UPPER PALEOZOIC ALLUVIAL PLAIN SEDIMENTATION IN THE MORIEN GROUP, EASTERN CAPE BRETON, NOVA SCOTIA

by

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Abstract

A section of upper Morien strata located near the western margin of the Sydney Basin was examined.

Three sub-assemblages of sedimentary facies were recognized:
1) Thick bedded sandstone characterized by a fining-up sequence with an erosional base containing mud filled channels and lateral accretion sets.
2) Coarsening-up mixed sandstones charcterized by coarsening up sequences and lenticular bedding, locally with upright plant fossils. 3) Coal-mixed fines chacterized by coal seams, mudstones and thin sandstones.

Deposition of the sub-assemblages occurred in the channels, levees and floodplain, respectively, of the alluvial plain of a meandering river. Paleocurrent dada and petrology of mudstones and sandstones suggest a metamorphic source area to the southwest of the basin with some input from local basement highs.

The abundant fossil trunks of Lepidodendron grew on the levees and floodplain and were preserved by infilling with sediment and by petrifaction by calcite.

Coal seams in the section are laterally persistent, but are thin and of poor quality.

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List of Figures and Tables

Chapter 1 Introduction

The strata of the Sydney Basin, particularly those of the upper Morien Group, have been the basic cause of industrial and social development in northeastern Cape Breton. The coal deposits have been regularly exploited since the early 1700's, although systematic mining did not begin until the 1820's (Muise, 1982). With the mines came mine workers from the surrounding countryside and abroad. The work force was transient in the early years, but with the establishment of the General Mining Association in 1827 a more permanent work force was established. The combination of Cape Breton coal and iron ore from Belle Isle, Newfoundland, brought the steel industry to Cape Breton, increasing industrialization. Around these labour-intensive industries grew a labour-oriented society, with a sense of solidarity unmatched by any other in the region.

The coal deposits are found in the Morien Group, which underlies approximately 330 square kilometers of coastal lowland in northeastern Cape Breton (Bell and Goranson, 1938 a,b and c).

In this study a short section of strata within the upper Morien Group is examined. The section lies on the Great Bras d'Or coast of Boularderie Island at approximately 46°18' N latitude and 60°21' longitude (Fig. 1). The nearest community is the village of Big Bras d'Or, 6 kilometers to the southwest. The city of Sydney is about 30 kilometers to the east. The section can be reached by following Highway 105 from Sydney or Port Hawksbury to exit 14 (near Boularderie East), taking the road to Big Bras d'Or, and then going northeast along the Black Rock Road that follows the shore for about 6 kilometers. Take the private road that goes to Table Head, and climb down the cliffs just south of the Head. Tides must be checked as much of the section is inaccessible at high tide.

The purpose of this study is to examine the section in detail, and from field and petrographic data, to determine the environment of deposition. Petrographic data, mudstone mineralogy and available paleocurrent studies are used to

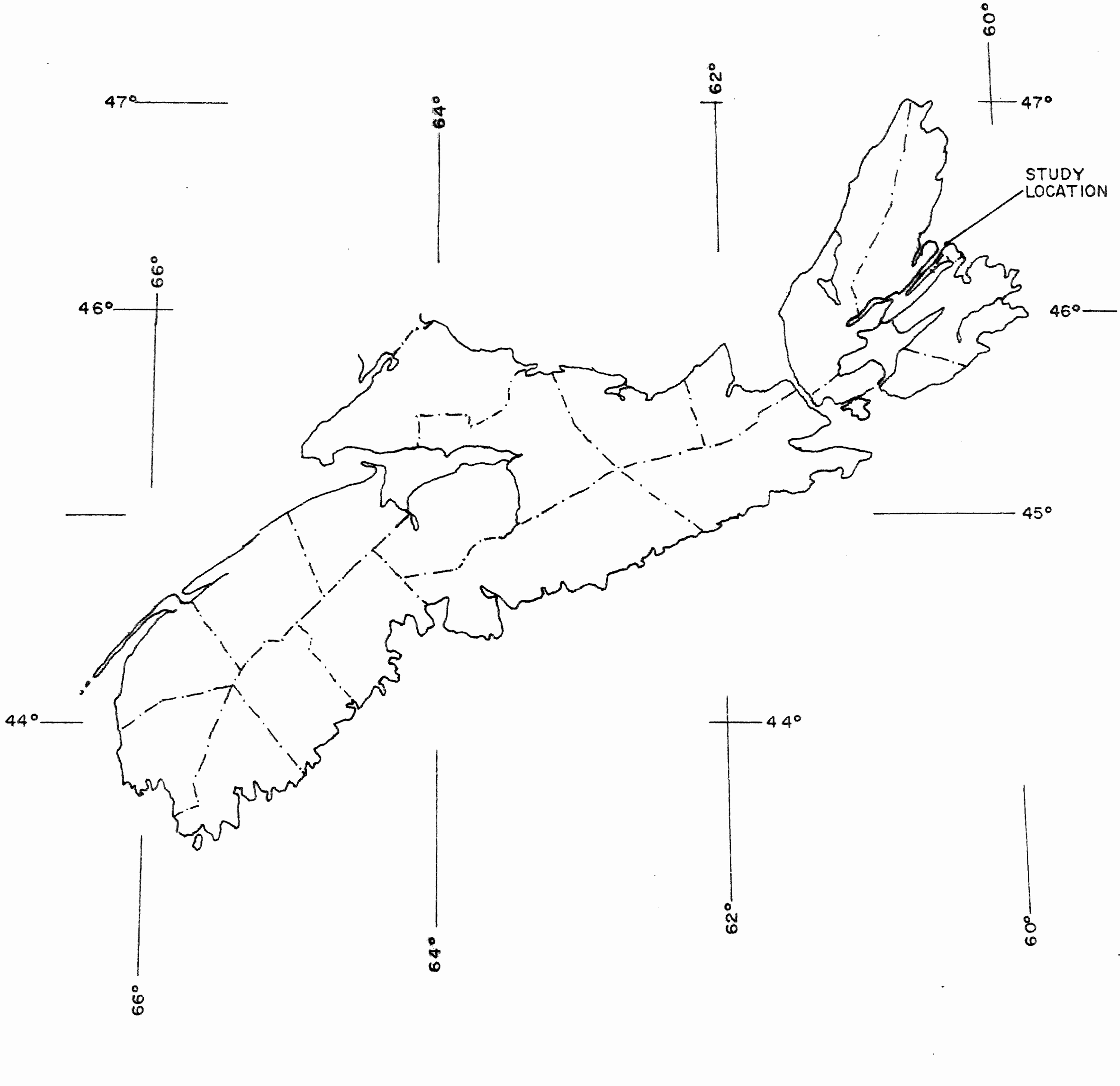


FIGURE I
Map of Nova Scotia, showing study location.

investigate the provenance of the clastic material. As the section is remarkable for its abundance of upright fossil trees, these are examined and their mode of preservation investigated.

Chapter 2 Geologic Setting

Regional Setting

The Sydney Basin is one of several Carboniferous basins in the Maritimes which formed in grabens and down flexures associated with extensional tectonism that started in the Early Devonian and operated until Mid Pennsylvanian time (Belt, 1968). These basins, collectively known as the Fundy Rift Zone, received sediments throughout the period of active tectonism and on until Early Permian time. The stratigraphic succession within these basins record most of this period. Local unconformities and disconformities reflect tectonic activity, and although the basins are broadly similar, each has a unique geologic history.

Sedimentation within the Fundy Rift Zone (Figure 2) began with the deposition of Horton Group sediments on eroded pre-Carboniferous basement. These strata consist of coarse conglomerates of local derivation near fault-bounded basin margins, and sandstones and shales away from the margins. Locally these strata contain basaltic to rhyolitic volcanics. Horton Group strata range in age from Tournaisian to Viséan (Kelly, 1967). The overlying Windsor Group records the only period of marine sedimentation in the Carboniferous. Throughout Viséan time (Kelly, 1967) there were several marine transgressions that deposited carbonates and evaporites interbedded with clastics shed from basin margins. Windsor Group carbonate units commonly can be correlated from basin to basin (for example the basal Macumber Formation of Cays River has a time and lithological equivalent in the Sydney Basin (Giles, 1983)) and thus make good stratigraphic markers.

After the last marine regression, continental sedimentation resumed with the sandstones and shales of the Canso Group. Fossils indicate ages of late Viséan to Westphalian A. The Riversdale, Cumberland and Pictou Groups are continental sandstones and shales of Westphalian to Permian age.

FIGURE 2

General Stratigrapy of Maritime Carboniferous Basins

P - present in Sydney Basin

Period	Epoch	Age	Stage	Group	Lithology
PERMIAN	Early Permian			Pictou	Continental sandstones and shales P
CARBONIFEROUS	Pennsylvanian	Stephanian		Pictou	
	Pennsylvanian	Westphalian	D C	Pictou	
	Pennsylvanian	Westphalian	B	Cumberland	Continental sandstones & shales
	Pennsylvanian	Westphalian	A	Riversdale	Continental sandstones & shales
	Pennsylvanian / Late Mississippian	Namurian		Canso	Non-marine shales, sandstones locally conglomerates P
	Late Mississippian	Viséan	Late Middle Early	Windsor	Marine limestones, evaporites P Local sandstones, conglomerates
	Early Mississippian	Tournaisian		Horton	P Continental conglomerates, sandstones and shales Local volcanics
DEVONIAN	Late Devonian			Horton	

Local Setting

The Sydney Basin is a fault-bounded synclinorium with three major synclines and two intervening arches (Giles, 1983). The basin is thought to have attained its major structural characteristics by Viséan time, and post-Carboniferous movement along the major fault boundaries resulted in the present configuration (Figure 3)(Giles, 1983).

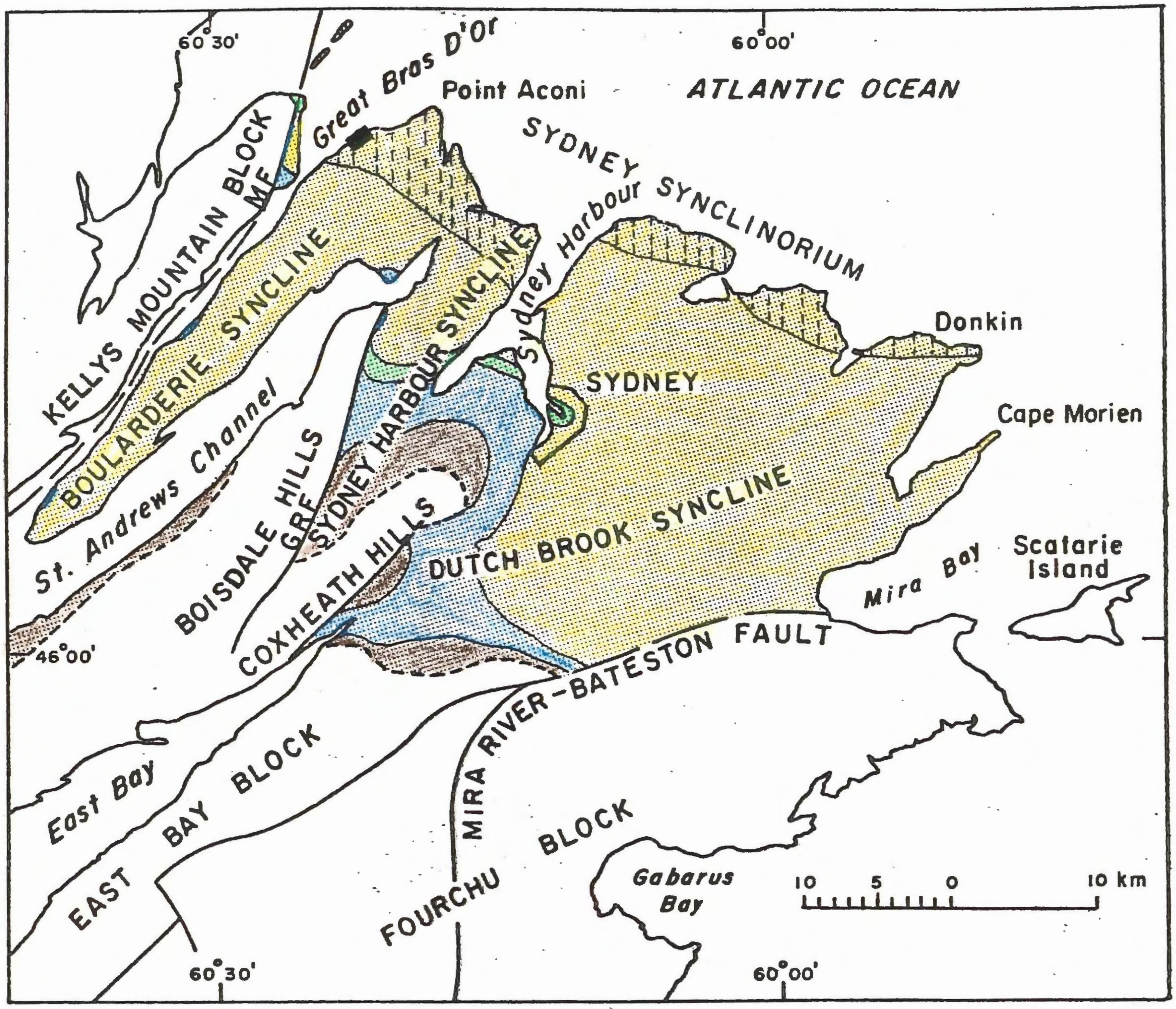
The basal unit within the Sydney Basin rests with a major unconformity on pre-Carboniferous basement. Sedimentation was continuous from Tournaisian through early Namurian time. Sedimentation resumed after a major hiatus (early Namurian to Westphalian B) in late Westphalian B time and continued into Permian time. The stratigraphy and general stratigraphic relationships within the Sydney Basin are shown in Figure 4. A description of the major units is as follows:

The Grantmire Formation

The Grantmire Formation is "...that succession of brick-red to maroon conglomerate, sandstone and shale extending from the major pre-Carboniferous unconformity to the base of the Macumber (or Gays River) Formation of the Windsor Group" (Giles, 1983, p.61). As described, it is a fairly typical "Horton Group" formation. It is coarse-grained, with angular clasts and poor sorting near basement highs, and fines distally. Giles tentatively attributes the origin of the Grantmire Formation to alluvial fan deposition.

The Windsor Group

The Windsor Group within the Sydney Basin consists of intercalated marine limestones, dolostones and evaporites, and coarse continental clastics. It conformably overlies the Grantmire Formation and locally onlaps onto pre-Carboniferous basement. The top of the Windsor Group is the top of the E_1 limestone member (Giles and Boehner, 1982). Evaporites occur in the lower



Morien Group (lower, upper)

Point Edward Formation

Windsor Group

Grantmire Formation

Pre-Carboniferous rocks

study location

MF Mountain Fault

GRF George River Fault

Figure 3 General geological setting of the Sydney Basin. (adapted from Giles, 1982)

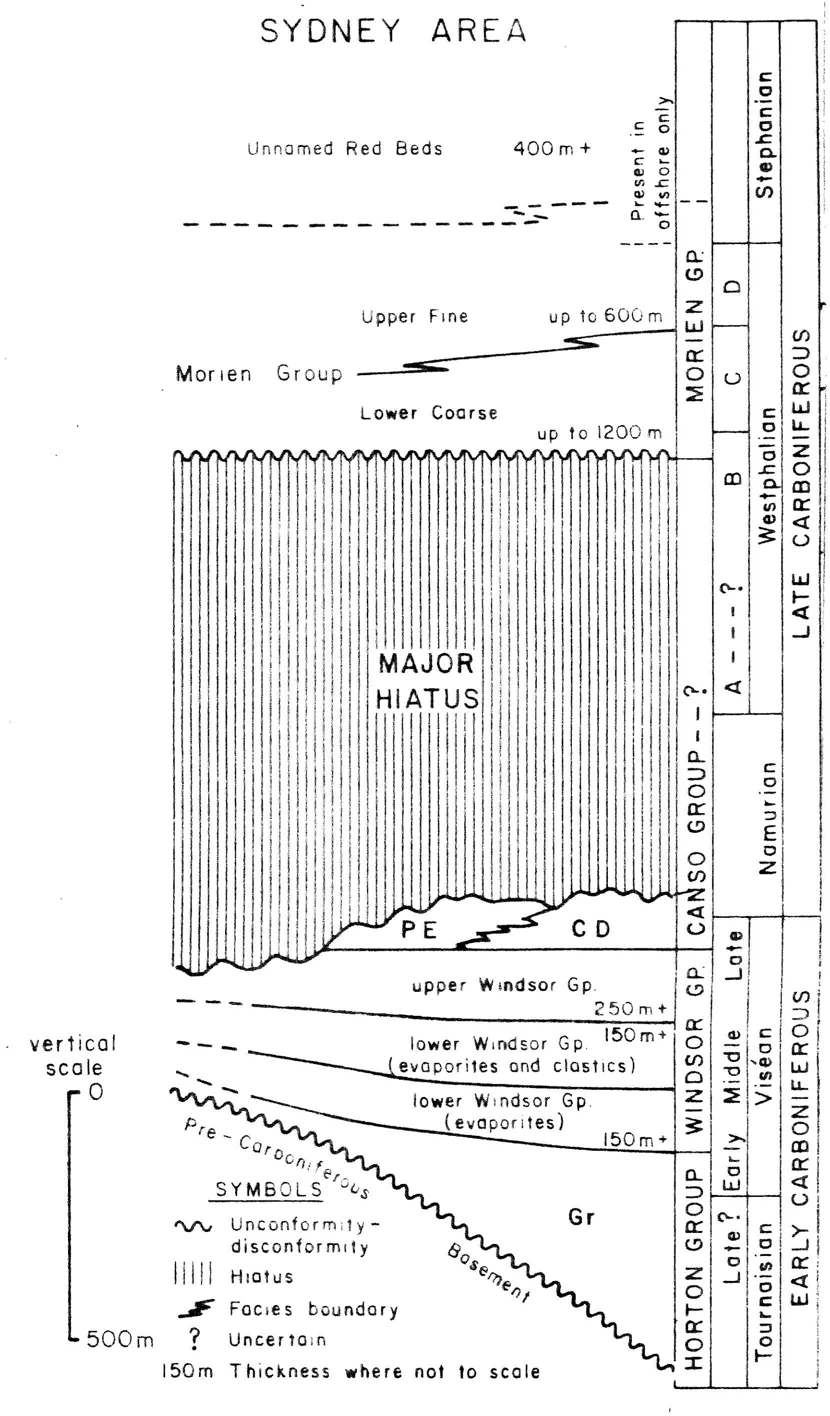


FIGURE 4

Stratigraphic relationships within the Sydney Basin. (Boehner, 1983)

Windsor but their extent is unknown, and they are generally considered to be much less abundant than clastic or carbonate lithologies. The environment of deposition was largely shallow marine.

The Point Edward Formation

The Point Edward Formation consists of grey and red shales interbedded with stromatolitic limestones, and is probably of lacustrine origin (Giles, 1983). The grey facies was formerly considered a separate unit, the Cape Dauphin Formation, but studies of its distribution (Giles, 1983) show the Cape Dauphin to be laterally equivalent with, and transitional into the Point Edward Formation. The basal contact of this unit is conformable, locally disconformable, with the top of the Windsor Group. The upper contact is the major regional unconformity that marks the base of the Morien Group.

The Morien Group

The Morien Group is the local name for the Pictou Group in the Sydney basin. It is made up of a sequence of continental sandstones and shales of Westphalian C and D to Stephanian age (Giles, 1983). Three biostratigraphic and two lithostratigraphic units have been recognized (Table 1). The lower Morien strata unconformably overlie strata of the Point Edward Formation and uppermost Windsor. Trough cross-stratified, medium to thick bedded sandstones predominate, with minor discontinuous mudstones, conglomerates and coals. The upper boundary, marked by the first appearance of thick, laterally persistent mudstones, roughly parallels the

timestratigraphic	biostratigraphic		lithostratigraphic
	Hayes, Bell and Goranson, 1938	Barss and Hacquebard 1967	Rust *et al*, 1983
Westphalian D	*Ptychocarpus unitus* zone	*Thymospora* zone C	upper Morien
Westphalian C	*Linopteris obliqua* zone	*Torispora* zone B	lower Morien
	Lonchopteris zone	*Vestispora* zone A	

TABLE I

Stratigraphic units within the Morien Group
(adapted from Dilles and Rust, 1983)

boundary between the Linopteris obliqua zone and the Ptychocarpus unitus zone in the west and central parts of the basin (Rust et al., 1983). In the eastern part of the basin, the boundary is below this division, and is thus diachronous. The upper Morien extends from this diachronous boundary to an as yet undefined limit (Giles, 1983). It comprises the Alternating Facies assemblage of Rust et al.(1983), consisting of shales, silty shales, coal and sandstone. The coals attain thicknesses of several meters and are mined in the coastal areas and offshore. Dilles and Rust (1983) and Rust et al. (1983) have outlined the depositional environments of the Morien Group and attribute its deposition to sedimentation on an alluvial plain which progressively evolved from a braided (lower Morien) to a meandering river plain (upper Morien). Paleocurrent measurements reported by Duff et al. (1982) and Rust et al. (1983) show a northeast mean paleocurrent direction with deflections around basement highs (Figure 5).

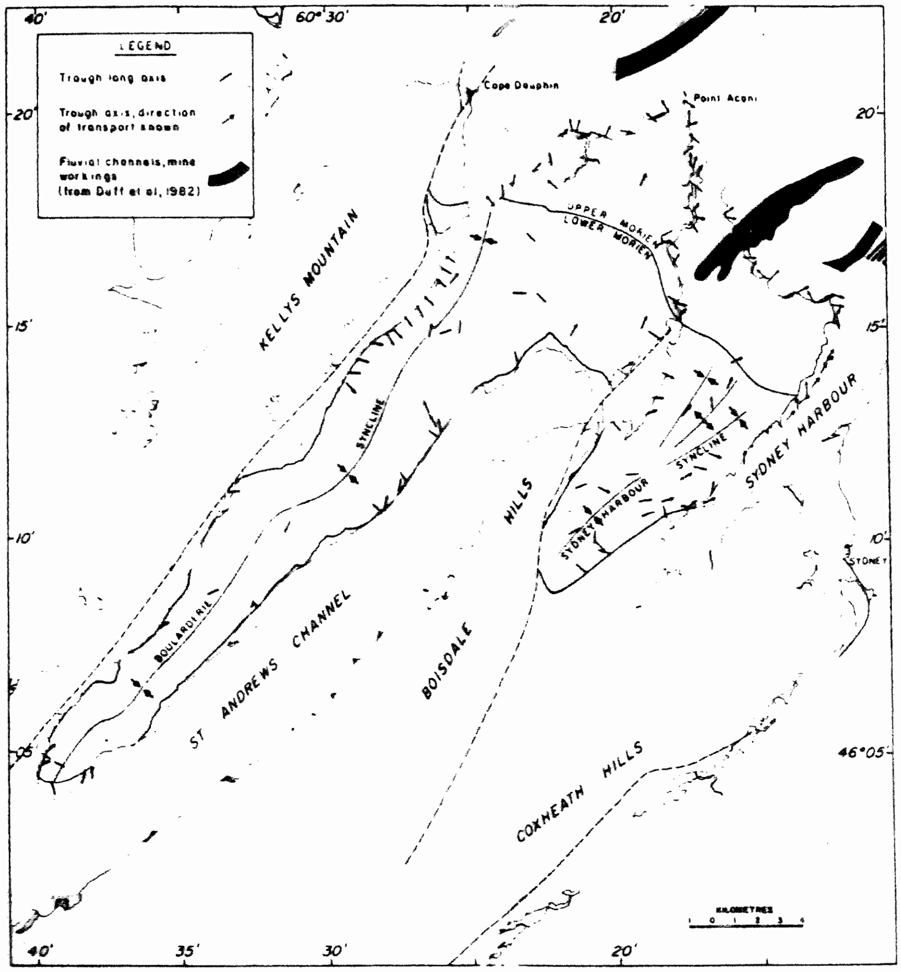


Figure 5: Sediment dispersal patterns in the northwestern part of the Sydney Basin (Giles, 1983)

Chapter 3 The Measured Section

Methods

The strata were measured using a 3 meter rod graduated in 10 centimeter intervals. Unit boundaries were defined where the lithology or style of sedimentation changed abruptly, or in the middle of gradational zones. Attitudes of bedding and sedimentary structures were measured with a Brunton pocket transit. A detailed log of the section is shown in Figure 6, and a description of the section is given below.

Facies Types

Nine facies types were recognized in the section. The types, following Miall's (1978) classification scheme, are as follows:

Gm: Massive pebble to granule conglomerate. This facies type is present only as thin (up to 10 centimeter) lags at the base of channels and large scours. Clasts are mudstone intraclasts and siderite nodules. Large plant fragments and peat mats are common.

St: Trough cross-stratified sandstone. Grouped trough sets, up to 20 centimeters thick, or medium- to coarse-grained sandstone are locally interbedded with planar-laminated sandstone and massive sandstone. Two trough axes gave azimuths of 300° to 312°. Where sediment is coarse-grained, the troughs have lags of mudstone intraclasts, siderite nodules and plant debris. Discontinuous pinch- and - swell carbonate beds are locally present along bedding planes.

Sh: Horizontally stratified sandstone. Planar laminated, fine- to medium-grained sandstone commonly occurs interbedded with trough cross-stratified sandstone. Primary current lineation occurs locally, and two such lineations gave bearings of 165° and 135°.

Sr: Ripple cross-laminated sandstone. This facies is fine-grained and commonly occurs with massive, bioturbated fine-

LEGEND

LITHOLOGY

Symbol	Meaning
	coal
mst	mudstone
fsst	fine grained sandstone
msst	medium grained sandstone
csst	coarse grained sandstone

UNIT CONTACTS

- abrupt
- gradational
- wavy

SEDIMENTARY STRUCTURES

- parallel lamination
- ripples
- cross lamination
- trough cross bedding
- scour and fill
- mud filled channel
- channel with epsilon cross beds
- sandy lens, muddy lens

COLOR

Symbol	Meaning
d	dark grey
r	red
g	green
r/g	red and green, mottled
y	yellow grey

note: color green grey unless indicated

OTHER

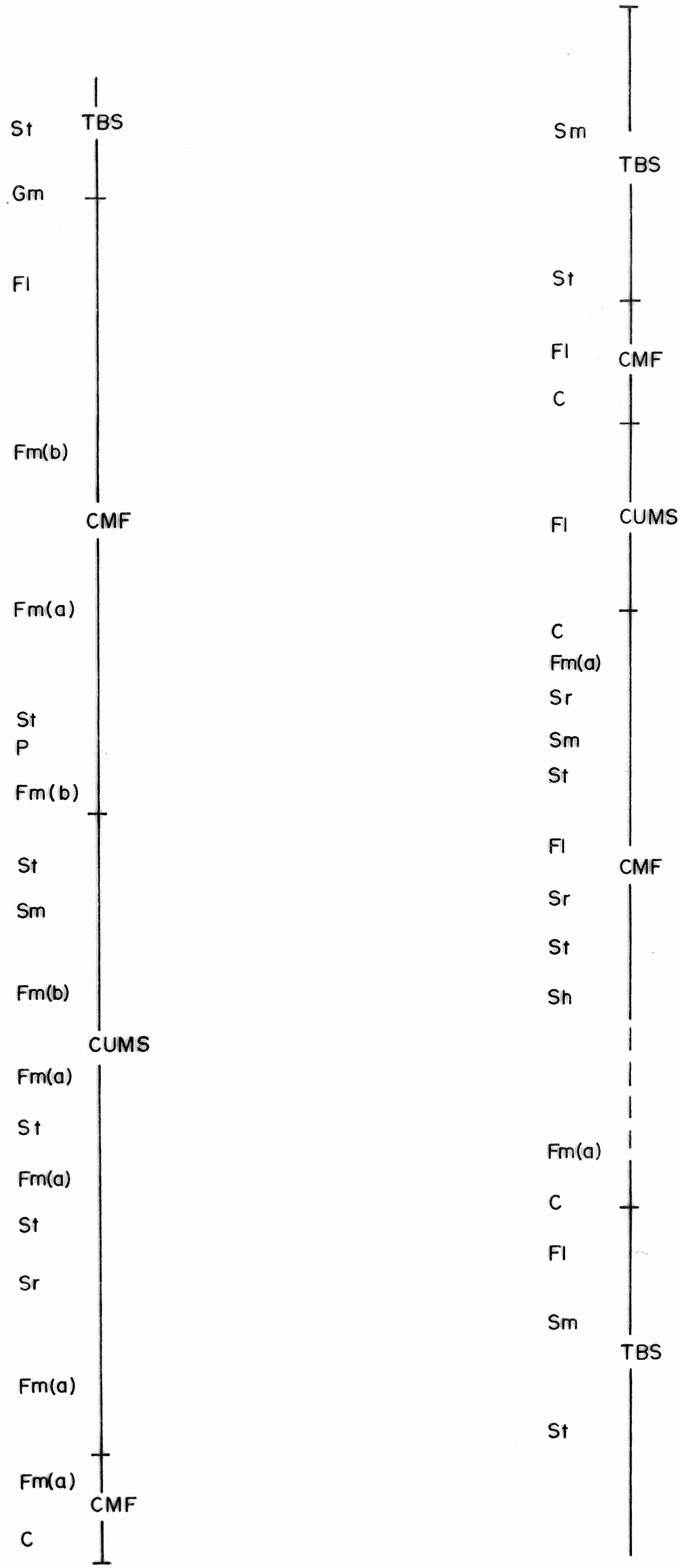
Symbol	Meaning
	aborescent plant fossil Lepidodendron
	coal mats
	plant debris, rootletts
	conical jointing
	pinch and swell carbonate beds
	carbonate nodules
c	carbonaceous
ca	calcareous
bl	bleached

Facies types: see text

Sub-assemblages:

- TBS thick-bedded sandstone
- CUMS coarsening-up-mixed sandstone
- CMF coal-mixed-fines

Figure 6 Section Log


St
TBS
Gm
Fl
Fm(b)
CMF
Fm(a)
St
P
Fm(b)
St
Sm
Fm(b)
CUMS
Fm(a)
St
Fm(a)
St
Sr
Fm(a)
Fm(a)
CMF
C
Sm
TBS
St
Fl
CMF
C
Fl
CUMS
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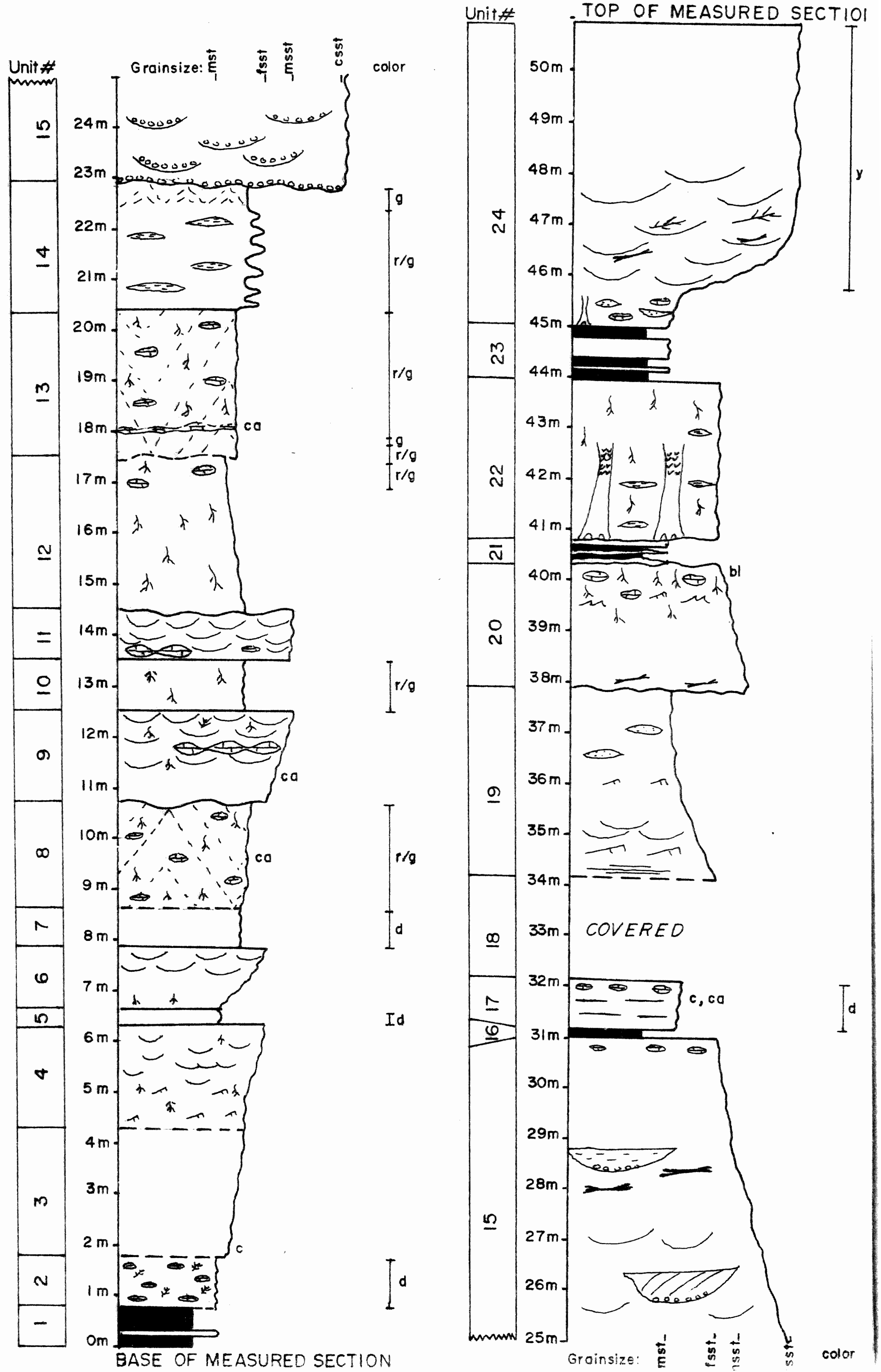
TBS
St


TOP OF MEASURED SECTION
Unit #
Grainsize: mst fsst msst csst
color
24m
23m
22m
21m
20m
19m
18m
17m
16m
15m
14m
13m
12m
11m
10m
9m
8m
7m
6m
5m
4m
3m
2m
1m
0m
ca
c
g
r/g
d
BASE OF MEASURED SECTION
50m
49m
48m
47m
46m
45m
44m
43m
42m
41m
40m
39m
38m
37m
36m
35m
34m
33m
32m
31m
30m
29m
28m
27m
26m
25m
COVERED
c, ca
bl
y
Grainsize: mst fsst msst csst

grained sandstone. The ripples are asymmetric, and variable in amplitude and wavelength. Crest patterns were not observed, due to the scarcity of bedding-plane exposure. Carbonate nodules are common in this facies, as are rootlets and Stigmaria.

Sm: Massive sandstone. Fine- to coarse-grained, massive sandstone commonly occurs interbedded with other sandy facies types. Bioturbation, carbonate nodules and rootlets are common. This facies commonly grades laterally into Sh, Sr or St.

Fl: Interlaminated mudstone, siltstone and fine-grained sandstone. Lenticular bedding, bioturbation, carbonate nodules and Stigmaria are common. Upright rooted trunks are locally abundant. This facies commonly grades into Fm(a) and Fm(b).

Fm: Massive mudstone and silty mudstone.
(a) grey and dark grey mudstone and silty mudstone. This facies type is locally carbonaceous and/or calcareous, and locally weakly laminated. Rootlets, carbonate nodules and plant debris are locally abundant.
(b) red and green mottled mudstone. The green color is best developed along root traces and on the surfaces of well developed conical joints. Carbonate nodules are common.

P: Carbonate nodules. Nodules up to 10 centimeters in diameter are scattered throughout all the fine-grained facies types, and many appear to be cored by organic material. Larger nodules (up to 25 centimeters in diameter) and masses of nodules are locally concentrated on the bedding planes of basal parts of St units, forming thir discontinous pinch - and - swell beds.

C: Coal and carbonaceous shale. This facies type is present as thin, laterally continuous banded bright coal (using Diesel's, 1965, classification scheme). Shaley partings are abundant and make up over 50 percent of some seams. Coal seams commonly have a bleached seat earth.

Some of the above mentioned facies types are shown in Figure 7.

a) Facies Type Sm cut by a channel. Gm at base of scour. Note poorly defined epsilon cross-beds in channel.

b) Sh interbedded with St.

Figure 7: Facies Types in the upper Morien near Table Head.

c) <u>Stigmaria</u> in facies type Fl

d) Fossil trunk in Fl facies type. Coal near bottom of picture.

e) Facies type Fm(b). Intersection of two conical joint sets just to left of rod.

Sub-Assemblages

Sub-assemblages are associations of facies on a scale of single beds to several beds. Individual facies types may have gradational or abrupt contacts, and are related by a gradual change in grain size or sedimentary style, or by small-scale cyclicity. Three sub-assemblages are recognized in the measured section: thick-bedded sandstones, coarsening-up - mixed sandstones and coal - mixed fines sequences.

The thick-bedded sandstone sub-assemblage is a single fining-up unit over 5 meters thick. Facies types included, in the most common vertical sequence, are Gm, Sh, St, Sm, Sr and Fl. The base is generally erosional and units are locally discontinuous. Lateral accretion sets, approximately 3 m thick and dipping perpendicular to the channel edge (where visible), are locally present, as are mud-filled channels. This sub-assemblage forms 28 percent of the measured section.

The coarsening-up-mixed sandstone sub-assemblage includes facies types Fm(a), Fl, Sr and St. Lenticular bedding, and small-scale scours are common. The contacts between facies types are laterally and vertically gradational, with local sharp contacts. This sub-assemblage forms 20 percent of the measured section.

The coal-mixed fines sub-assemblage consists of thin beds of sandstone of all facies types, facies types Fm(a), Fm(b) and coal. Thin fining-up and coarsening-up units are included, and the coarsest units are medium-grained sandstones. Contacts between units can be gradational or erosional. This sub-assemblage is the most abundant in the section forming 48 percent. Four percent of the section is covered.

These sub-assemblages combined belong to the Alternating Facies Assemblage described by Rust et al., (1983) in the Victoria Mines section measured along the eastern shore of Sydney Harbour.

21/...

Vascular Plant Fossils

One of the most remarkable features of this measured section is the abundance of large upright fossil trunks. They are confined to one facies type, Fl, and all but one were observed in one unit near the top of the section. They are uniform in size, about 50 cm in diameter at the base, and tallest exposed has a height of approximately 3 meters. Their upright position over a coal seam indicates that they are in place. The internal structures and mode of preservation will be described in a later chapter. Comparisons between these fossils and those in the collection of the Nova Scotia Museum (Zodrow and McCandlish, 1980) indicate that they are fossils of the arboraceous Lycopod, Lepidodendron.

Coals

The thickest coal unit measured in this section was 43 cm, and the combined thickness of all four units is under 2 meters. The units are laterally persistent and of uniform thickness. Hacquebard and Donaldson (1970) sampled coal units along this section (index 103, samples GB1-17) and found them to be high volatile bituminous coals with vitrinite reflectance between 0.71 and 0.78 percent.

Chapter 4 Petrography

Sandstones

Two coarse-grained sandstone samples and four fine-grained sandstones were examined microscopically to determine their composition and to investigate textures. Point counts of 700 points were done to determine proportions of components. The results of thin section analysis are shown in Table 2.

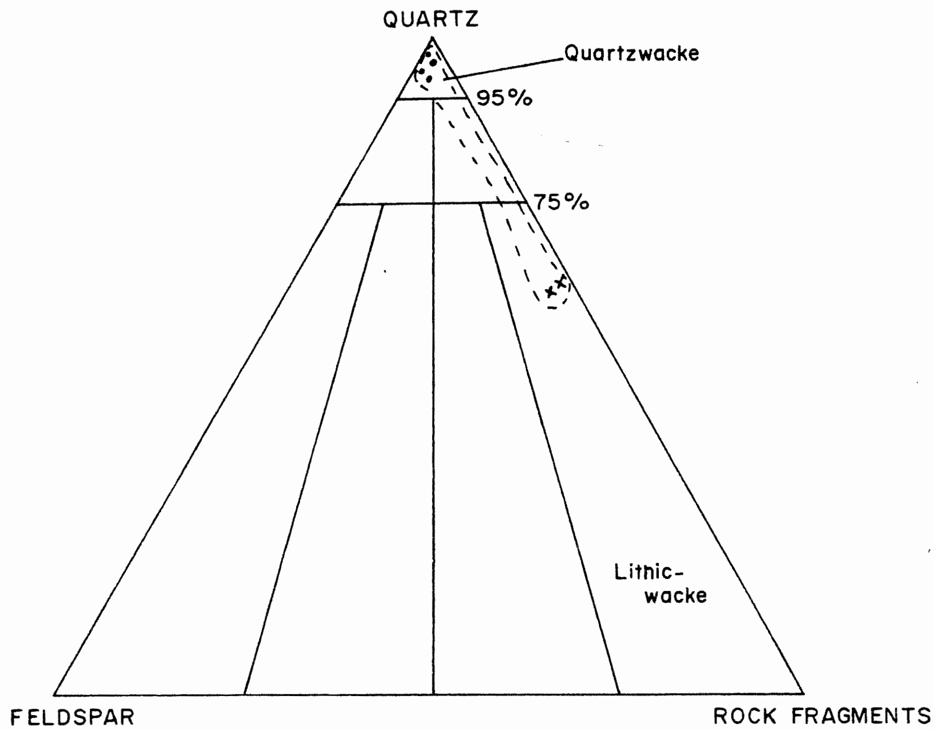
Sandstones were classified using Folk's (1974) classification. They range in type from lithic greywacke to quartzwacke with decreasing grain size (Fig. 8). The amount of matrix increases with decreasing grain size. This is consistent with the decrease in flow regime suggested by sedimentary structures in the units sampled, indicating a decrease in flow competence (Blatt et al., 1980). Lithic grains include quartzite and phyllite, and mineral grains are predominantly strained quartz, with biotite, muscovite and plagioclase forming a small proportion. The coarse-grained sandstone is moderately sorted, poorly cemented and porous. Grains are angular to subangular, and grain contacts are mainly tangential. Fine-grained sandstones are less sorted. Bands very rich in platy minerals alternate with quartz-rich layers that commonly have opaque mineral lags. Again, the grains are angular to sub-angular and grain contacts are long to sutured. Fine-grained sandstones are less porous, and are well cemented, with calcite filling insterstices.

The major difference between the coarse-and fine-grained sandstones can be summarized as follows:

1) Grain types - lithic grains are lacking in the fine-grained sandstones.

2) Matrix abundance - fine-grained sandstones have a higher percentage of matrix.

Both these differences can be explained by a decrease in flow competence. Lithic grains are too coarse to be deposited with the fine-grained sediments. The products from the break up of the lithic grains, quartz and fine micas, account for the abundant matrix in the fine-grained sandstone.



MATRIX >15 %
(Matrix = less than 30 μ fraction)

• Fine-grained sandstone   x Coarse-grained sandstone

Figure 8 Classification of sandstones (Folk, 1974)

Table 2: Sandstone Petrography

Sample #	J-6-0	J-14-0	J-20-1
Facies type	(sm)	(fl)	(sr)
Grain size	Vf	F	F
Roundness	SA	SA	SA
% clasts	63	68	64
% matrix + cement	37	32	36
Quartz	43% - strained and unstrained grains	53% - strained and unstrained grains	55% - strained and unstrained
Feldspar	1% plagioclase and k-feldspar (plagioclase>> k-feldspar) very fine, highly altered plag. has polysynthetic twins	<1% plagioclase very fine SE highly altered polysynthetic twins	1% plagioclase very fine highly altered polysynthetic twins
Lithic	--	--	--
Other	15% micas fine biotite and muscovite plates 4% opaques	12% micas fine biotite and muscovite plates 6% opaques	5% micas fine biotite and muscovite plates 3% opaques in layers and rimming grains
Matrix	27% very fine micas and clays minor chlorite	20% very fine micas, clays minor chlorite	23% very fine quartz, micas, clays
Cement	10% calcite pore filling	12% calcite pore filling	13% calcite sparry and finely crystalline in pores
Grain contacts	irregular to sutured	long to sutured	long to sutured
Comments	matrix-supported in mica-rich bands, calcified rootlets	quite porous clast-supported	mostly clast-supported, some matrix-supported in platy-rich layer 3

Table 2: Sandstone Petrology (cont'd)

Sample #	J-22-1	J-26-1-A	J-26-1-B
Facies type	(fl)	(st)	(st)
Grain size	F	C	C
Roundness	SA	A-> SA	A-> SA
% clasts	59	84	82
% matrix + cement	41	16	18
Quartz	38% - strained, unstrained and polycrystalline	44% - strained, polycrystalline, and unstrained	46% - strained, polycrystalline and unstrained
Feldspar	<1% plagioclase very fine highly altered polysynthetic twins	3% plagioclase and k-feldspar (plagioclase> k-feldspar) fine grains plag. has polysynthetic twins	2% plagioclase fine grains polysynthetic twins
Lithic	--	30% phyllite and quartzite	29% phyllite and quartzite
Other	14% micas fine biotite (minor muscovite) plates 7% in layers and rimming some grains	1% micas ragged plates biotite> muscovite 6% opaques, organics and mineral	2% micas ragged plates biotite> muscovite 3% opaques organic with mineral rims
Matrix	26% very fine micas, clays, minor chlorite	16% silt-sized quartz, fine micas and clays	18% silt-sized quartz, fine micas and clays
Cement	15% calcite - sparry and finely crystalline	<1%	<1%
Grain contacts	tangential, long and sutured	tangential and long	tangential and long
Comments	graded bedding with opaque-rich, quartz-rich and mica-rich layers	very porous brown halos around opaques, clots of opaques in vugs	very porous brown halos around opaques, opaque grains rimming organics

Key

for facies types see Ch. 3

grain size
- Vf very fine
- F fine
- C coarse

Roundness
- A - angular
- SA - sub-angular
- SR- sub-rounded
- R - rounded

3) Grain contacts - The presence of sutured and long contacts in the fine-grained sandstones and tangential and long contacts in the coarse grained sandstones reflect differences in compaction.

4) Cement - almost totally lacking in the coarse-grained sandstones.

These differences may be related to the sorting and permeability of the sandstones, and the history of cementation and diagenesis.

A possible sequence of events leading to these differences is: a) Early cementation of sediments - coarse, well sorted sediments initially well cemented. Less permeable, fine-grained sediments poorly cemented. b) Mechanical compaction of fine-grained sediments. The coarse-grained sandstones are protected from mechanical compaction by having filled pore spaces (Schmidt and McDonald, 1980). c) Dissolution of carbonate from coarse-grained sandstones at some stage in the diagenetic history. The reduced permeability of the fine-grained sediments due to compaction protects much of their cement from dissolution. The evidence for early carbonate cementation is good, in that there are abundant carbonate nodules and carbonate-replaced plant fossils.

Mudstones

The clay mineralogy of four mudstone units and one intraclast-nodule lag were investigated using X-ray diffraction analysis. The <2 micron fraction was separated from the mudstone by settling milled samples for 16 hours and removing the top 20 cm of a 1000 ml graduated cylinder. The sample was then treated with saturated calcium chloride to flocculate the clays, and the excess liquid was centrifuged off. Smear slides were prepared using the clay material obtained, and were allowed to air dry before analysis.

The samples were run in the diffractometer using CuKa radiation, a scanning speed of 1° 2θ per minute over a range of 2° to 32° 2θ.

Table 3: Clay Mineralogy of Mudstones

Sample	Minerals / peak location	mineral
Sample # 3-0	kaolinite, illite, chlorite	
grey mudstone	peak location (2θ)	mineral
	6.2°	chlorite
	8.9°	illite
	12.4°	kaolinite + chlorite
	17.8°	illite
	18.9°	chlorite
	25.2°	chlorite
	26.9°	illite + kaolinite
	29.4°	illite
Sample # 14-0	kaolinite, illite, chlorite	
grey mudstone	peak location	mineral
	8.7°	illite
	12.3°	kaolinite + chlorite
	17.7°	illite
	24.9°	chlorite + kaolinite
	26.8°	illite + kaolinite
Sample # 10-0	kaolinite, illite, chlorite	
red mudstone	peak location	mineral
	8.7°	illite
	12.4°	kaolinite + chlorite
	17.7°	illite
	24.0°	kaolinite + chlorite
	26.6°	illite + kaolinite
Sample # 10-0	kaolinite, illite, chlorite	
green mudstone	peak location	mineral
	8.7°	illite
	12.2°	kaolinite + chlorite
	17.6°	illite
	24.9°	kaolinite + chlorite
	26.7°	kaolinite + illite
Sample # 17-2	kaolinite, illite, chlorite, dolomite	
channel lag	peak location	mineral
	12.4°	kaolinite + chlorite
	24.9°	kaolinite + chlorite
	26.5°	illite + chlorite
	30.7°	dolomite

The peaks obtained in the analysis were compared with 2θ values listed in Piper (1977). The mineralogy of the samples is given in Table 3. Relative abundances of minerals were estimated by peak area. Generally, kaolinite is the most abundant clay mineral, followed by illite and chlorite. Dolomite, observed in the channel lag sample, may be a constituent of the carbonate nodules. The color of mudstones in the measured section is quite varied. Red, green and grey units are present. This variability is not reflected in the clay mineralogy. The color differences are probably due to the difference in the oxidation state of iron, and in the amounts of carbonaceous material. These differences are the result of depositional environment, and possibly early diagenesis (Blatt <u>et al</u>., 1980).

Chapter 5 Interpretation

Depositional Environment

The criteria for determining the environment of deposition are shown in Table 4. The presence of *in situ* terrestrial plant fossils, coals, rooted horizons and carbonate horizons indicates that the section was deposited in a terrestrial environment.

Sub-assemblages and sedimentary features such as lateral accretion sets and mud-filled channels indicate that the environment was fluvial.

A mudstone:sandstone ratio of approximately 3:2 (in Table 4) points to deposition in the alluvial plain of a meandering stream. Each sub-assemblage (thick-bedded sandstone, coarsening-up-mixed sandstone, and coal-mixed fines) can be related to an aspect of the meandering stream environment.

Channel deposits are represented in the thick-bedded sandstone assemblage. The upward decrease in grain-size accompanied by the succession of sedimentary structures, planar lamination to trough cross-beds to ripples, indicates deposition on a point bar. Preservation of these features is due to lateral and down stream migration of the point bar (Walker and Cant, 1979), and lateral accretion sets, dipping perpendicular to channel margins are observed in the section. Mud-filled channels are the result of vertical accretion of suspended-load sediments in abandoned channels. Channel cut-off could be due to avulsion, chute or neck cut-off, but the high proportion of mudstone in the fill suggests that neck cut-off is most likely. The creation of a neck cut-off causes flow to diminish almost immediately. Coarser, bed-load sediments are not carried through the cut-off meander, and sedimentation is achieved only by vertical accretion (Walker and Cant, 1979). Channel and scour lags consist of mudstone intraclasts and carbonate nodules eroded from the channel margins. The size and form of the carbonate nodules matches those in interbedded fine-grained units. This indicates that they are of local origin and that their formation was synchronous with sedimentation.

Table 4: Summary of Interpretation

sub-assemblage	important features	environment
thick-bedded sandstone	erosional base fining-up sequence of facies types Gm → (sh) → (sm) → st → sr → fl lateral accretion sets mud-filled channel	point bar abandoned channel
coarsening-up-mixed sandstone (20%)	coarsening up sequence of facies types Fm(a) → (Fl) → sm → st lenticular bedding large plant fossils	levee
coal mixed-fines (48%)	coals red and green mottled mudstones, pedogenic carbonate nodules, abundant plant debris	peat swamp overbank deposits

= fluvial environment

mst:sst = 3:2 = meandering

Levees and proximal overbank deposits are represented by the sub-assemblage coarsening-up-mixed fines. Coarsening up sequences are deposited in times of high water, when the stream carries bed load over the stream banks. As the flood water tops the stream banks, a sudden decrease in turbulence decreases flow competence and the suspended sediments are deposited, fining away from channel margins. Coarsening up sequences result from the progradation of the levee across the floodplain. Interbedded, lenticular sandstones and mudstones are deposited on the distal parts of levees, where sands are deposited in crevasse splays, and mudstones in depressions (Reineck and Singh, 1980). Levee deposits are fairly abundant in the measured section (20%). Their preservation and formation can partly be attributed to the abundant vegetation, represented by rooted horizons and trunks. The vegetation probably aided in trapping sediment, and the roots of plants acted to stabilize the sediments, protecting them from erosion..

The deposits of the floodplain and its vegetation are represented by the coal-mixed fines sub-assemblage. Mudstones are the result of vertical accretion of fine sediment from the suspended load of flood waters. Compaction and subsidence of the fine-grained sediments allowed peat swamps to form on the flood-plain. Water table fluctuations may also have been important for the growth of peat swamps. Two coal seams overlie rooted or vegetated sandy units, indicating that a rise in water level was necessary for swamp development. Lateral and vertical color changes in mudstone units also indicate fluctuating water levels. Red mudstones (indicating well drained conditions) commonly grade vertically and laterally into grey mudstones with abundant carbonate nodules indicating a change from well drained to poorly drained conditions (Coleman, 1966).

Carbonate nodules, believed to be syngenetic, are found in most of the fine-grained facies types. Nodules are formed within the host sediment under near surface conditions, either by evaporation and precipitation of calcite in well drained areas or by chemically induced precipitation of iron carbonate in

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acidic, poorly drained conditions (Reineck and Singh, 1980). The association of nodules with rootlets and organic material indicates that the majority of the nodules are of the latter type.

Provenance of Clastic Sediments

The abundance of metamorphic rock fragments, strained and polycrystalline quartz grains in the sandstones of the measured section indicate that the sediments were derived from a metamorphic source area. A single source rock type is possible as the quartzite and phyllite grains are related in type and are observed to form phyllite-quartzite clasts.

Some of the clay minerals could also be derived from such a source. Illite and chlorite can be derived from the weathering of phyllites. Kaolinite could also be of detrital origin (as in the Amazon, where it forms a large proportion of the suspended load (Gibbs, 1968)), or it could be formed in soils as the result of *in situ* leaching by plants.

The structural grain of the Sydney Basin runs northeast-southwest (Keppie, 1982) and paleocurrent measurements (Dilles and Rust, 1983; Duff *et al.*, 1982) indicate a mean northeast transport direction for the upper Morien. The source of these sediments probably lies to the southwest, with some local input from basement highs. Possible source rocks are members of the Forchu and Georgeville Groups. The rock types represented in the sandstone are not distinctive, and a more exact determination of provenance is beyond the scope of this study.

Chapter 6 Description of Fossil Trees

The abundant fossil trees preserved in unit 22 of the measured section were identified by examining "bark" impressions and fossil form. Comparisons of the collected data with literature descriptions (Taylor, 1981; Zodrow and McCandlish, 1980) indicate that these trunks are the remains of Lepidodendron. These aboraceous Lycopods were woody seedless vascular plants, and were one of the most abundant plant species of the Carboniferous (Taylor, 1980). They may have grown to heights of 38 meters, with trunks up to 2 meters in diameter at their base. The general form of Lepidodendron is shown in Figure 9. The plant differs greatly from modern trees. It was supported by a massive cortex which surrounded a relatively small amount of vascular tissue. As it grew it shed its epidermis and outer cortex, leaving the older parts of the plant without the distinctive leaf scars. When the plant had attained about one half of its height it branched dichotomously, and continued branching until the branches could divide no further, and growth stopped. The roots or Stigmaria were shallow and also branched dichotomously. They were covered with tubular appendages that probably acted like rootlets. These were abscised during growth leaving circular scars. The internal organization of Lepidodendron varies with plant species and plant age (Taylor, 1980).

It is interesting to note that one of the nearest living relatives of this large tree-like plant is the tiny club moss.

Fourteen fossil trunks were observed in the strata near Table Head.(Figure 10). Only half of these are actual trunks, the other half being imprints only. In the debris at the base of the cliffs can be found what the author believes to be the partial remains of fossil trunks. This interpretation is based on observations of the internal structures both in hand specimen and thin section and on comparison with in place fossil trees.

All but two of the trunks are positioned directly above the underlying coal seam, and these fossils terminate sharply above this seam (Figure 11). They range in height from 70

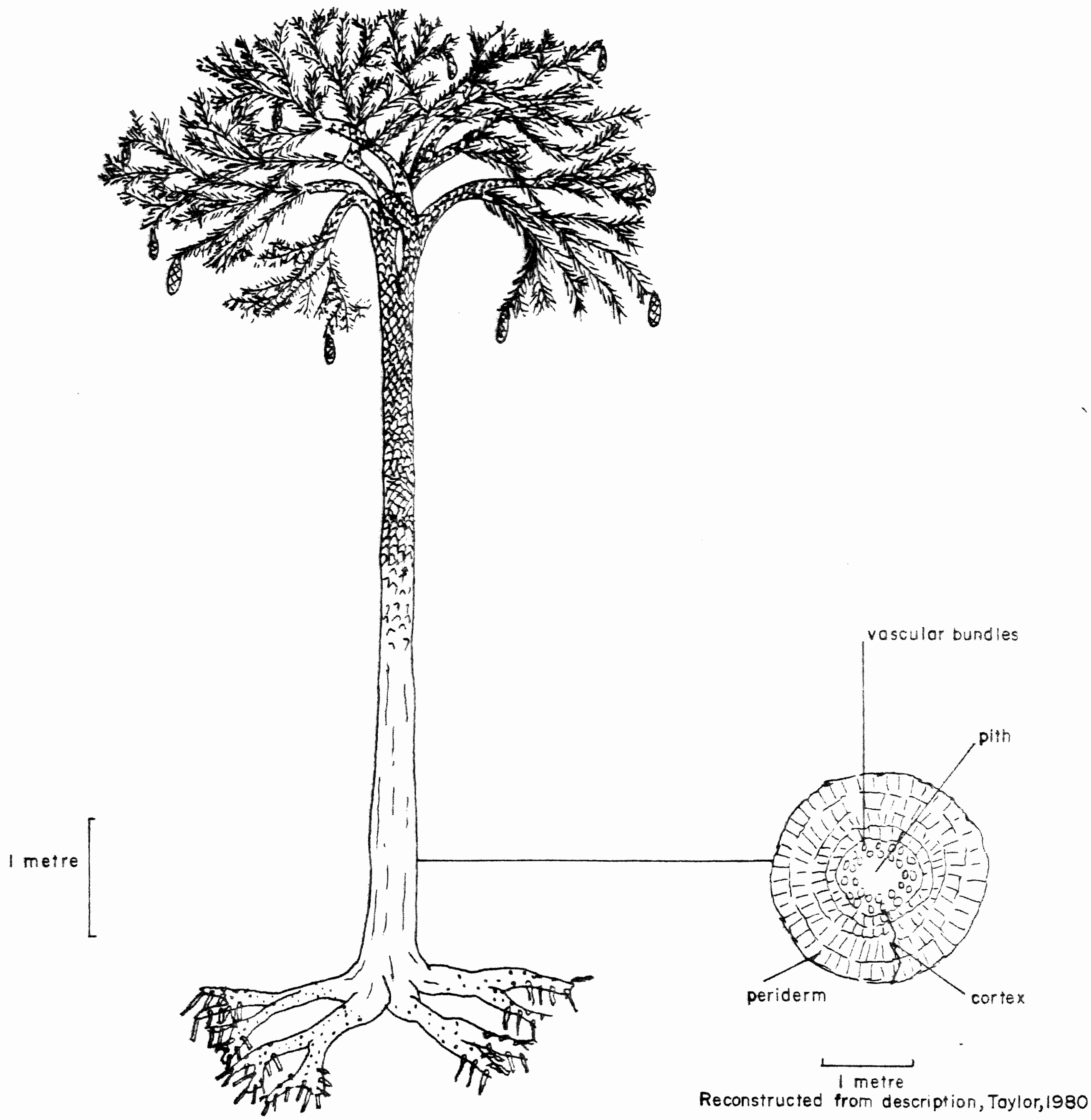

FIGURE 9

Lepidodendron: reconstruction suggested by D.A. Eggert, 1961

Figure 10: Fossil trunks exposed near Table Head

a) Two trunks. Large one over 3 m in height (coal seam 40 cm).

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b) Fossil trunk not roofed in coal seam.
Stigmaria may be present

c) Three fossil trees (below arrows)
coal seam 40 cm

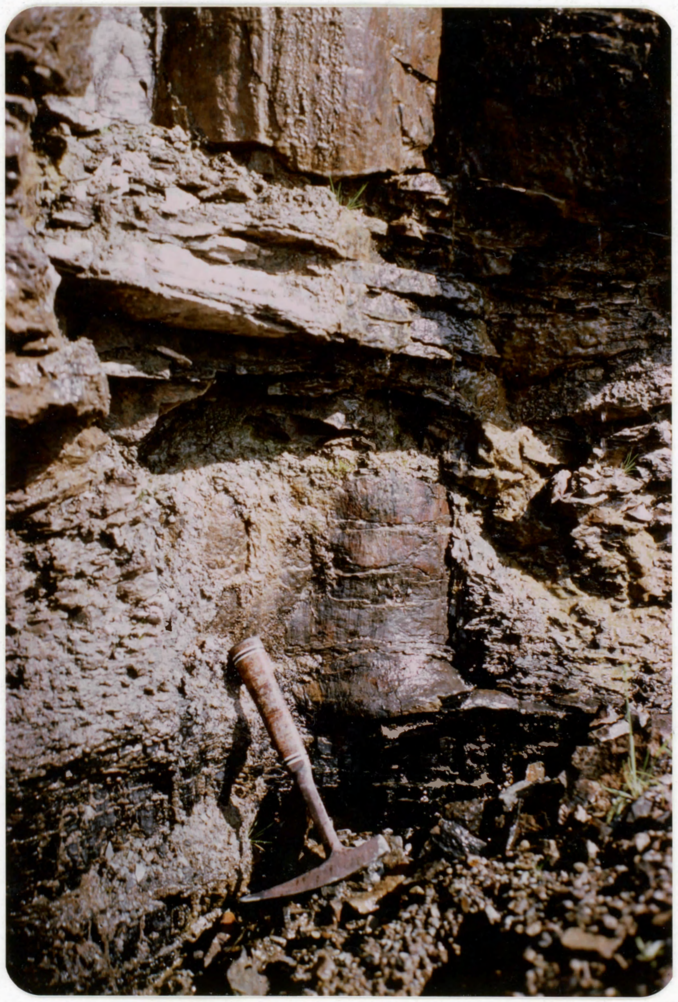

Figure 11: Trunk showing abrupt termination above coal seam and disruption (hammer 30 cm)

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centimeters to 3 meters, with an average exposed height of 1.5 meters. The heights may be underestimated, as the upper termination of the trunk is rarely exposed. Diameters at the base of trunks range from 30 to 80 centimeters with an average of 50 centimeters. Attached Stigmaria were not observed. The trunks were rooted in the underlying peat mat so that the Stigmaria were probably coalified with the peat. Some trunks are disrupted (Figure 11). The shearing of the trunks and the continuity of strata along these disruptions may indicate bedding plane slip during folding after lithification.

The internal structure of in situ trunks was observed at one location. Most of the fossil trunks are inaccessible, being exposed only near the tops of steep, high cliffs. The trunk was infilled with medium-grained sandstone and green mudstone similar in appearance and composition to the surrounding strata. The epidermis and vascular bundles were coalified. Based on the observations on fallen trunk remains, an additional mode of preservation is proposed. A sketch of sample examined is shown in Figure 12. Thin section examination reveals delicate cell structures preserved in calcite, with a radial structure characteristic of the perideum cells of the cortex (Taylor, 1980). Inward from this is a relatively structureless zone that is cut by vascular bundles. This sample represents a fragment from near the core of a larger trunk. Petrification of plant material indicates that carbonate-rich fluid was present in the sediments soon after deposition. Ground water and river waters with a high solution load of calcium and bicarbonate are suggested as the source for this fluid. This hypothesis is supported by in situ pedogenic nodules, the presence of carbonate nodules in channel lags (indicating that they were eroded, ready formed, from the surrounding sediments) and by the presence of calcite cements in sandstones. Early calcification probably played an important role in preserving the trunks. The plant immersed in carbonate-rich ground water would rot slowly, allowing parts to be replaced by calcite (Taylor, 1980). The cemented sediments surrounding the trunk would support it, preventing it from being crushed or overturned.

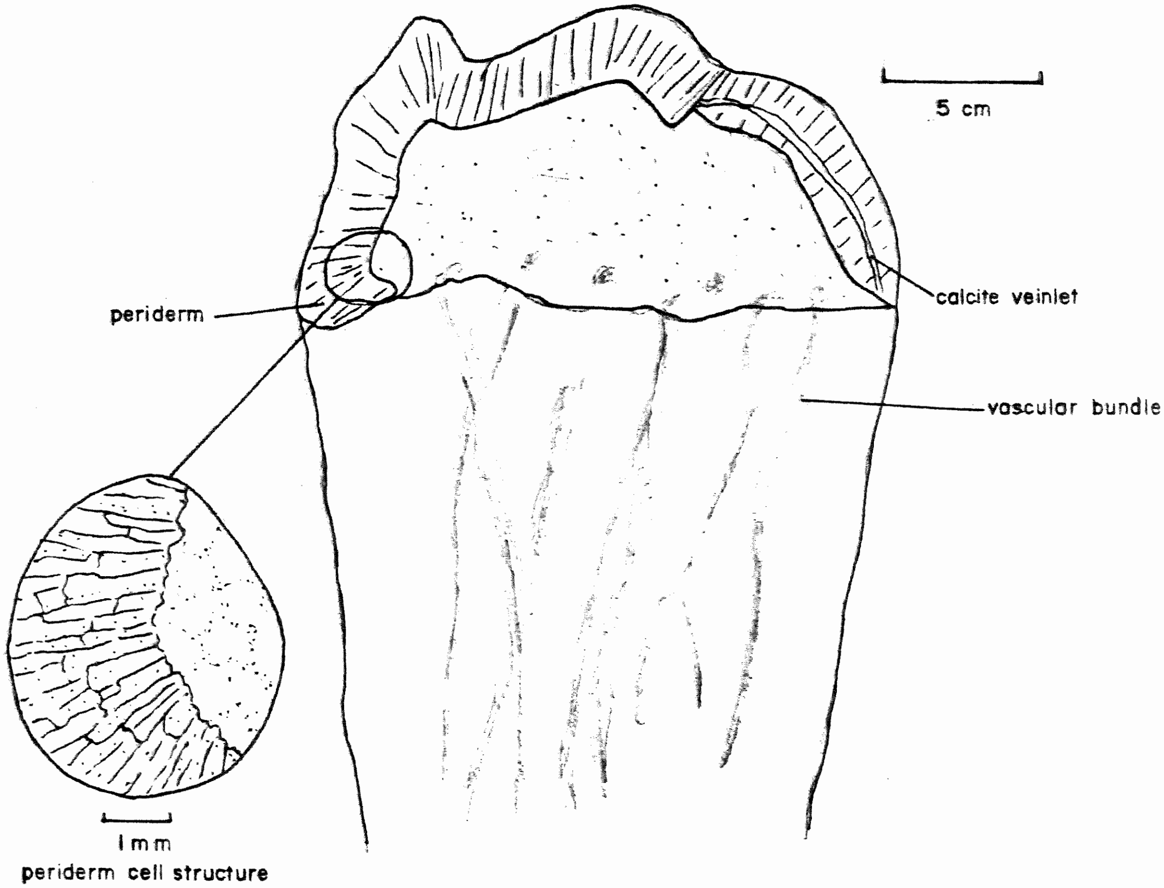

FIGURE 12

Petrified (calcified) trunk fragment

A summary of the sequence of events leading to the preservation of the fossil trunks is shown in Figure 13. As shown, the lower portion of the trunk is more likely to be calcified, as it is immersed first and has less chance to rot.

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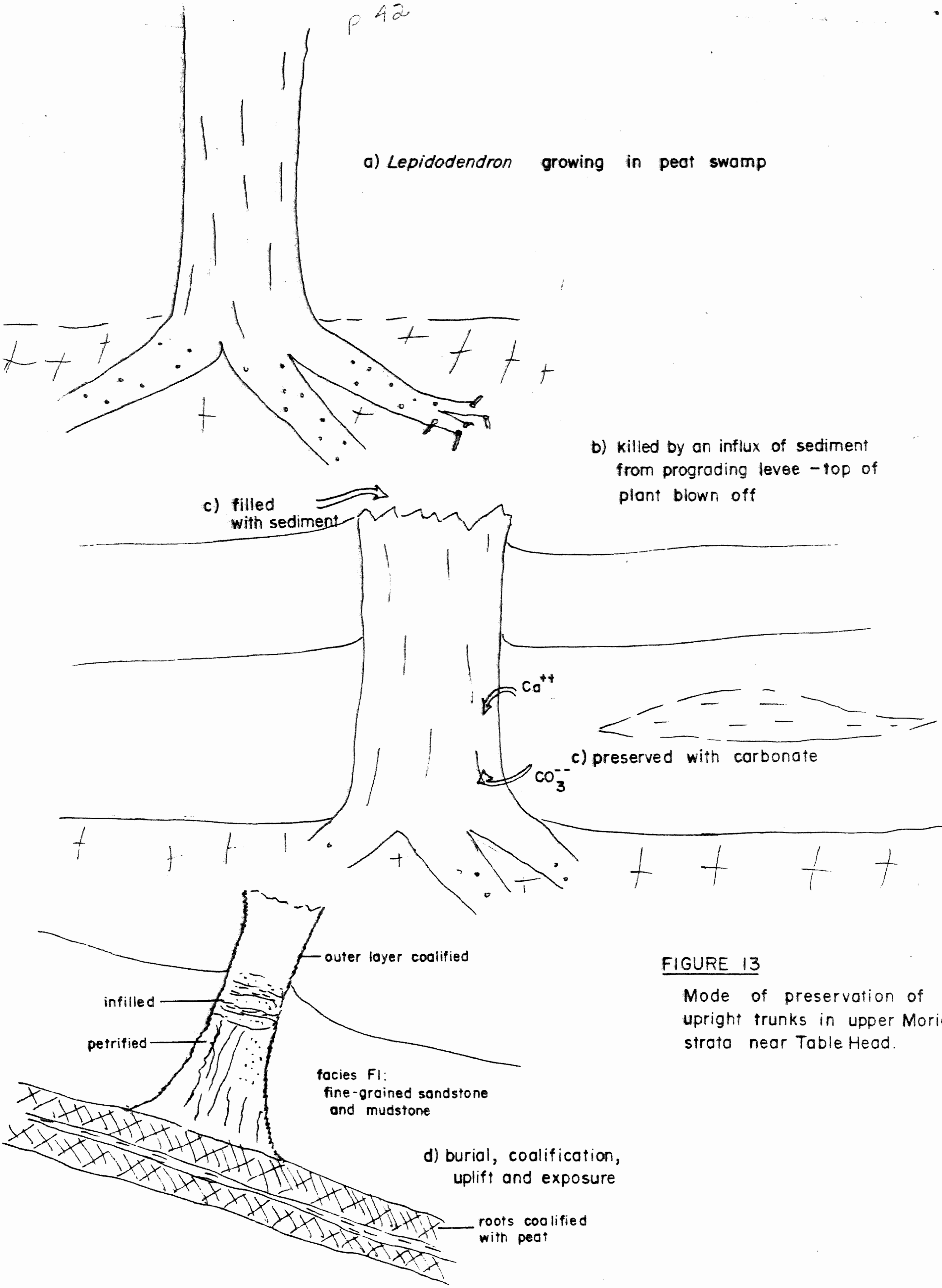

FIGURE 13

Mode of preservation of upright trunks in upper Morien strata near Table Head.

Chapter 7 Conclusions

From the preceding data and discussion the following conclusions are drawn:

1) The strata at Table Head were deposited in an alluvial plain with meandering channels. Major physiographic features of alluvial plains are represented in the sub-assemblages defined: channel (thick-bedded sandstones), levee (coarsening-up-mixed sandstone), and flood plain (coal-mixed fines).

2) The clastic sediments were derived from a metamorphic source terrain. Paleocurrents indicate a source to the southwest, with possible input from local basement highs.

3) The coal seams near Table Head are continuous, but thin and of poor quality. Shaley partings commonly comprise 50 percent of seams. They are presently uneconomic.

4) Fossil trunks of Lepidodendron were preserved by infilling with sediment and by calcification of plant parts. Early cementation of sediments may have aided preservation.

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Recommendations for Future Work

A closer examination of the fossil trunks may reveal the extent of each type of preservation. Features such as bark scours and sediment drapes may reveal the timing of preservation.

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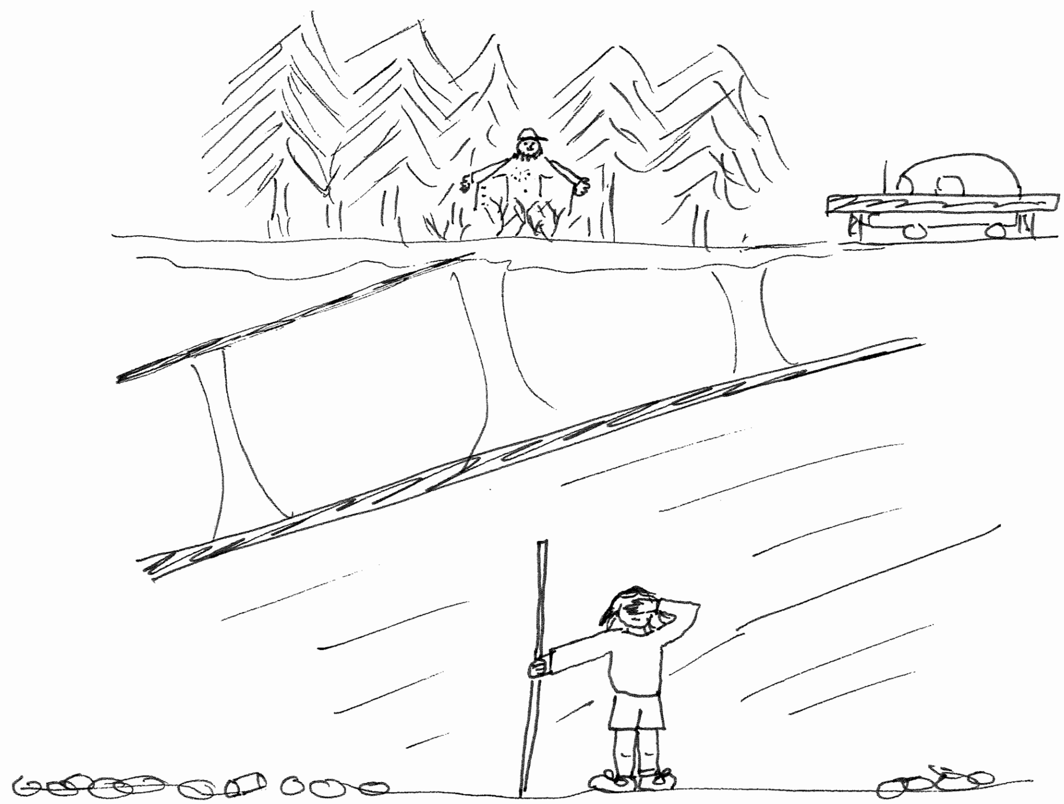

Schematic sketch of the Table Head section (flasher for scale)

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Appendix A

Work Schedule

Task	Time
Fieldwork	12 hours
Literature search	50 hours
Lab work	35 hours
Seminar preparation	6 hours
Writing	50 hours
Drafting	6 hours
	159 hours