds are present (Boehner and Giles 1986). The distribution of the facies assemblages corresponds to the positions of the anticlines and synclines (Gibling and Rust 1990). The coals are thickest over the axial centres of the New Waterford and Bridgeport anticlines where fluvial sandstones are dominant. The coal splits and predominantly subaqueous strata appear on the eastern side of the basin in the locality of the Glace Bay Syncline and the Coxheath Fault (Boehner and Giles 1986). During the Westphalian B/C interval when Morien Group sediments accumulated over an unconformable surface, relative relief between the topographic highs and lows would have been be significantly greater than during later periods. Any minor fluctuation in base level would cause water to back up in localities offering the least resistance. The synclines would be the most likely area for water bodies to accumulate. Were the synclines already formed prior to sediment accumulation in the MCI or was there simultaneous active tectonic subsidence during deposition? The lack of structural deformation within the South Bar strata suggest that there was little tectonic activity during deposition of the MCI. However, fault movement along the Coxheath Fault (Fig. 1.1) might help explain the rise of base level and subsequent marine incursion. A combination of deltaic basinal compaction, tectonic subsidence, and changes in sea-level is probably responsible for the sedimentation patterns in the MCI.

4.5 Interpretation

The South Bar Formation began with the deposition of a basal coarse-grained sand and gravel substratum above a mid-Carboniferous unconformity. The combination of fault-block subsidence along the Coxheath Fault, differential compaction of the coastal plain itself, and a change in base-level (possibly in response to a Gondwanan glacial event) caused the formation of a standing water body in the topographic low situated in the Glace Bay Syncline (Fig. 4.1). Coastal processes caused sediments to stockpile at the head of the bay mouth forming a sand barrier protecting the bay from wave and tidal influences. Minor deltaic processes caused infilling of the inner bay, generating stratal successions similar to coarsening-up packages observed in modern interdistributary embayments (Coleman and Prior 1980; Tye and Kosters 1986; Tye and Coleman 1989; see also Staub and Cohen 1978; Breyer and McCabe 1986; and Nemec 1993). Low quality paralic peat developed first on the inner bay perimeters. With continued sea-level rise, accommodation space on the distal braidplain increased, causing fresh water to back up (Kosters and Suter 1993). Conditions were favourable for the accumulation of high quality peat over the braidplain and low quality peat towards the basin center (Tye and Kosters 1986; Kosters and Suter 1993). During periods when peat accumulation kept pace with sedimentation, high quality peat extended over the salt marsh (Staub and Cohen 1978). A sea-level highstand followed increasing progradation and compaction rates in the basin. The development of thin coarsening-up bayfill deposits over the high quality peat (Mullins Seam) resulted during the highstand. Low quality peat formed on the bayfill tops when increased fluvial discharge seaward reduced fresh water recharge in the bay and allowed salinity to rise (Staub and Cohen 1978; Kosters and Suter 1993; Tye and Coleman 1989; Tye and Kosters 1986; and Coleman and Prior 1980). Following the transgressive highstand, a regression and lower baselevel saw the return of fluvial deposition in the more elevated localities at Victoria Mines. The topographically lower eastern localities experienced predominantly subaqueous deposition with periodic subaerial exposure resulting in the formation of a well-drained floodplain (Coleman 1966).

CHAPTER 5 ECONOMIC APPLICATIONS

5.1 Introduction

The Mullins coal seam is a potential economic unit. This chapter provides information on the lateral extent of the coal, seam thickness, orientation of the strata, coal quality, mining considerations, roof and floor rocks, and coal seam splitting. Section 5.5 provides a brief economic evaluation.

5.2 Seam Description

The lateral extent of the Mullins coal seam is 15.8 km extending from North Sydney to River Ryan (Fig. 5.1). Figure 1.2 shows the trace of the Mullins seam and the location of the NSDME, North Sydney, and Devco cores. Tables 5.1 and 5.2 show the seam thickness, the depth below sea-level, and the thickness of the coal splits for the New Waterford (NW) series and Devco (C) series cores (Fig 1.2). Table 5.3 shows the coal thickness from cores at North Sydney (Haites, 1942).

A generalized cross-section (Fig. 5.1) shows the localities of maximum and minimum thickness and the divisions of the coal seam (splits). The Sydney Mines area has thicknesses of coal ranging from 0.3 m minimum (core 1009) to a 1.86 m maximum in core 724 (Table 5.3) (Fig. 1.2). The thickest coal units occur inland from the coastal outcrop at Victoria Mines and extend

Table 5.1 The Mullins Coal data sheet from the NSDME cores. All units are in meters.

Hole #	Total	Coal Top	Coal Base	Seam Thick.	Total Thick.	Split
NW1	61.6	48.25 49.01	48.62 49.5	0.37 0.49	0.86	0.39
NW2	61.3	51.66 52.58	52.03 53.04	0.37 0.46	0.83	0.55
NW3	64.9	57.33 58.37	57.68 58.33	0.35 0.46	0.81	0.69
NW4	61.3	59.91 53.46	52.27 53.89	0.36 0.43	0.79	1.19
NW5	58.8	47.91 49.59	48.25 50.05	0.34 0.46	0.8	1.34
NW6	52.7	41.38 43.66	41.68 44.1	0.3 0.44	0.74	1.98
NW7	43.6	15.45 20.67	15.61 21.06	0.16 0.29	0.55	5.06
NW8	44.5	36.03	38.04	2.01	2.01	
NW9	39.6	30.48	32.54	2.06	2.06	
NW10	93.3	84.12	86.18	2.06	2.06	
NW11	28.0	20.06	22.19	2.13	2.13	
NW12	30.8	22.46	24.4	1.94	1.94	
NW13	21.8	14.37	16.45	2.08	2.08	
NW14	18.8	11.0	12.86	1.86	1.86	
NW15	44.0	5.5	7.45	1.95	1.95	
NW16	24.4	15.87	17.84	1.97	1.97	

Table 5.2 The Mullins Coal Data sheet for the Devco C- series cores. All units are in meters.

Core #	Total	Depth Top	Depth Base	Seam	Total Thick.	Split
C94	44.8	30.94	32.86	1.92	1.92	----
C95	20.4	12.73	14.33	1.60	1.60	----
C96	50.6	47.24	49.16	1.92	1.92	----
C97	26.5	21.56 22.25	22.10 23.50	0.54 1.25	1.79	0.15
C98	35.7	29.81	30.72	0.91	0.91	----
C99	14.3	11.58	12.50	0.92	0.92	----
C100	203.6	194.16	195.83	1.67	1.67	----
C101	290.0	285.66	286.88	1.22	1.22	----
C102	228.2	222.75	224.56	1.81	1.81	----
C106	138.7	127.71	129.00	1.29	1.29	----

Table 5.3 The Mullins coal data sheet for the North Sydney cores (Haites 1942).

Mine Report Number	**Thickness of the Coal**
1009 - 1944	0.30 m mud
1051 - 1945	0.73 m coal
721 - 1930	1.21 m coal
723 - 1930	1.82 m coal
724 - 1930	1.86 m coal

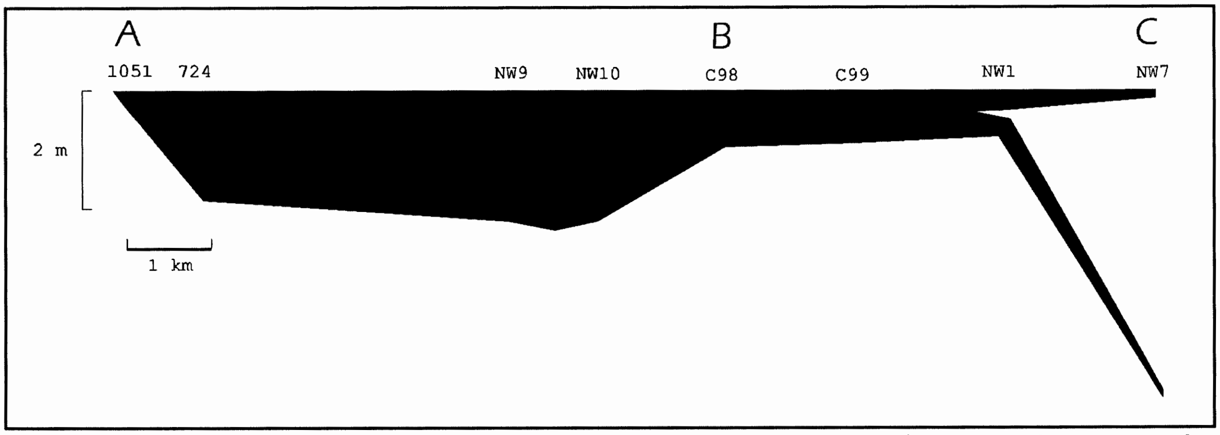

Figure 5.1 A cross section of the Mullins coal seam (Figure 1.2 shows the location of A, B, and C).

several kilometers towards River Ryan (Fig. 1.2). The coal in cores NW1 through NW7 becomes progressively thinner south-eastward and is not of economic grade (Fig. 1.2). Coal split thicknesses increase south-eastward to as much as 5.06 m (Core NW7, Figs. 1.2 and 5.1). The best potential economic coal site is 6 km east (inland) from Victoria Mines where the coal ranges from 1.92 m (C99) to 2.13 m (NW11)(Figs. 3.1, 1.2, and 5.1) thick averaging approximately 1.94 meters. Where the coal is thickest, the depth below the surface ranges from an 84 m maximum in core NW10 to as shallow as 5 m in core NW15 (Table 5.1). The Devco cores show decreasing thicknesses towards the NNE and River Ryan (Table 5.3).

The strata containing the MCI, measured at the coastal outcrop at Victoria Mines (Fig. 1.2), strike 270° and dip 20°. The structural deformation in the area is minor, with gentle NNE trending folds (Boehner and Giles 1986). The coal is thickest in the New Waterford Anticline area (Fig. 1.2) at a 43.6 m depth below the surface. The eastern extent of the basin, the Glace Bay

Syncline locality, contains the thinnest coal (Fig. 1.2).

5.3 Coal Quality

Very few petrographic data are available for the Mullins Coal Seam. Hacquebard and Donaldson (1969) analyzed 6 samples from the seam for sulphur and ash contents. The Mullins seam has an ash content of 11.06% and a sulphur content of 5.93%. The microlithotype classification (microscopic composition) of the Mullins is a spore-rich clarite of a telmatic reed-moor depositional environment (Section 2.2.4) (Hacquebard and Donaldson 1969). The rank of the coal is a high volatile bituminous A (Hacquebard and Donaldson 1969). The volatile matter content is 31%, the fixed carbon content is 69%, and the estimated calorific value is 14000 BTU/lb (32.6 MJ/kg)(Calder 1985).

5.4 Mining Considerations

5.4.1 Seat-earths or Paleosols

Seat-earth or poorly developed paleosols underlie most coals. The surface horizon directly below the coal seam is the working floor of a mining operation, and soft mudstone (paleosols) reduce machinery efficiency, destabilize support pillars, and contaminate the coal by increasing ash content

(Forgeron et al. 1986). The seat earths below the Mullins are relatively thin, usually less than 1 meter in thickness (Fig. 3.1), containing few quartz or pyrite crystals, and should not constitute a major problem. Below the seat earths are thick sandstone deposits (Fig. 3.1) which constitue a solid operational floor.

5.4.2 Paleo-Channels (Sandstone)

Channel sandstone locations are important to a mining operation. Channel scours or rolls commonly cut down into coal seams. The abundance of quartz and pyrite in these bodies can cause sparks when struck by coal-cutting equipment. If methane gas is present, an explosion may result where workings are underground. Water in the porous sandstones is also a problem as it greatly reduces the strength of roof and floor rocks, especially at lithological contacts (Forgeron et al. 1986). Directly below the base of the Mullins seam are thin seat earths. Above the coal seam the channel sandstones overlie 2-8 m coarsening-up packages (Fig. 3.1). Coarsening-up packages that grade from shale into sandstone cause few problems for underground mining operations (Horne et al. 1978). However, the channel sandstones are within 5-8 m of the coal where the seam is thickest (cores NW14-NW10).

5.4.3 Coal-Seam Splitting

Unstable conditions may result where minor coal horizons occur less than 2 m above the main seam. The fissile nature of these horizons reduce the strength of the roof rocks, especially when water is present (Forgeron et al. 1986). Cores NW14-NW11 have impure coal units, less than 0.75 m thick, within 3 m of the main seam (Fig. 3.1). The major splitting of the seam occurs south of River Ryan where the high percentage of shaly coal makes the coal uneconomic (Figs. 1.2 and 3.1).

5.5 Economic Evaluation

The Harbourside Mine at North Sydney operated from 1928-1932. Production of coal from the Mullins Seam peaked in 1932 at 15,641 tonnes with a total production of 48,446 tonnes over the four years of operation (Gregory 1978). Previous coal surveys of the Sydney Basin included the Mullins Seam. The Mullins is estimated to have a total accumulation of 91 million metric tonnes of coal (Hacquebard 1983). In 1979 the Mullins Coal, at Victoria Mines, was reported to have an average 1.9 meter thickness over a 1.52 km strike (Gillis 1979). A follow-up survey suggested that 500,000 tonnes of coal at a 10:1 waste rock to coal ratio could be mined from an open pit (Gillis 1981).

5.6 Summary

The Mullins coal has an average thickness of 1.94 m (Victoria Mines), extends SSE for 4.3 km, lies less than 50 meters below the surface where the coal is thickest, occurs with minor paleosols, and has a shallow dip. These factors make the Mullins extremely attractive for an open cast mining operation.

CHAPTER 6 CONCLUSION

6.1 Introduction

The purpose of this thesis is to provide an interpretation for the depositional environment for the Mullins Coal Seam and to provide information on its geometry for mining purposes. Drill cores and outcrop data provided the information to construct the basinal cross-section used to present and interpret the data. Figure 6.1 shows a general summary.

6.2 Depositional Environment

The Mullins Coal Interval contains ten facies that comprise four facies assemblages:

1. *Fluvial Channel*. Predominantly trough-cross bedded sandstone and conglomerate, interpreted as braided fluvial deposits.
2. *Bayfill*. Predominantly cross-laminated sandstone and laminated siltstone containing agglutinated foraminifera, interpreted as subaqueous, minor deltaic deposits formed in brackish bays.
3. *Coal*. High volatile bituminous A grade coal and impure shaly coal, interpreted as paralic peat deposits.
4. *Well-Drained Floodplain*. Predominantly red to mottled-red fine sandstone and siltstone, interpreted as well-drained floodplain deposits.

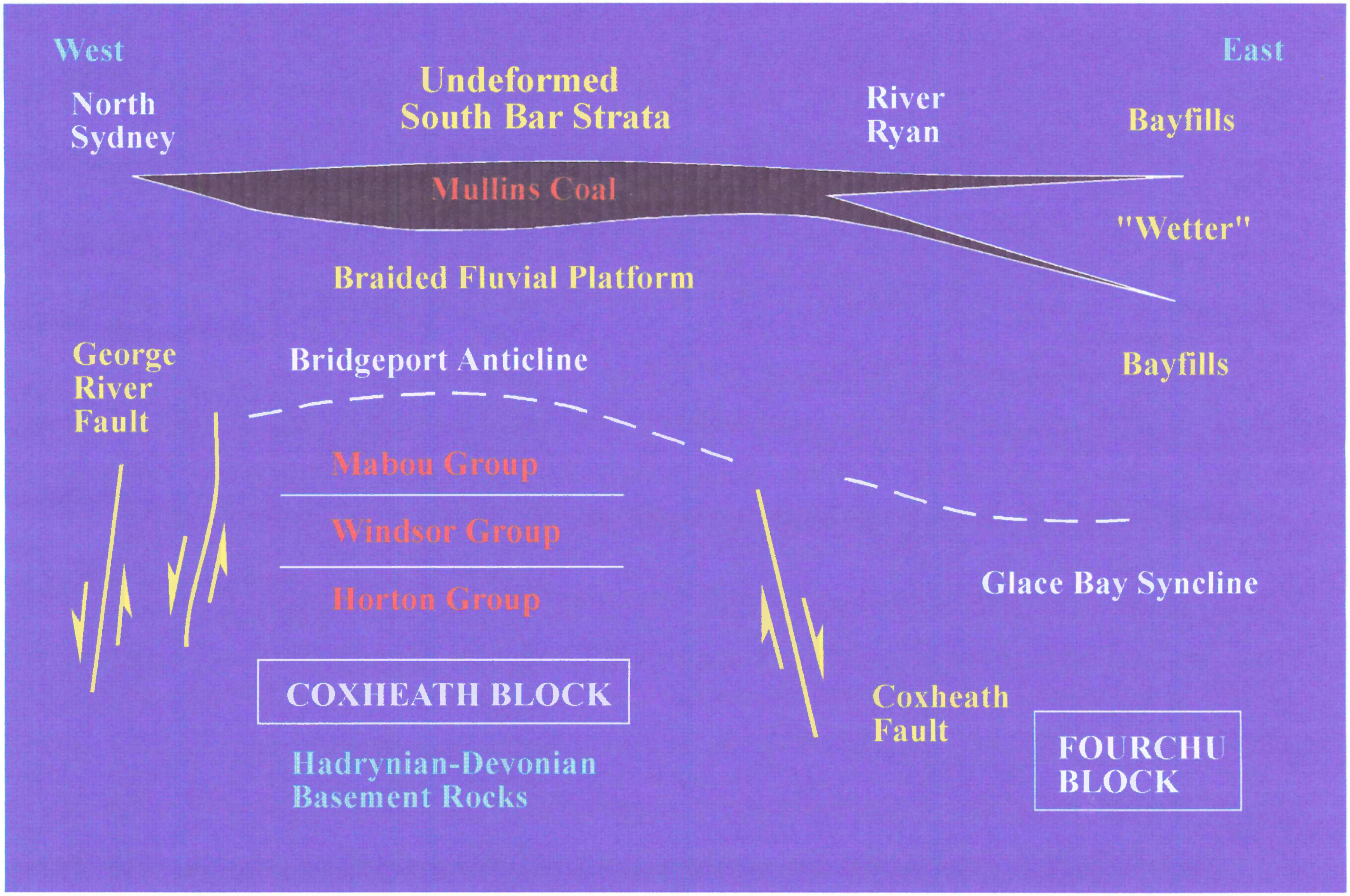

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Figure 6.1 A general summary of the geometry and the basinal setting of the MCI.

The depositional history was as follows: In Westphalian C times a significant rise in base level interrupted braided fluvial deposition prior to the accumulation of the Mullins Coal. Water backed up into topographic lows, forming an inner protected bay in the locality of the Glace Bay Syncline. High quality peat formed on a stable platform directly overlying thick braided, relatively noncompactible, fluvial sandstones. The major phase of peat accumulation probably corresponded to the near-maximum transgressive phase. During the subsequent sea-level highstand, brackish conditions led to the development of coarsening-up progradational packages capped with impure shaly coal. A regression followed and fluvial deposition recommenced over topographic highs situated on the New Waterford and Bridgeport anticlines, with some incision into the bayfills above the Mullins. Well-drained floodplains, with periodic subaerial exposure, developed in the topographic lows during lower baselevels. The thin coal horizons associated with the subaerial deposits formed during higher baselevels in the Glace Bay Syncline.

6.3 Coal Geometry

The Mullins coal seam extends from North Sydney to River Ryan and is a potentially economic unit. Coal thicknesses range from 0.56-2.13 m. The eastern portion of the seam splits and is uneconomic. The best potential coal extraction site is 3-5 km inland from the coastal outcrop at Victoria Mines where the coal has an average thickness of 1.94 m. The coal overlies fluvial sandstone and is thickest within 50 meters of the surface.

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APPENDIX A

A.1.1 Visual Logs

Description of the 16 NSDME drill cores included an accurate record of the organic, pedogenic, and sedimentological structures. Detailed notes were taken at the core storage facility in Stellarton, Nova Scotia. Visual logs were then prepared using computer assisted drawing software at Dalhousie University during the summer of 1993.

When the cores were extracted in 1978, by the NSDME, some of the shale and coal was not recovered. Therefore, the visual representation of the coal and impure shale in these visual logs may not be accurate. The correct thicknesses of the coal and splits , obtained from geophysical logs, are provided in Table 5.1. and figures 3.1 and 5.1.

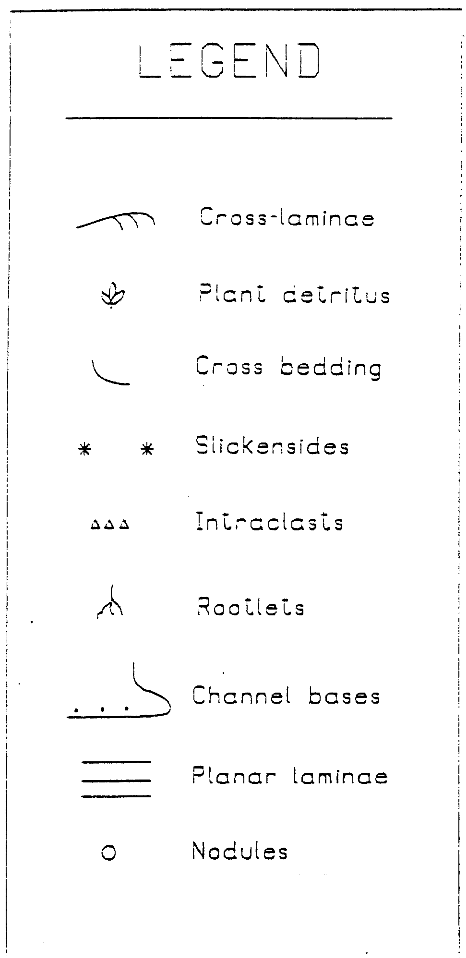
The numbers on the left of the cores represent the depth below surface taken from tags provided in the core boxes.

Core NW1 contains a legend of geological symbols that applies to all of the visual logs.

APPENDIX A

THE VISUAL LOGS FROM THE NSDME

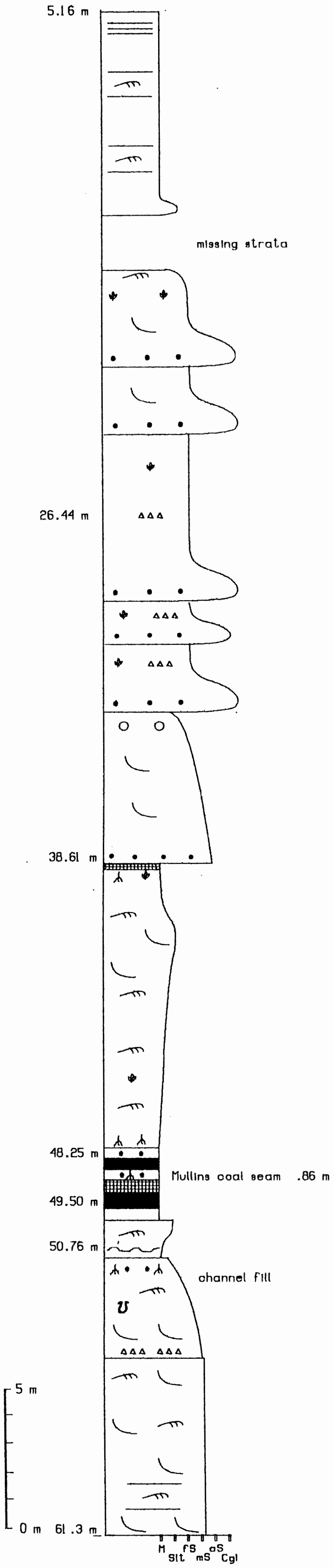
DRILL CORE NW1-16



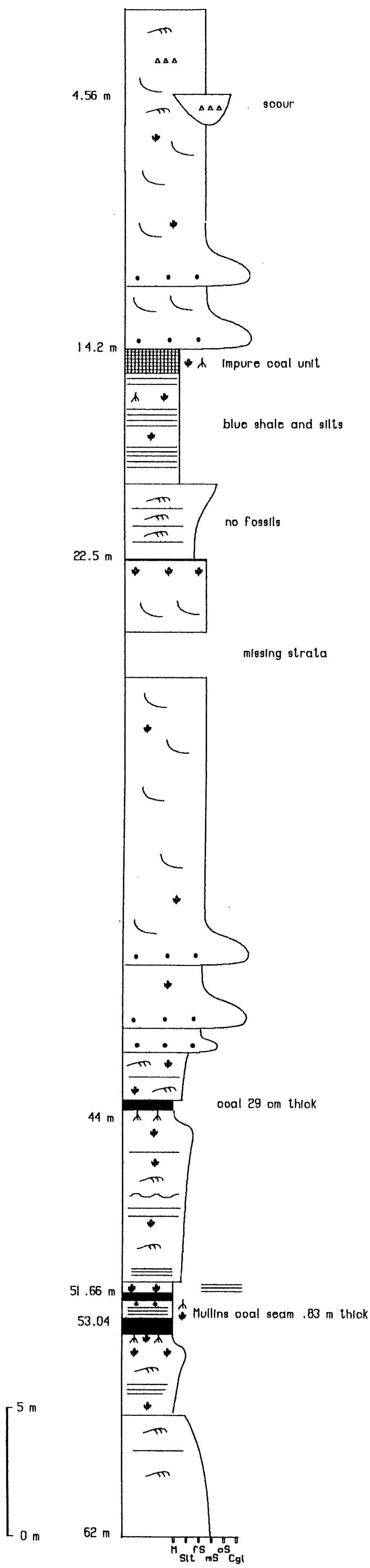
DRILL CORE NW1 FROM THE MULLINS SEAM

total thickness 61.6 m

elevation 8.4 m



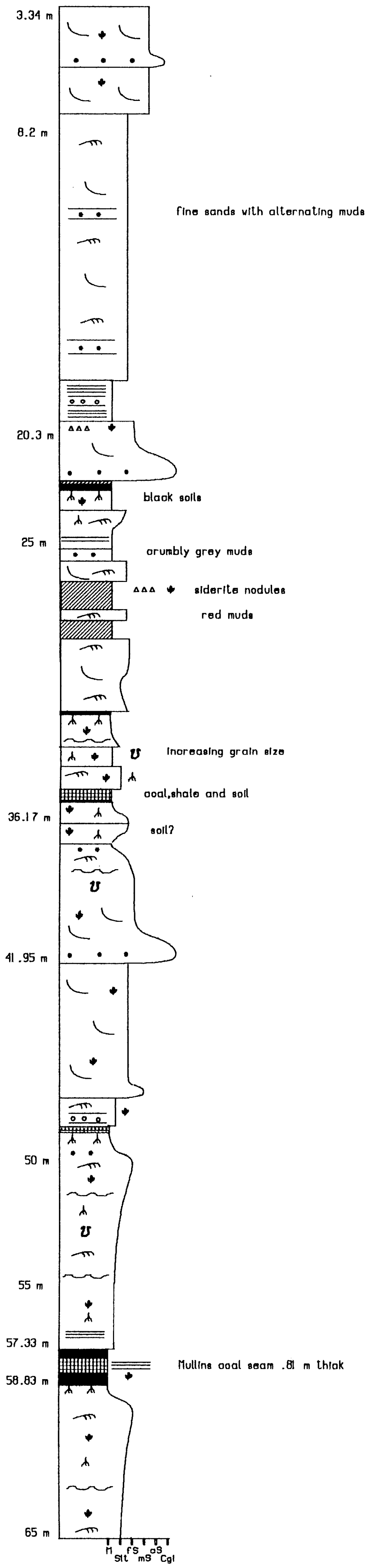
DRILL CORE NW2 FROM THE MULLINS SEAM
total thickness 61.3 m
elevation 12.7 m



DRILL CORE NW3 FROM THE MULLINS COAL SEAM

total thickness 64.9 m

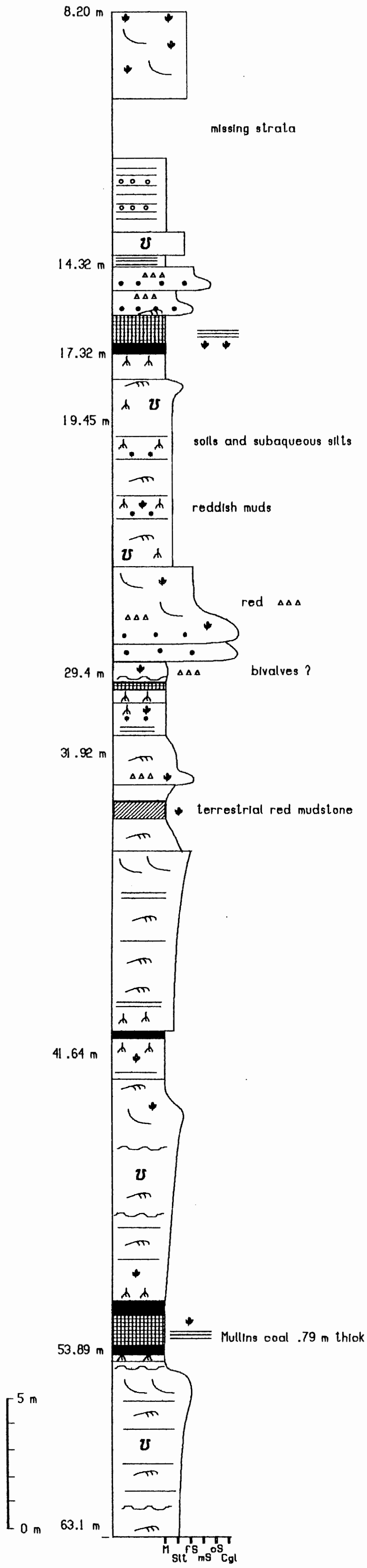
elevation 16.6 m



DRILL CORE NW4 FROM THE MULLINS SEAM

total thickness 61.3 m

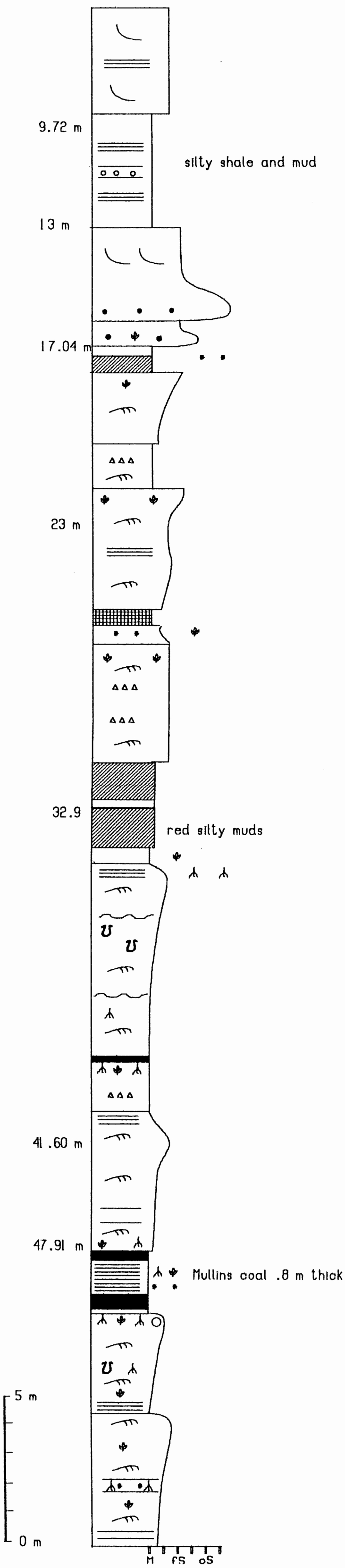
elevation 16.0 m



DRILL CORE NW5 FROM THE MULLINS SEAM

total thickness 58.8 m

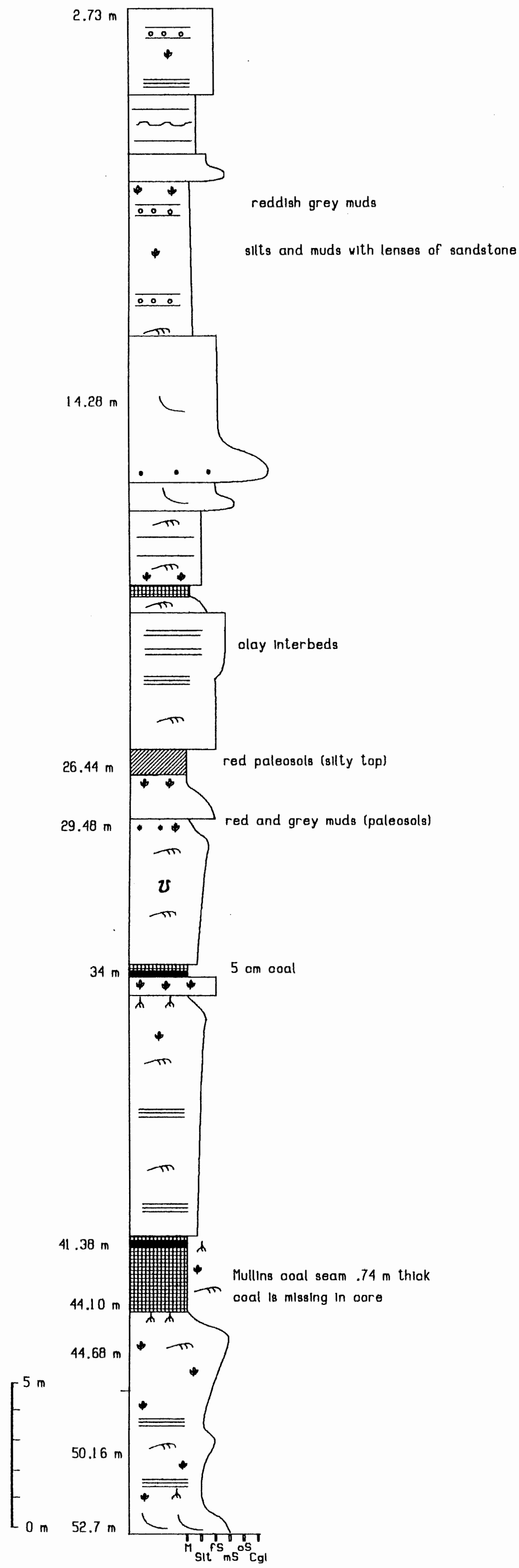
elevation 18.4 m



DRILL CORE NW6 FROM THE MULLINS SEAM

total thickness 52.7 m

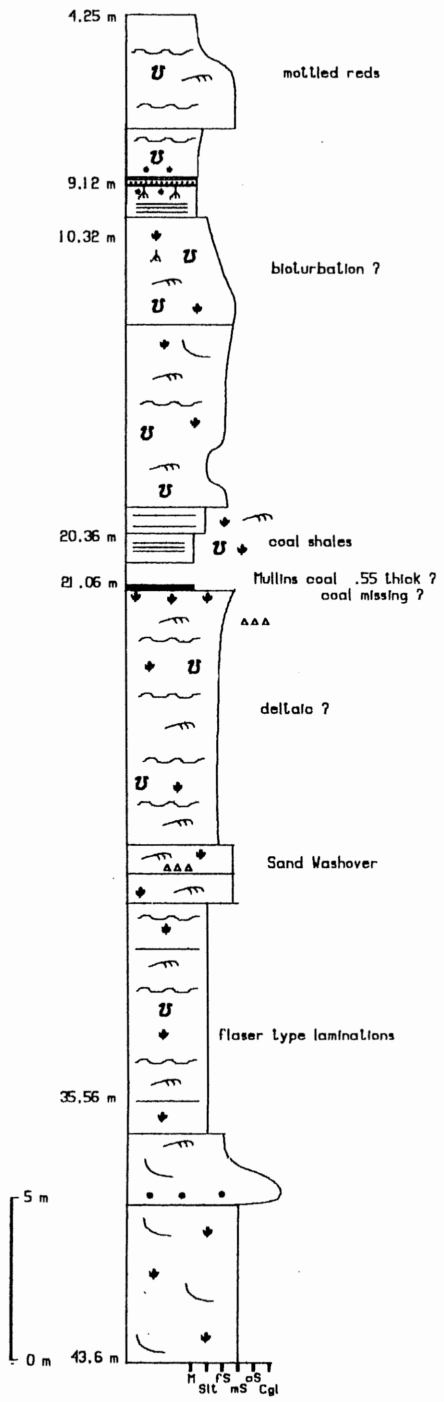
elevation 20.5 m



DRILL CORE NW7 FROM THE MULLINS COAL SEAM

total thickness 43.6 m

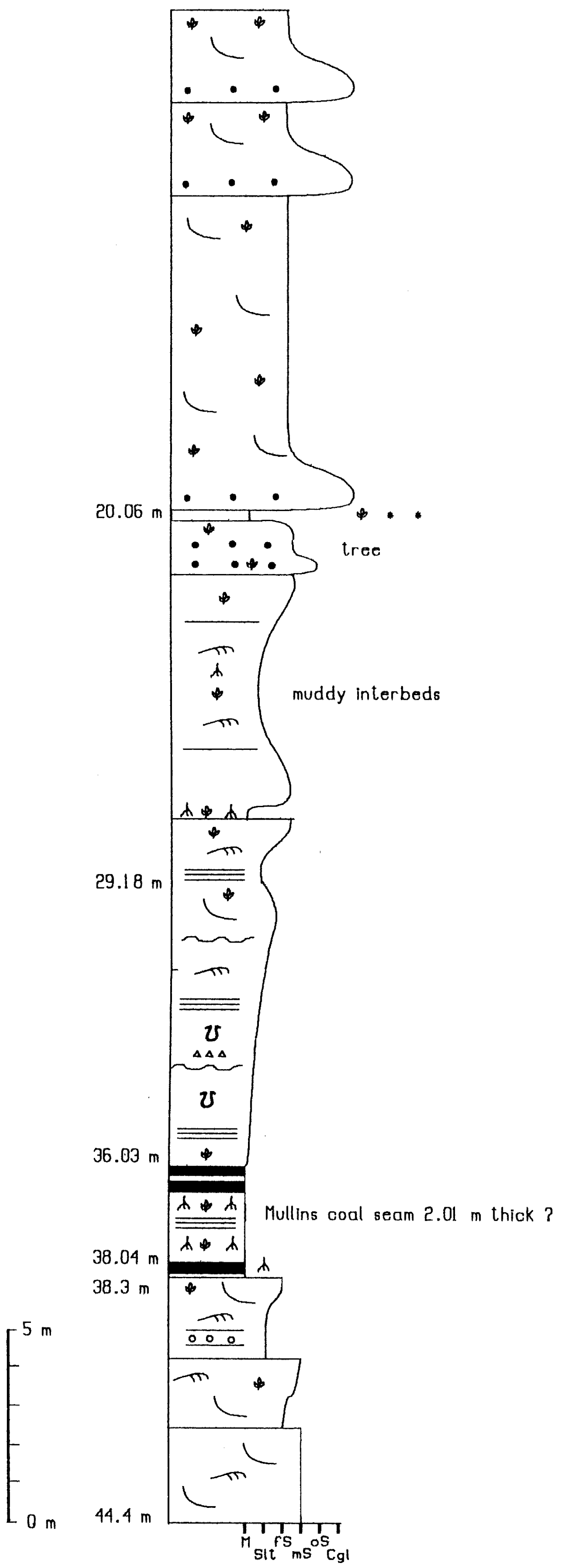
elevation 29.0 m



DRILL CORE NW8 FROM THE MULLINS SEAM

total thickness 44.5 m

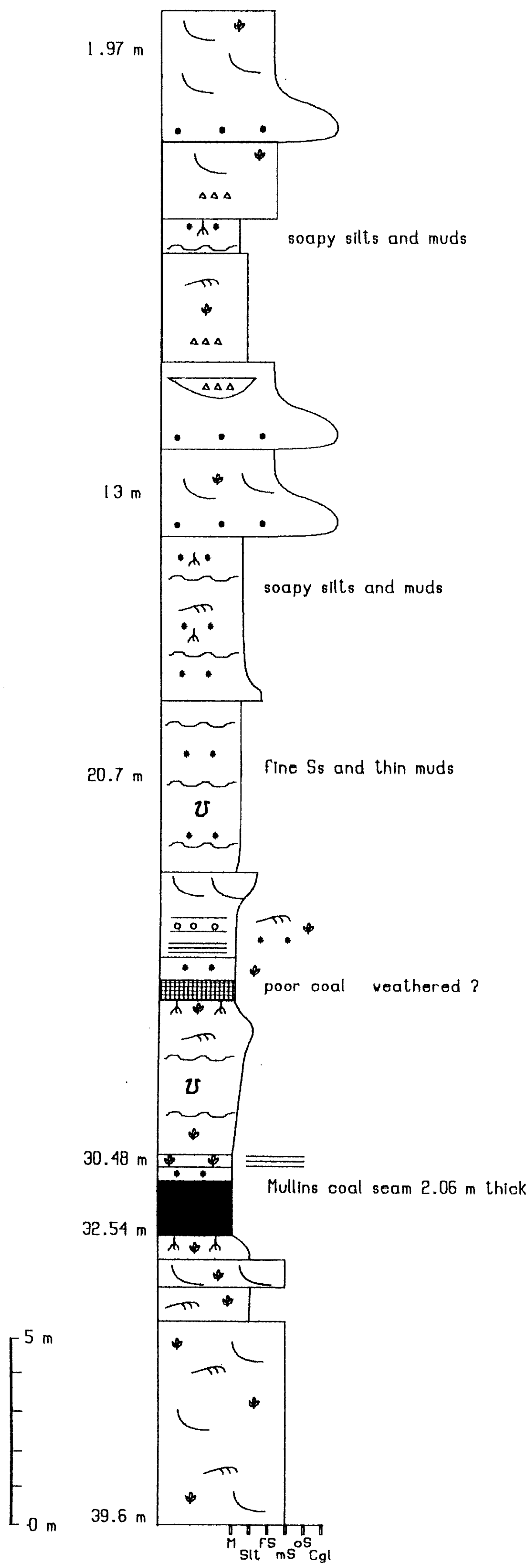
elevation 44.7 m



DRILL CORE NW9 MULLINS COAL SEAM

total thickness 39.6 m

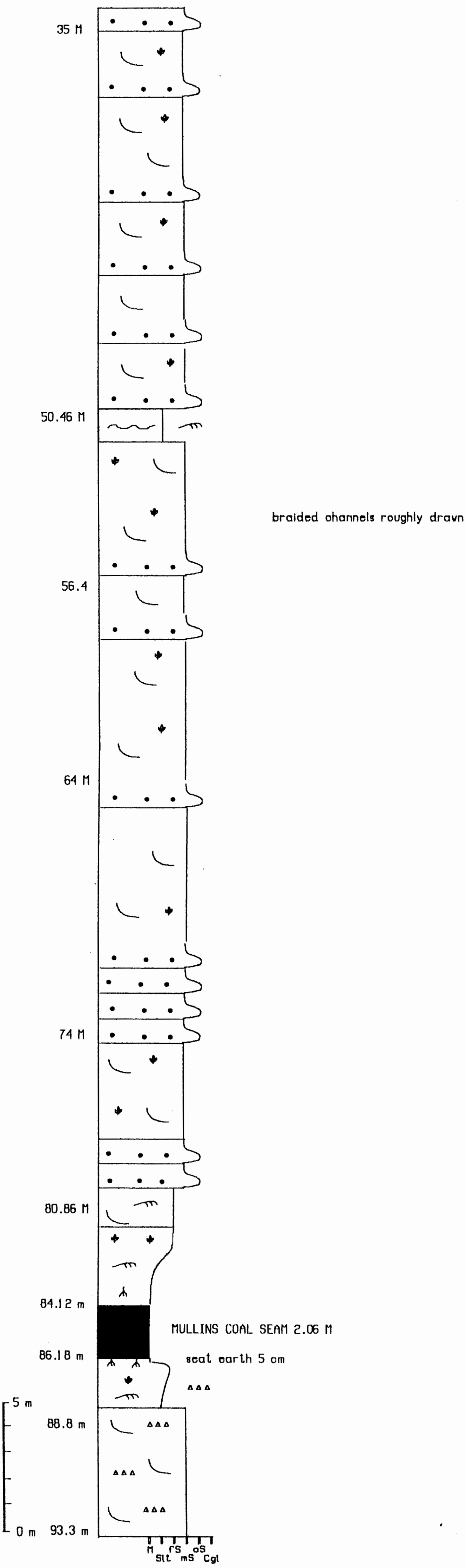
elevation 37.7 m



DRILL CORE NW10 FROM THE MULLINS SEAM

total thickness 93.3 m

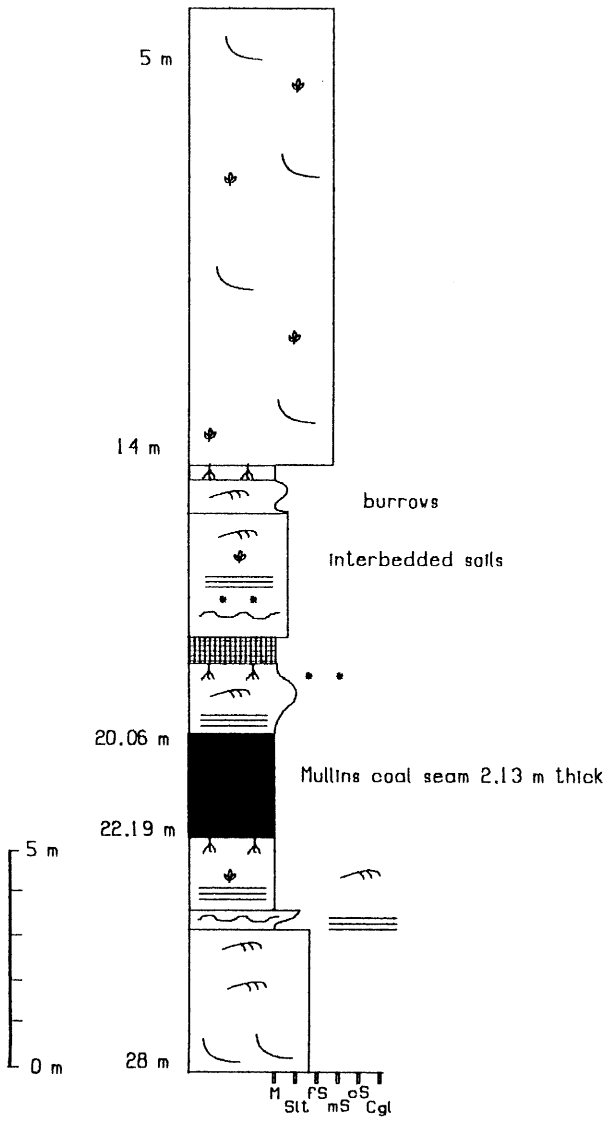
elevation 37.2 m



DRILL CORE NW11 FROM THE MULLINS SEAM

total thickness 28 m

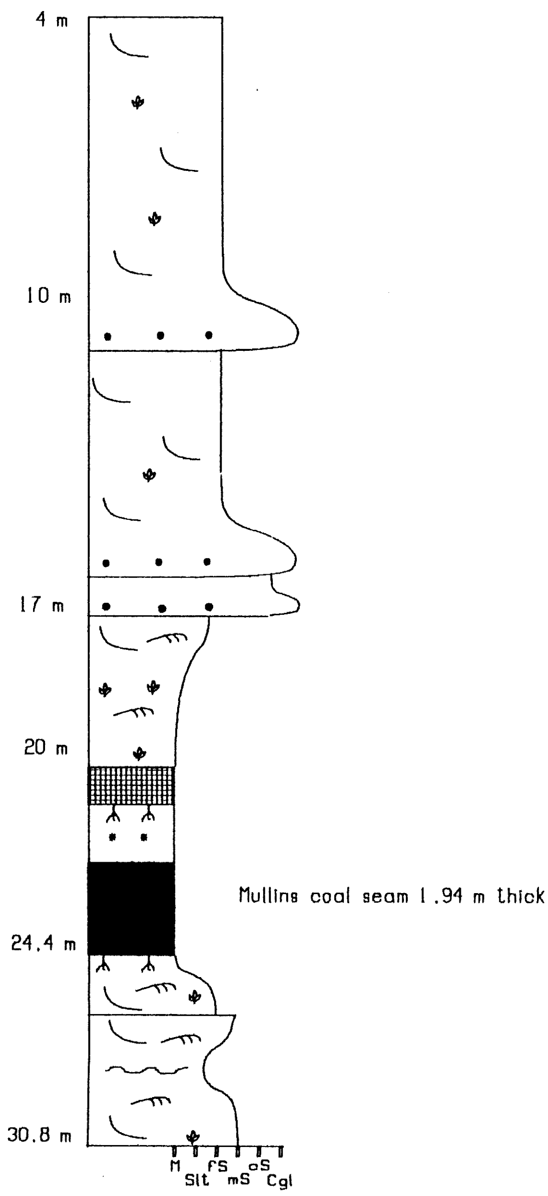
elevation 41.7 m



DRILL CORE NWI 2 FROM THE MULLINS SEAM

total thickness 30.8 m

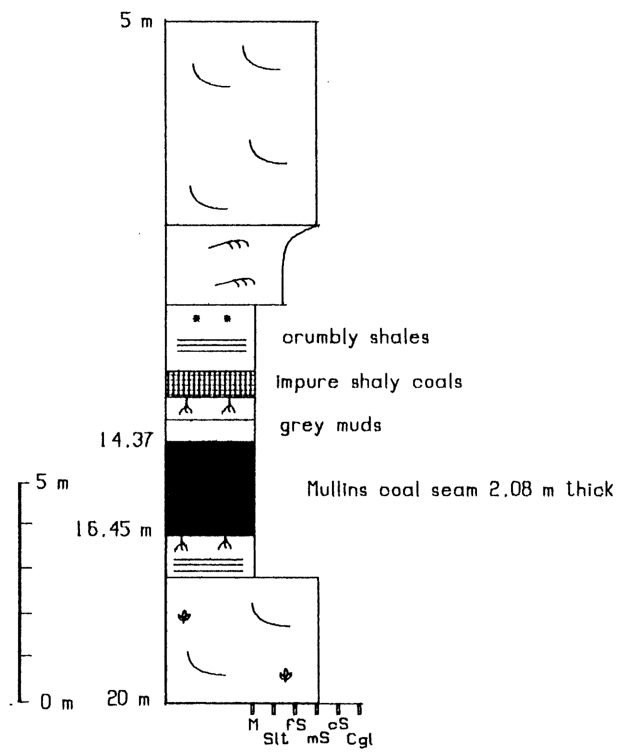
elevation 47.7 m



DRILL CORE NW13 FROM THE MULLINS COAL SEAM

total thickness 21.8 m

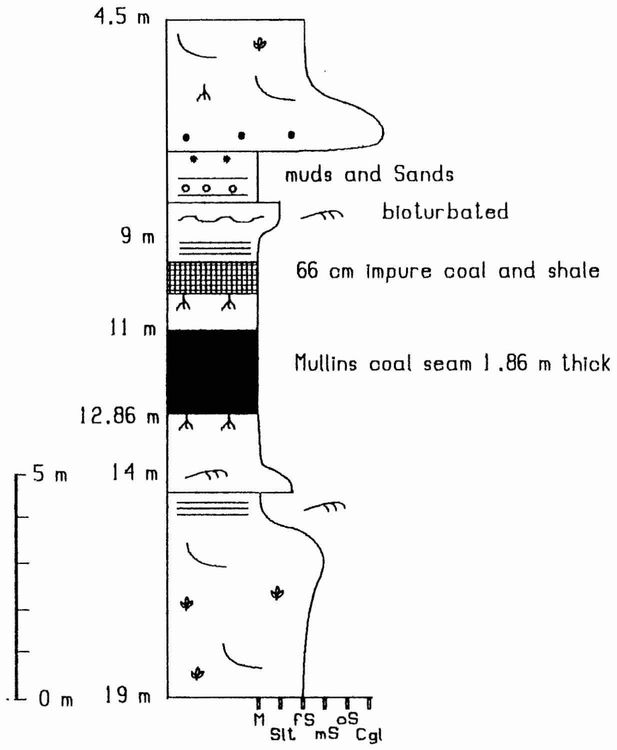
elelvation 43.6 m



DRILL CORE NW14 FROM THE MULLINS SEAM

total thickness 18.8 m

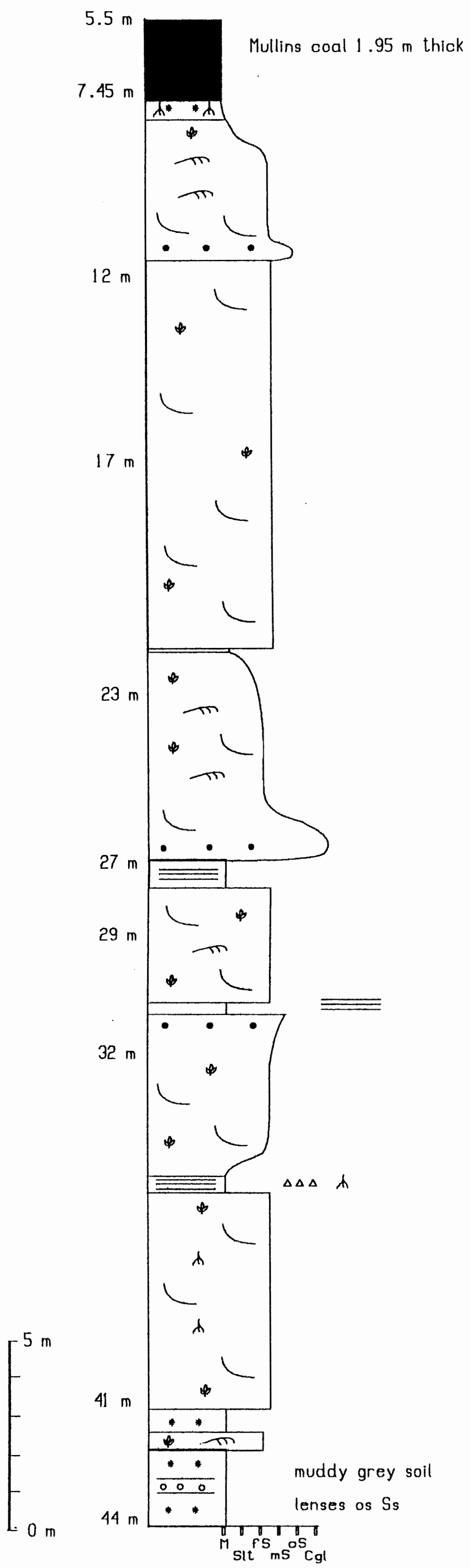
elevation 47.6 m



DRILL CORE NW15 FROM THE MULLINS SEAM

total thickness 44 m

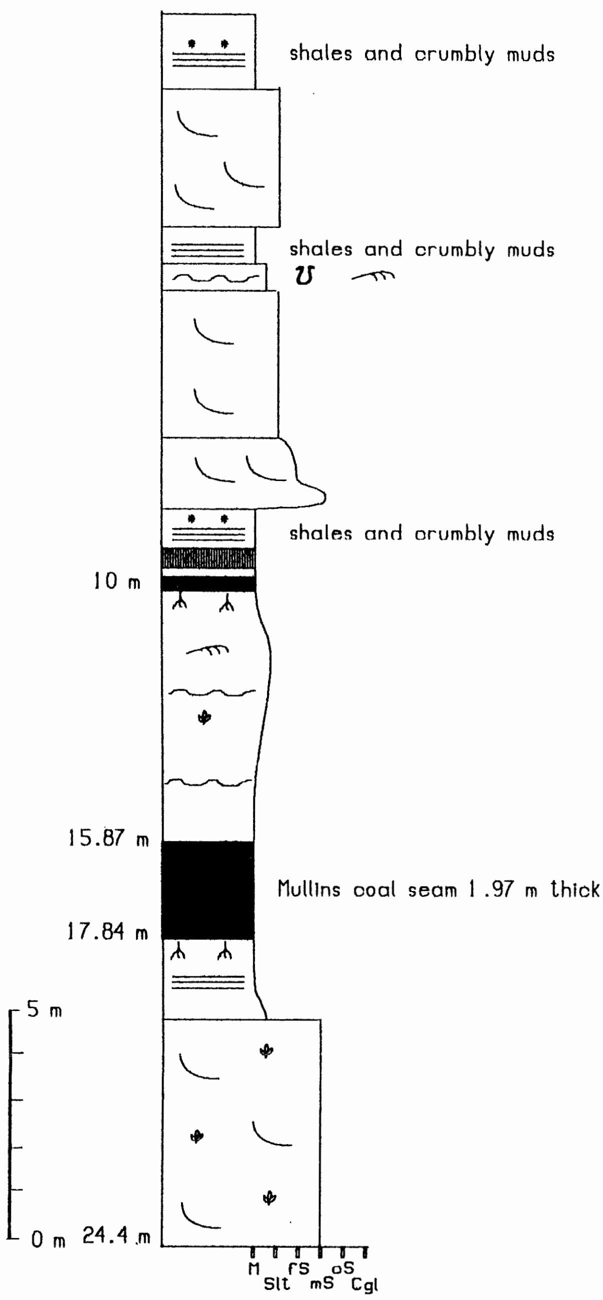
elevation 42.3 m



DRILL CORE NW16 FROM THE MULLINS SEAM

total thickness 24.4 m

elevation 47.8 m



APPENDIX B

B.1.1 Mudstone Petrography

Thin section: # NW5.7a

Facies: Red mudstone (Fmr)

Core and Depth: NW5, 17.5 m

Composition:	Ferruginized Clay Material	40%
	Quartz (Angular-subangular)	30%
	Calcareous Nodules	25%
	Mica	3%

Grainsize: Quartz ranges from 0.1-0.25 mm. Average 0.1-0.2 mm. Grain contacts are tangential.

Soil Components

Fabric: Isotropic microfabric; Sepic plasma fabric; inundulic

Cutans: Sesquans (Fe); Silans (SiO_2); Soluans ($CaCO_3$)

Glaebules: Concretions - 0.25 mm in size; center is quartz surrounded by calcareous rings with decreasing birefringence outwards.

Nodules - Hematite (Opaque); subangular; 0.25-0.3 mm

Roots: Filled with quartz grains and calcareous glaebules.

Classification: Oxidized paleosol; resembles a modern "Vertisol"

APPENDIX C FORAMINIFERAL RESULTS

Ten samples were taken from the NSDME cores and coastal outcrop for a purely qualitative assessment of the faunal distributions in the MCI. Dr Winton Wightman of Dalhousie University prepared and analyzed the samples. The following three pages contain his report of methods and results.

NEW WATERFORD CARBONIFEROUS AGGLUTINATED FORAMINIFERA

Background

Assemblages of agglutinated foraminifera and thecamoebians recently described from coal-bearing strata of the Sydney Basin have enabled marine influences to be recognized in strata formerly thought to be of freshwater origin (Wightman *et al.*, 1992, 1993a). Detailed study of the assemblages within the Bonar Cyclothem of the Sydney Mines Formation supported sedimentological and sequence-stratigraphic interpretation (Gibling and Wightman, in press). These protozoans have also been recognized in exploration wells in the Gulf of St. Lawrence (Wightman *et al.*, 1993b), demonstrating the widespread occurrence and practical application of agglutinated foraminifera in coal-bearing strata.

Methods

Ten samples from the New Waterford area were selected for foraminiferal analysis. Samples were of fine siltstone facies and were moderately to well indurated. A mortar and pestle was used to crush the rock pieces into smaller fragments for chemical treatment. An industrial surfactant (Fisher Versaclean) was used to process the samples using the method outlined in Wightman et al., (1993). Those of a carbonaceous, coaly, nature were also treated with sodium hypochlorite. Given the variability in degree of induration of the samples, it was hard to achieve standardized results. In an attempt to reduce any bias introduced through processing, all the specimens occurring within a given portion of processed residue were picking out. All residues were sieved into >63μm, >125μm, >250μm and >500μm size fractions, and each of these was systematically examined by sprinkling an even, light coating of the residue over a 5 cm x 10 cm picking tray. Preservation difficulties of the Carboniferous agglutinated foraminifera, and some of the observational techniques used to recognize them are discussed in Wightman *et al.*, (1992, 1993).

Results

The results for each sample are outlined below together with possible interpretations.

Sample 2.1.

Ammobaculites (20, may include poorly preserved *Ammotium*), *Trochammina* (28), moderately preserved, agglutinated from medium silt grains. Interpreted as middle to ?lower estuarine.

Sample 2.2

Trochammina (8) - one specimen is well preserved and shows coil and chambers. *Ammobaculites* (3). Hard to assign to an environment other than "estuarine" -these could have been reworked/transported.

Sample 2.6

A few specimens of *Trochammina* (5) and *Ammotium* (5) recovered from the 63-125μm size fraction. Specimens were agglutinated from fine silt, poorly preserved. A few (5) pyritized spheres, possibly (?) thecamoebians, were found in the 45-63μm size fraction. The spheres were too small and poorly preserved to be firmly identified under the binocular microscope. Three fragments of tubes were also recovered, which may be representatives of the genus *Hyperammina*. The presence of foraminifera indicates marine influence, but there is not enough material to suggest any particular type of paleoenvironment. The specimens could easily have been transported in.

Sample 2.7

Ammobaculites (24) and *Trochammina* (16) recovered from the 125-250μm size residue. Poorly preserved, but identifiable. Tests constructed from medium silt grains. *Ammotium* may be present, but may have been grouped with *Ammobaculites* because of poor preservation. The "assemblage" is interpreted as middle to ?lower estuarine.

Sample 4.1a

Two specimens identified as *Trochammina* came from the 63-125 μm size residue. Three additional specimens were grouped with *Trochammina*, but were badly preserved and regarded as "questionable". Indicates marine influence. May have been transported.

Sample 7.2

Trochammina (7) and *Ammotium* (2). Difficult to interpret because of the low numbers. Indicates marine influence, but again, the specimens could have been transported in

Sample 7.43

Ammotium (5), *Ammobaculites* (20), *Trochammina* (23). A relatively "rich" assemblage of moderate preservation. Tests were agglutinated from medium silt and occurred in the 63-125μm residue. Interpreted as middle to ?lower estuarine.

Sample 15.03

Ammotium (3) *Ammobaculites* (23) *Trochammina* (22). Moderately preserved, tests made from medium silt, from 63-125μm residue. Similar to the assemblage in sample 7.43. Interpreted as middle-?lower estuarine.

Sample M.02

Possible specimens of *Ammobaculites* and *Trochammina* were picked out, but these are regarded as "questionable" i.e. it is possible that these are artifacts, and not foraminifera.

Sample M.03

Barren- no foraminifera observed.