Upper Carboniferous Fluvial Sedimentation in the Gulf of St. Lawrence Coal Basin, Mabou Mines, Nova Scotia

by

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the requirement for the degree
of Bachelor of Science with
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ABSTRACT

Mabou Mines is located on the northwestern coast of Cape Breton Island, Nova Scotia. Steeply dipping sedimentary strata of the Upper Carboniferous Pictou Group (dated as Late Westphalian C) are exposed on the shoreface. These are faulted slivers of coal measures that can be correlated to strata extending far out into the Gulf of St. Lawrence Coal Basin (Hacquebard, in press).

The section contains four major lithosomes; two are shale-dominated and two are sandstone-dominated. Beds within these units were classified on the basis of parameters such as lithology, sedimentary structures, fossil content and colour and subsequently described as lithofacies for analysis.

Shale lithosomes contain abundant shale, coal and black limestone and have been interpreted as flood-plain deposits. The flood-plain was heavily vegetated and studded with shallow lakes. Sandstone lithosomes are interpreted as fluvial channel sandstones on the basis of their lithology and facies associations.

The depositional environment for these strata was a braided river system, not unlike the South Saskatchewan River in Western Canada. Thick vegetative growth on the flood-plain, however, was much greater than in a normal sandy braided river, restricting lateral channel movement. This resulted in an entrenched river that developed vertically-stacked channels through aggradation. As a result, the Carboniferous fluvial system at Mabou Mines developed characteristics usually associated with either braided or meandering systems.

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TABLE OF CONTENTS

Title Page

Abstract....................................i
Acknowledgements...........................ii
Table of Contents..........................iii
List of Figures.............................v
List of Appendices.........................vii
List of Tables.............................vii

CHAPTER 1: INTRODUCTION
1.1 Location of Study Area......................1
1.2 Aim of Study................................5
1.3 Field Work..................................5
1.4 Previous Work...............................6

CHAPTER 2: CARBONIFEROUS BASIN EVOLUTION
2.1 Tectonic History............................8
2.2 Regional Carboniferous Stratigraphy.........10

CHAPTER 3: STRATIGRAPHIC SECTION
3.1 Explanation.................................17
3.2 Correlation Within the Basin................28

CHAPTER 4: LITHOFACIES
4.1 Introduction................................35
4.2 Lithofacies Descriptions....................36

CHAPTER 5: MARKOV CHAIN ANALYSIS
5.1 The Markov Test.............................56
5.2 Procedure...................................56
5.3 Results.....................................57

CHAPTER 6: PETROGRAPHY
6.1 Procedure...................................61
6.2 Results.....................................61

CHAPTER 7: BIOTA
7.1 Fauna.......................................65
7.2 Flora.......................................68

CHAPTER 8: SIDERITE NODULES
8.1 Field Relations.............................72
8.2 X-Ray Diffraction Analysis..................73
8.3 Interpretation..............................74

CHAPTER 9: COAL

9.1 Seams at Mabou Mines........................78
9.2 Coal Quality.................................79
9.3 Sulphur in Coal..............................80
9.4 Future Mining Potential......................82
9.5 Interpretation...............................83

CHAPTER 10

10.1 Eagle and Stack Sandstones.................85
10.2 Shale Members..............................87
10.3 Synthesis..................................91

REFERENCES......................................94

LIST OF FIGURES

FIGURE PAGE

1.1 Study Area....................................1

1.2 Local Geology.................................3

1.3 Local Distribution of Major Lithologic Units....................................4

2.1 The Fundy Basin...............................9

2.2 The Fundy Basin...............................9

2.3 Stratigraphic Divisions of the Maritimes....................................13

2.4 Comparison of Spore Assemblages of Europe and the Maritime Provinces.............14

2.5 Characteristic Plants and Animals of the Upper Carboniferous in the Maritimes....................................15

3.1 Lithofacies Log...............................18

3.2 (3.2a) List of Symbols for the Stratigraphic Column..........................19

3.2 Stratigraphic Column..........................20

3.3 Correlations of Offshore Boreholes............30

3.4 Intrabasinal Correlations.....................31

3.5 Structural Reconstruction of the Mabou Mines area..............................32

4.1 Facies C....................................37
4.2 Facies C....................................37
4.3 Facies Lst..................................38
4.4 Facies Fsc, Sr..............................38
4.5 Facies Sr...................................41
4.6 Facies Sr...................................42
4.7 Facies Sh...................................43
4.8 Facies Sr...................................43
4.9 Facies P....................................45
4.10 Rooted Horizons............................45
4.11 Large trough cross-beds....................47
4.12 Eagle Sandstone............................47
4.13 Large trough cross-beds....................48
4.14 Lensoid body of Sho facies.................48
4.15 Siderite nodule............................49
4.16 Fossil trunk in sandstone..................49
4.17 Crevasse-splay Feeder Channels.............51
4.18 Vegetated crevasse-splay...................51
4.19 Crevasse-splay Feeder Channels.............52
4.20 Root System................................53
4.21 Contemporary System........................54
4.22 Flood-plain facies assemblage analog.........54
5.1 Matrices of the Markov chain analysis.........59
5.2 Flow Chart - Markov chain analysis............60
10.1 Migration of Sandstone Members.............93b

LIST OF APPENDICES

APPENDIX A: Stratigraphic Section Description..Page 102

APPENDIX B: Petrography........................Page 110

APPENDIX C: Coal Seams.........................Page 116

APPENDIX D: Facies Distributions...............Page 117

APPENDIX E: Braided River Facies...............Page 118

LIST OF TABLES

TABLE 1: Paleocurrent Data.....................Page 55

TABLE 2: Analysis of Fsc Facies Shales.........Page 64

TABLE 3: Floral Distributions..................Page 71

TABLE 4: X-ray Diffraction Data................Page 77

TABLE 5: Mining Potential......................Page 84

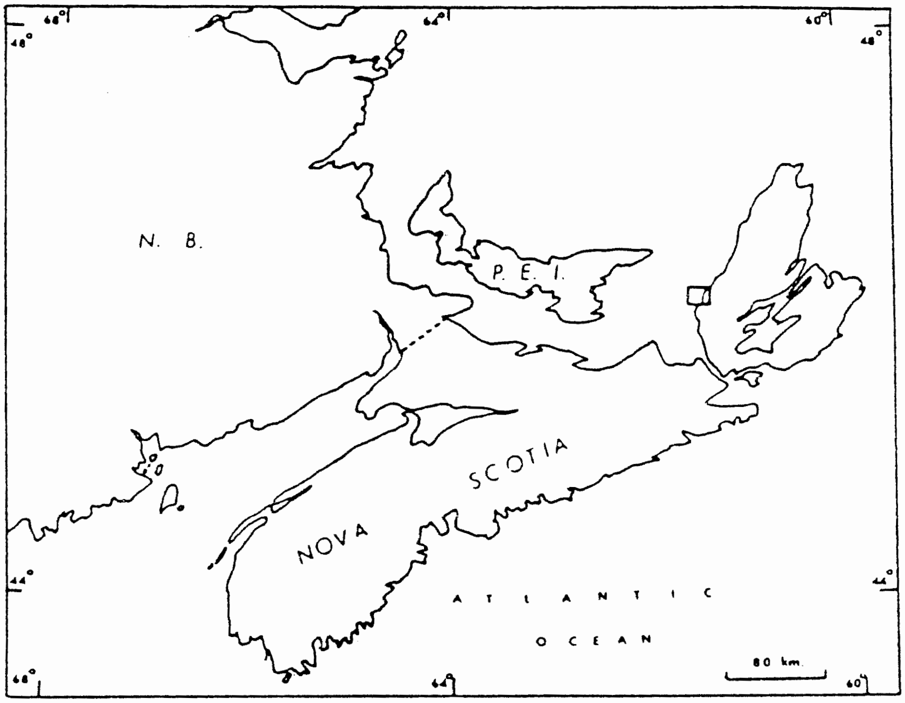


Fig. 1.1 Study Area - Mabou Mines, Cape Breton Island.

CHAPTER ONE

INTRODUCTION

1.1 Location of Study Area

Coal-mine Point is located at Mabou Mines, 4.8 km north of Mabou Inlet on the northwest coast of Cape Breton Island (Fig. 1.1). Coal-mine Point and its counterpart, Finlay Point (Fig. 1.2), both sections of the Pictou Group coal measures, constitute 0.25 km^2 of land exposure of the Gulf of St. Lawrence Coal Basin. In the Mabou Mines area, strata crop out in several, steep, individual cliff sections that are bounded by the Gulf of St. Lawrence to the northwest and dip steeply to the north.

The Pictou Group in the Mabou Mines area onshore constitutes over 320m of sandstone and shale which can be separated into four lithosomes. These lithosomes have been attributed informal "member" status for purposes of study and discussion. Hereafter in the text these units will be referred to as: the lower shale member, the Eagle Sandstone, the upper shale member, and the Stack Sandstone. These units are presented here as they occur in the section, that is, from stratigraphically lowest to highest. The shales contain several coal seams and stringers, six of which exceed 1m in thickness and so are potentially mineable (Hacquebard, 1985; in press).

The physiographic character of this region consists of gently rolling hills, reaching heights of 60m near the shore

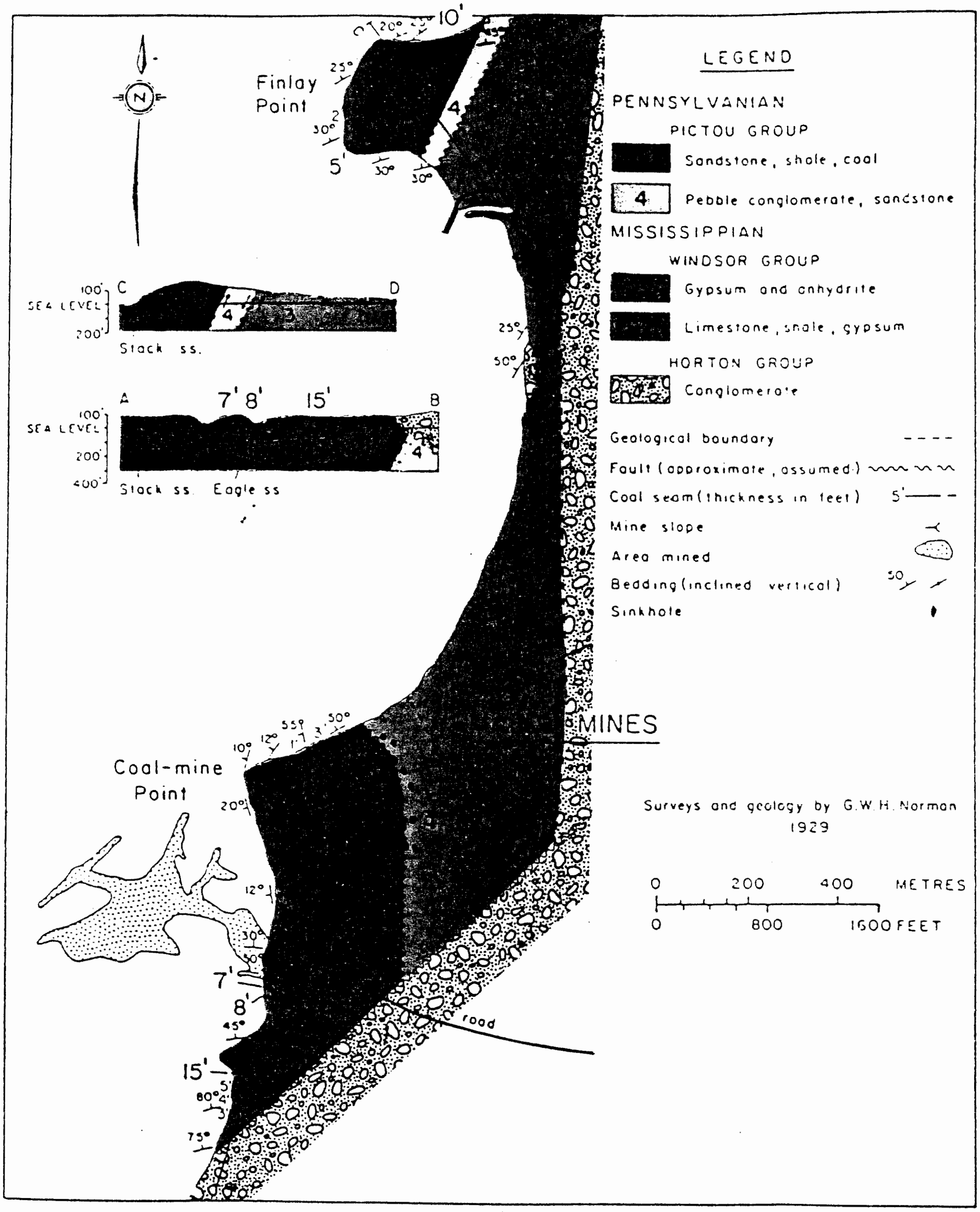


Fig. 1.2 Local Geology - Mabou Mines

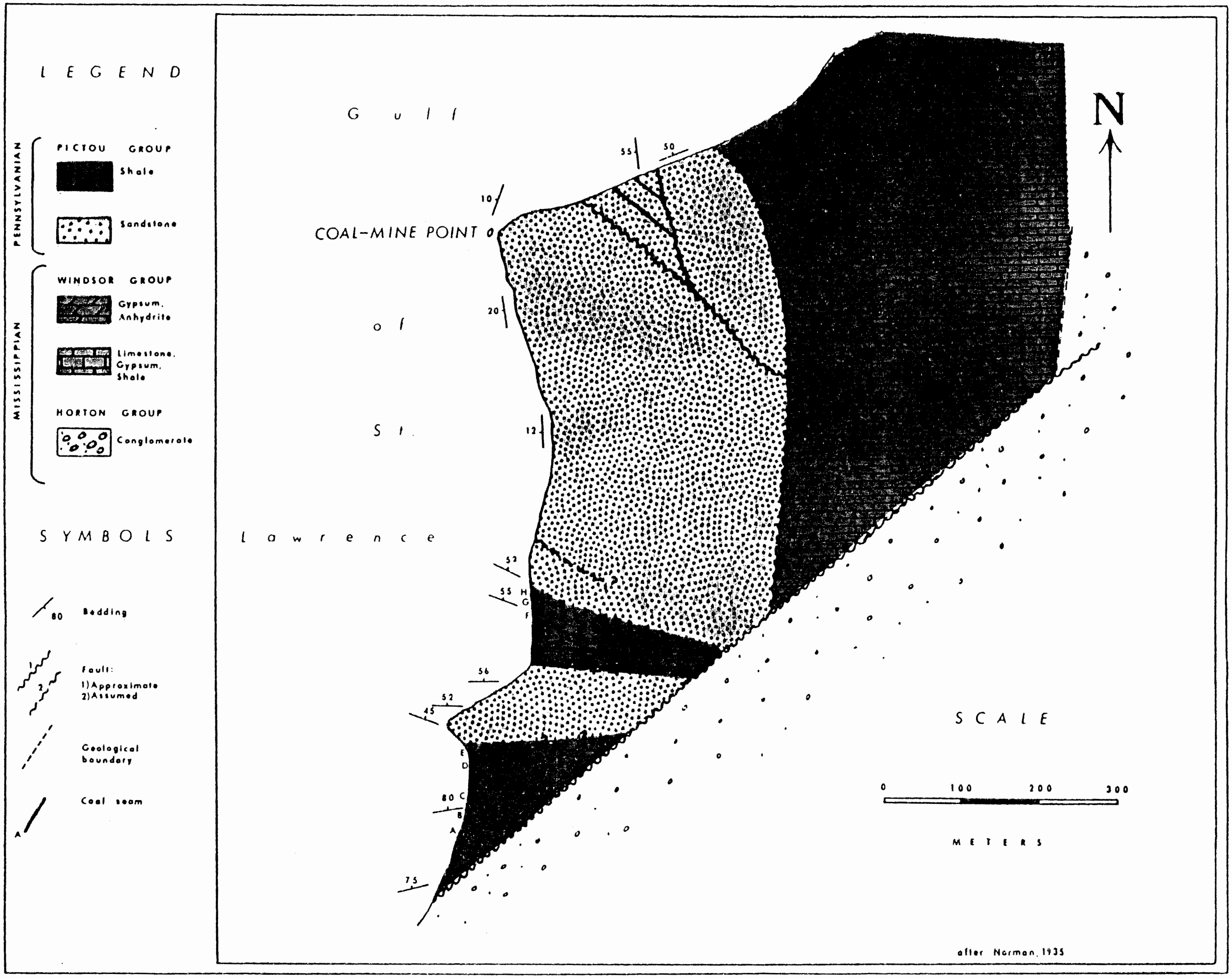


Fig. 1.3 Local Distribution of Major Lithologic Units - Mabou Mines.

where very steep cliffs occur. The presence of Visean carbonates and evaporites of the Windsor Group gives rise to karst topography, evidenced by irregular surface features near gypsum outcrops as well as by the presence of sinkholes (Fig. 1.2).

1.2 Aim of Study

This thesis studies in detail the strata at Coal-mine Point and infers the sedimentary processes that governed their deposition during Late Carboniferous time. The study involved bed-by-bed descriptions of the rocks in the cliff section and the subsequent assignment of each unit to a particular lithofacies. The depositional history can be inferred as a function of physical and ecological parameters. Later analysis determined the sedimentary environment in which this stratigraphic sequence was deposited. A correlation with other strata of comparable age from the same basin was attempted in order to more completely understand the Gulf of St. Lawrence Coal Basin in a sedimentological context.

1.3 Field Work

Field work for this project began in April, 1985, with a two week excursion to the study region. At this time, the section of interest was delineated for analysis and stratigraphic mapping was undertaken on a bed-by-bed scale with a metre-stick. Measurement was made perpendicular to bedding in order to obtain a true thickness. Most data was tabulated in the field at the base camp in Scotsville, Cape Breton. Ice cover and snowstorms during the first trip necessitated a second trip in October, 1985, to re-examine the section and complete the field work. A reconnaissance of the exposure north of Coal-mine Point (up to the Windsor evaporites- See Figs. 1.2, 1.3) showed vertical cliffs and unstable talus slopes which prevented safe mapping. As the strike of the Stack Sandstone is about parallel to the shore, it was deduced that very little sedimentologic data would be lost by omitting this portion of the section. Thus, the Stack Sandstone was recorded as a "representative section" and its precise thickness is uncertain. Further detail on this part of the shore section would necessitate photographing the cliffs from a boat, but this could not be done given the resources at hand.

This study emphasizes the section up to about 40m above the base of the Stack Sandstone, beginning at the faulted contact between the Pictou Group beds and the Horton Group conglomerate (Figs. 1.2, 1.3).

1.4 Previous Work

The earliest studies on the Mabou Mines coal-bearing sequence were in conjunction with coal mining operations begun in 1899 and terminated in 1909 when the submarine colliery on the 7' and 8' seams (See Fig. 1.2) was flooded by the sea (Norman, 1935; Hacquebard, in press). Since that time, the seams have been worked intermittently on a smaller scale by Macdonald Coal Mines Ltd. of Sydney, and some reconnaissance work on coal reserves was done around 1960-1962 by the Nova Scotia Department of Mines (Hacquebard, 1962). The most recent work was on the 15' seam in 1962 (Hacquebard, in press), and the collapsed mine workings from this venture are readily visible in the cliffs.

A general stratigraphic study was undertaken by Fletcher (1884), Norman (1935), Douglas (1944) and others. The most comprehensive study on the Mabou Mines coals was by Hacquebard in various publications over the past thirty years. These syudies focussed primarily on coal petrology with special emphasis on spore assemblages, dating and stratigraphic correlations of seams. His most recent work (Hacquebard, in press) combines seismic-stratigraphy and coal petrology to reconstruct the very complex structural deformation of the Gulf of St. Lawrence Coal Basin.

To date, however, no previous studies have centered on the sedimentology of these strata other than to suggest a fluvial origin. of St. Lawrence Coal Basin (Hacquebard, in press).

CHAPTER TWO

CARBONIFEROUS BASIN EVOLUTION

2.1 Tectonic History

The Carboniferous basins of the Maritime Provinces of Canada show many interbasinal similarities. This is ascribed to a large-scale tectonic control that imparted a particular structural grain to the region. Fralick and Schenk (1981) provided a comprehensive overview of sedimentation resulting from strike-slip(transpressional) tectonism in Devonian through Early Carboniferous time. The San Andreas Fault Zone in southwestern California is a superb example of this kind of tectonic control where strike-slip motion created numerous synchronously-filling basins with similar lithofacies assemblages (Crowell, 1974; McLaughlin _et_ _al_.). This example can be compared to the Devonian-Early Carboniferous of Eastern Canada.

The strata at Mabou Mines were deposited within the Fundy Basin (Figs. 2.1, 2.2) (Hacquebard, 1972). Belt (1963) attributed the formation of this basin to rift-valley construction, where dropped blocks of basement rock through normal faulting created horsts and grabens following the arrest of strike-slip interplate motions in Tournaisian time. Hacquebard (1972) described intermontane basins and interconnected troughs with intervening "saddles" of basement formed by normal and strike-slip faulting.

Bradley (1982) described the development of the Fundy

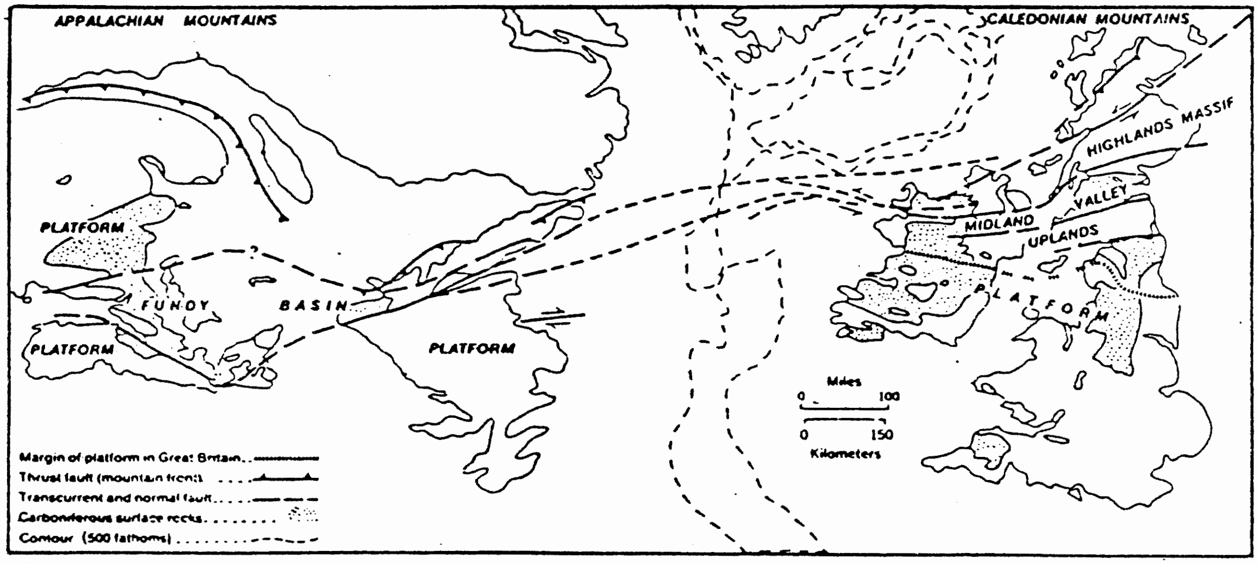


Fig. 2.1 The Fundy Basin
A reconstruction of the close association of the North American and British continental margins in the Carboniferous.

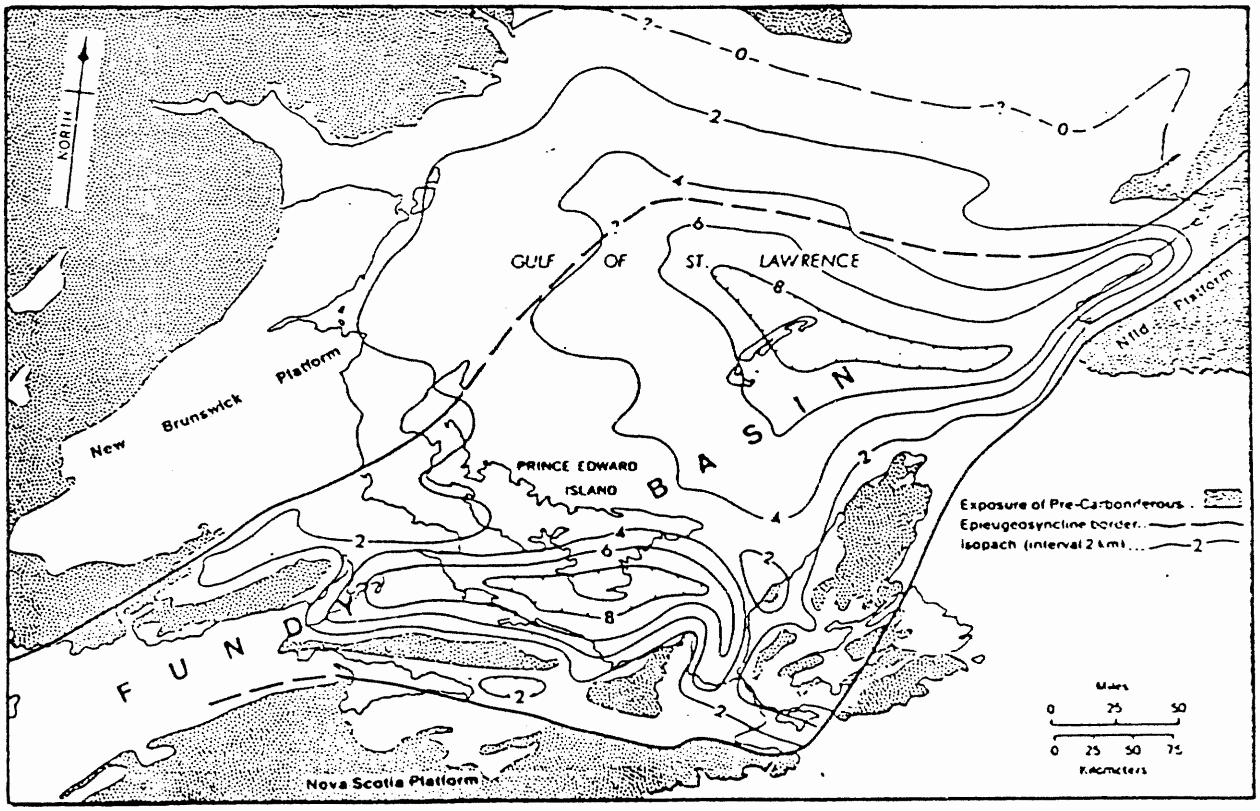


Fig. 2.2 The Fundy Basin
A detailed figure of the Fundy Basin depicts Carboniferous basin-fill thickness. (Both figures from Hacquebard, 1972)

Basin in terms of the model developed by McKenzie (1978) and Jarvis and McKenzie (1980). The thermal subsidence induced by stretched lithosphere created a downward sagging of the lithosphere in the Late Carboniferous. As a consequence, the Pictou Group sediments prograded over many of the earlier subbasins as a "blanket" of material (Fralick and Schenk, 1981; Bradley, 1982). According to Bradley (1982) the Magdalen Basin is the thermal subsidence-induced depression that is co-extensive with the Fundy Basin. The tectonic setting in the basin is that of a large pull-apart system where stretched lithosphere between the two "pulled-apart" basin margins resulted in extensive normal faulting (Bradley, 1982). The Gulf of St. Lawrence Coal Basin of Hacquebard (in press) refers primarily to the coal-bearing Pictou Group strata within the Magdalen Basin.

Post-Carboniferous faulting displaced Carboniferous strata, with a compressional event thrust-faulting lowermost Carboniferous rocks into fault-contact with Pictou Group strata in the Mabou Mines area. This was dated as probably Early Triassic (Hacquebard, in press).

2.2 Regional Carboniferous Stratigraphy

The Carboniferous record in the Maritime Provinces is generally similar in most basins, which is a reflection of large-scale tectonic controls on sedimentation.

Basal Carboniferous sedimentary strata is underlain, usually with angular unconformity or disconformity, by

Cambro-Ordovician metasedimentary rocks and Devonian granites in southwestern Nova Scotia. Devonian volcanics and pre-Carboniferous metasedimentary and metavolcanic rocks of Precambrian age occur in the Lake Ainslie map district of Norman (1935). These older units formed the uplands, which acted as a source of sediment, and the basin floors which served as depocentres throughout the Carboniferous period.

The Carboniferous of mainland Nova Scotia and Cape Breton Island can be divided into six main groups (Fig. 2.3). Originally, several of these groups were only dated on the basis of floral macrofossil assemblages. This is an excellent method, however, in several cases dating was restricted to coal measures because fossil material was rare or poorly preserved elsewhere. As a result of insufficient regional data, the Carboniferous groups were considered to be time-stratigraphic units (Bell, 1944), however, spore analysis on the entire Carboniferous allowed accurate time divisions to be made and showed that most of the Carboniferous groups were time-transgressive and so were recategorized as lithostratigraphic units (Hacquebard et al., 1960; Barss and Hacquebard, 1967; Hacquebard, 1972). In many cases, the spore assemblages closely followed the fossil macrofloral divisions of the Maritime and European Carboniferous (Figs. 2.4, 2.5).

The Horton Group of Tournaisian to Visean age represents the lowest occurrence of strata in the Maritime Carboniferous basins. Good descriptions were made by Bell (1929), Norman (1935), Weeks (1948) and others. The coarse strata of this group have been interpreted as a marginal facies to the fault-bounded, steep-sided basins, formed as coalesced bajadas fed by sporadic torrential streams. Braided fluvial and lacustrine facies are the more distal equivalents (Bell, 1929; 1944).

Visean marine carbonates of the Windsor Group onlapped Horton Group strata as a result of rapid marine transgression (Schenk, 1967; 1969). Thick accumulations of anhydrite, gypsum, potash, halite and terrigenous strata comprise the upper part of the Windsor Group and indicate an arid environment (Schenk, 1967; Evans, 1970).

Clastics of continental origin continued to fill the basins after Windsorian time. The Canso, Riversdale and Cumberland Groups (Fig. 2.3) represent fluvial to lacustrine sedimentation with alluvium derived from upland sources. The lithofacies assemblages point to an arid, continental-interior basin environment (Bell, 1944; Fralick and Schenk, 1981; McCabe and Schenk, 1982). The last pulse of sediment was deposited over the entire basin system due to regional downwarping of the lithosphere with associated normal faulting (Bradley, 1982). This thick clastic cover of mid- to late Westphalian age, the Pictou Group, is entirely continental and was deposited in fluvial-fluviolacustrine systems with extensive peat swamps. These swamps were to become the most extensive coal deposits in the Maritime Provinces (Hacquebard, 1972; McCabe and Schenk, 1981; Hacquebard, 1985).

The Pictou Group contains from 100m to 2400m (maximum

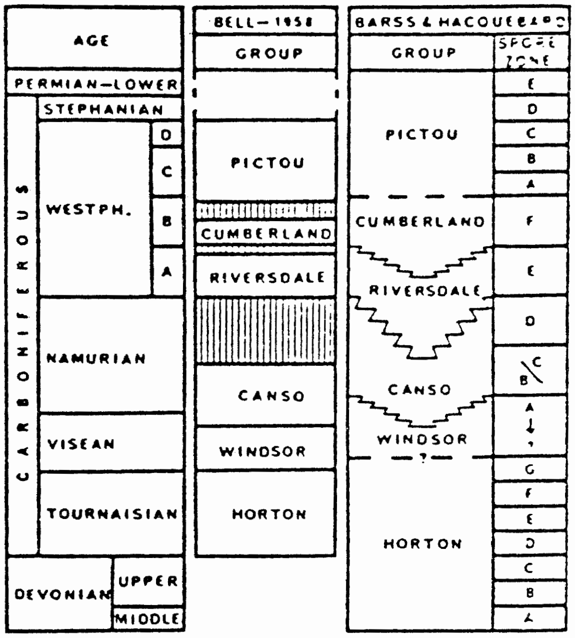
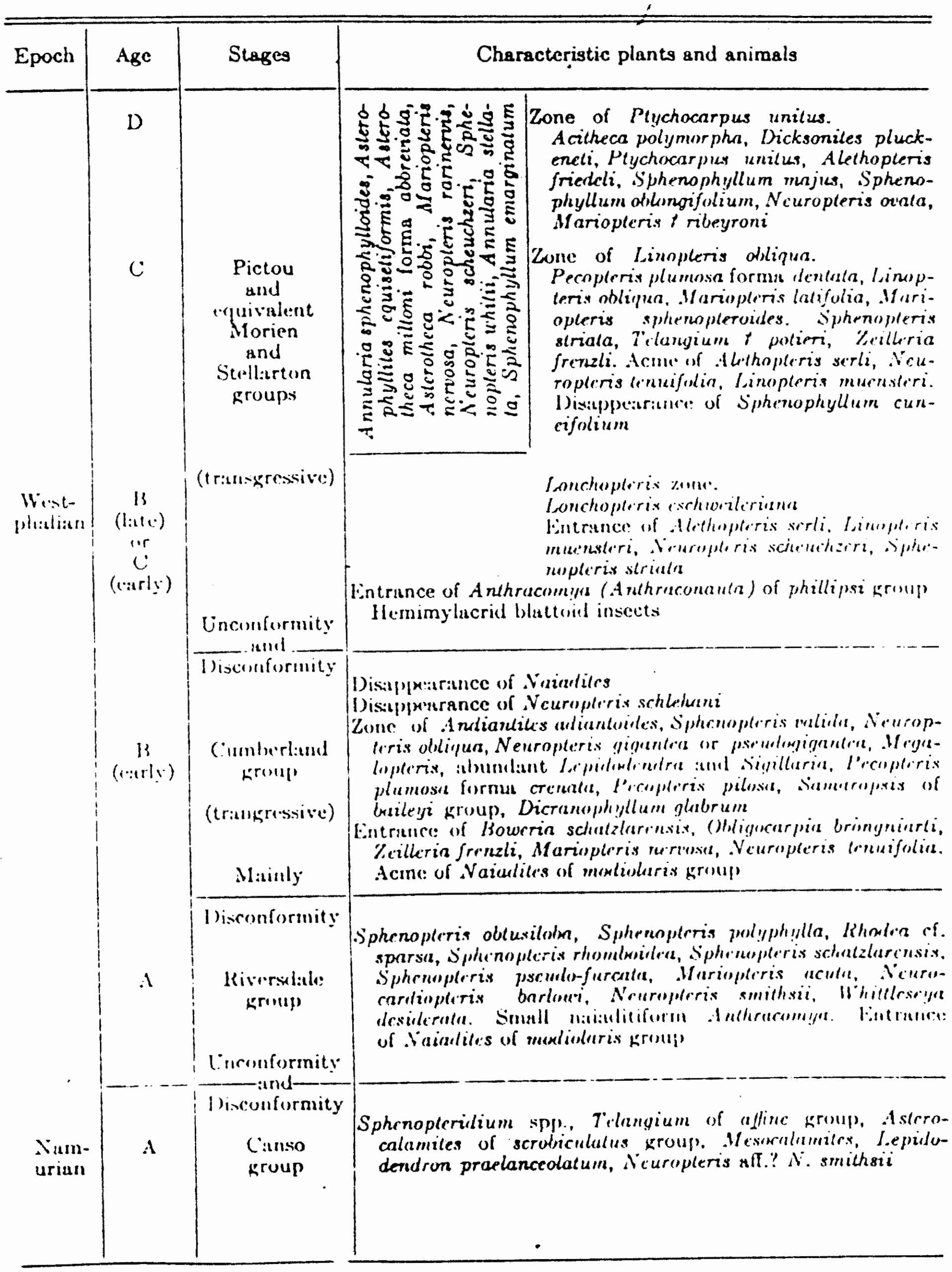


Fig. 2.3 Stratigraphic Divisions of the Maritimes (from Barss and Hacquebard, 1967).

<table>
<tr><th colspan="9">DISTRIBUTION OF SMALL SPORE GENERA</th><th colspan="3" rowspan="2">MARITIME STRATIGRAPHY</th><th colspan="2">CORRELATION WITH EUROPE</th></tr>
<tr><th colspan="9"></th><th>MICROFLORA</th><th>MEGAFLORA</th></tr>
<tr><td rowspan="9">*Lycospora, Endosporites, Punctatisporites, Raistrickia, Reticulatisporites, Leiotriletes, Calamospora,*
Granulatisporites, Lophotriletes, Cyclogranisporites, Verrucosisporites, Apiculatisporis, Microreticulatisporites</td><td rowspan="8">*Laevigatosporites, Punctatosporites, Camptotriletes, Pustulatisporites, Florinites*</td><td rowspan="6">*Planisporites, Acanthotriletes*</td><td rowspan="5">*Triquitrites, Foveolatisporites, Converrucosisporites,*
Wilsonia, (cf.) Illinites, Cirratriradites, gen. nov. A & B</td><td rowspan="4">*Verrucososporites, Torispora*</td><td rowspan="3">*Guthorlisporites, Murospora*</td><td rowspan="2">*Schopfites, Mooreisporites*</td><td>*Savitrisporites*</td><td>DIVISION V B 2: *Knoxisporites*
Rare: *Torispora*
Without: *Anapiculatisporites*</td><td>Upper</td><td rowspan="2">*Ptychocarpus unitus* zone</td><td rowspan="5">PICTOU GROUP</td><td rowspan="4">WESTPH. D</td><td rowspan="2">WESTPH. D</td></tr>
<tr><td colspan="2">DIVISION V B 1: *Alatisporites, Anapiculatisporites,* gen. nov. C
Rare: *Densosporites* (one seam only)
Acme: *Verrucososporites*
Without: *Knoxisporites*</td><td>Lower</td></tr>
<tr><td colspan="3">DIVISION V A 2: *Alatisporites, Dictyotriletes, Anapiculatisporites,* gen. nov. C
Rare: *Cadiospora* (one seam only)
Without: *Knoxisporites*</td><td>Upper</td><td rowspan="2">*Linopteris obliqua* zone</td><td rowspan="3">WESTPH. C</td></tr>
<tr><td colspan="4">DIVISION V A 1: *Knoxisporites*
Without: *Anapiculatisporites, Alatisporites, Dictyotriletes, Cadiospora,* gen. nov. C</td><td>Lower</td></tr>
<tr><td colspan="5">DIVISION IV: *Vestispora, Alatisporites, Anapiculatisporites, Mooreisporites, Knoxisporites, Cristatisporites, Convolutispora, Dictyotriletes*</td><td colspan="2">*Lonchopteris* zone</td><td>WESTPH. C</td></tr>
<tr><td colspan="6">DIVISION III: *Cristatisporites, Convolutispora, Anapiculatisporites*
Rare: *Densosporites*
Acme: *Lycospora*
Without: *Knoxisporites*</td><td colspan="3">CUMBERLAND GROUP</td><td colspan="2">WESTPHALIAN B</td></tr>
<tr><td colspan="7">DIVISION II B: *Cristatisporites, Convolutispora, Callisporites, Knoxisporites*
Rare: *Florinites* and Monolete spores
Without: *Densosporites, Anapiculatisporites*
N.B.: Appearance of genera erratic</td><td colspan="3">RIVERSDALE GROUP</td><td colspan="2" rowspan="2">WESTPHALIAN A</td></tr>
<tr><td colspan="7">DIVISION II A: *Densosporites, Callisporites,* (cf.) *Grandispora, Knoxisporites, Cristatisporites, Convolutispora, Triquitrites*
Rare: *Florinites* and Monolete spores
Without: *Anapiculatisporites*</td><td colspan="3">"HOWLEY BEDS", NFLD.</td></tr>
<tr><td colspan="8">DIVISION I: *Stenozonotriletes,* thick perispore types (*Spinozonotriletes, Leiozonotriletes*), *Grandispora, Densosporites, Convolutispora, Knoxisporites, Triquitrites, Cirratriradites, Acanthotriletes*
Without: *Anapiculatisporites*</td><td colspan="3">CANSO GROUP
(Pomquet River Section only)</td><td colspan="2">NAMURIAN A
(Mississippian)</td></tr>
</table>

Fig. 2.4 Comparison of Spore Assemblages of Europe and the Maritime Provinces (From Hacquebard et al., 1960).



Epoch	Age	Stages	Characteristic plants and animals
Westphalian	D	Pictou and equivalent Morien and Stellarton groups	*Annularia sphenophylloides, Asterophyllites equiseliformis, Asterotheca milloni* forma *abbreviata, Asterotheca robbi, Mariopteris nervosa, Neuropteris rarinervis, Neuropteris scheuchzeri, Sphenopteris whitii, Annularia stellata, Sphenophyllum emarginatum* Zone of *Ptychocarpus unitus.* *Acitheca polymorpha, Dicksonites pluckeneti, Ptychocarpus unitus, Alethopteris friedeli, Sphenophyllum majus, Sphenophyllum oblongifolium, Neuropteris ovata, Mariopteris ? ribeyroni*
	C		Zone of *Linopteris obliqua.* *Pecopteris plumosa* forma *dentata, Linopteris obliqua, Mariopteris latifolia, Mariopteris sphenopteroides. Sphenopteris striata, Telangium ? potieri, Zeilleria frenzli.* Acme of *Alethopteris serli, Neuropteris tenuifolia, Linopteris muensteri.* Disappearance of *Sphenophyllum cuneifolium*
	B (late) or C (early)	(transgressive) Unconformity and	*Lonchopteris* zone. *Lonchopteris eschweileriana* Entrance of *Alethopteris serli, Linopteris muensteri, Neuropteris scheuchzeri, Sphenopteris striata* Entrance of *Anthracomya (Anthraconauta)* of *phillipsi* group Hemimylacrid blattoid insects
	B (early)	Disconformity Cumberland group (trangressive) Mainly	Disappearance of *Naiadites* Disappearance of *Neuropteris schlehani* Zone of *Andiantites adiantoides, Sphenopteris valida, Neuropteris obliqua, Neuropteris gigantea* or *pseudogigantea, Megalopteris,* abundant *Lepidodendra* and *Sigillaria, Pecopteris plumosa* forma *crenata, Pecopteris pilosa, Samaropsis* of *baileyi* group, *Dicranophyllum glabrum* Entrance of *Bowenia schatzlarensis, Obligocarpia brongniarti, Zeilleria frenzli, Mariopteris nervosa, Neuropteris tenuifolia.* Acme of *Naiadites* of *modiolaris* group
	A	Disconformity Riversdale group Unconformity and	*Sphenopteris obtusiloba, Sphenopteris polyphylla, Rhodea* cf. *sparsa, Sphenopteris rhomboidea, Sphenopteris schatzlarensis, Sphenopteris pseudo-furcata, Mariopteris acuta, Neurocardiopteris barlowi, Neuropteris smithsii, Whittleseya desiderata.* Small naiaditiform *Anthracomya.* Entrance of *Naiadites* of *modiolaris* group
Namurian	A	Disconformity Canso group	*Sphenopteridium* spp., *Telangium* of *affine* group, *Asterocalamites* of *scrobiculatus* group, *Mesocalamites, Lepidodendron praelanceolatum, Neuropteris* aff.? *N. smithsii*

Fig. 2.5 Characteristic Plants and Animals of the Upper Carboniferous in the Maritimes (From Bell, 1944).

of 2700m in the Pictou coalfield) of siliciclastics that can be divided into a lower, red-coloured non-coal-bearing unit and an upper, grey-coloured coal-bearing sequence. It is the grey facies, deposited in lacustrine, palludal and flood-plain environments, that contains most of the economically significant Maritime coal measures, including those of Pictou, Mabou, Inverness and Sydney (Hacquebard, 1972). In general, Upper Pictou strata represent extensive fluvial and flood-plain environments containing extensive forests of Lycopods and peat buildups in swamps. The equivalent Stellarton Group in central Nova Scotia has been attributed to a limnic environment whereas the Cape Breton Pictou Group coalfields were considered to be part of a large paralic basin, although associated marine beds are lacking (Hacquebard, 1985; Gibling, personal communication).

The sandstones and shales at Mabou Mines have been placed within the Inverness Formation of the Pictou Group (Norman, 1935). According to miospore data from the 7', 8' and 15' coal seams at Coal-mine Point, these rocks fall into the Torispora spore zone (spore zone B) (Hacquebard et al., 1960; Hacquebard, 1962; Barss and Hacquebard, 1967). Faunal assemblages (invertebrate) give a late Westphalian C to Westphalian D age (Vasey et al., 1983; 1985) which is in agreement with the spore data of Hacquebard (1962).

CHAPTER THREE

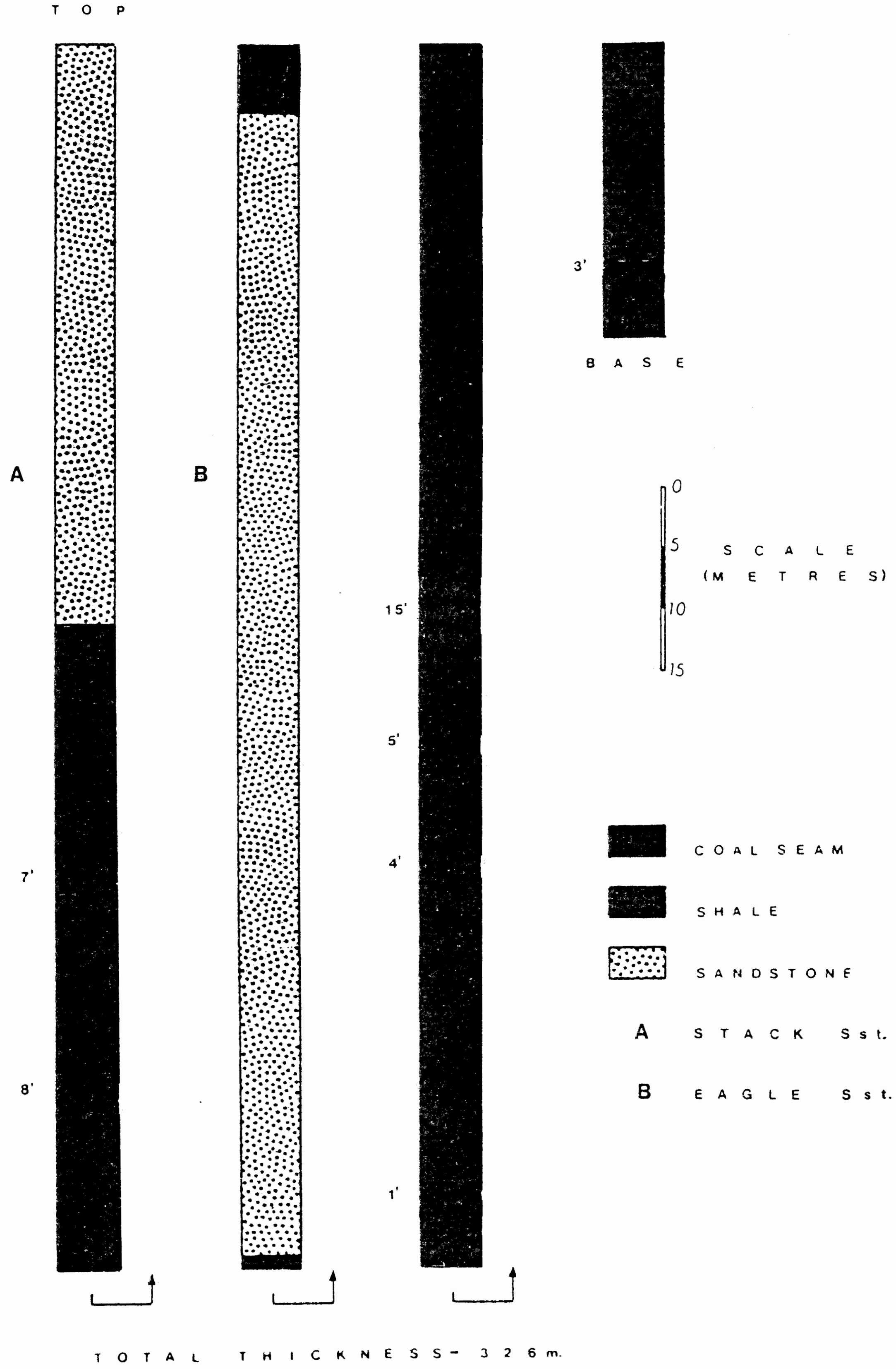
STRATIGRAPHIC SECTION

3.1 Explanation

A graphical display is the best way to show data in order to obtain a quick understanding of sedimentological changes through a stratigraphic section. The drafted section (Fig. 3.2) is an idealized one and depicts the cliff section at Coal-mine Point. A lithofacies log of lesser detail is presented at a much smaller scale (Fig. 3.1) for comparison with the study area maps (Figs. 1.2, 1.3). A descriptive guide to the detailed section is found in Appendix A.

It must be noted that the thickness of the measured section is depicted as 320m although 326m was measured. This is due to the fact that the last few metres are very similar. Also, a true thickness was difficult to obtain in the field due to high cliffs and a faulted upper contact.

Fig. 3.1 LITHOFACIES LOG



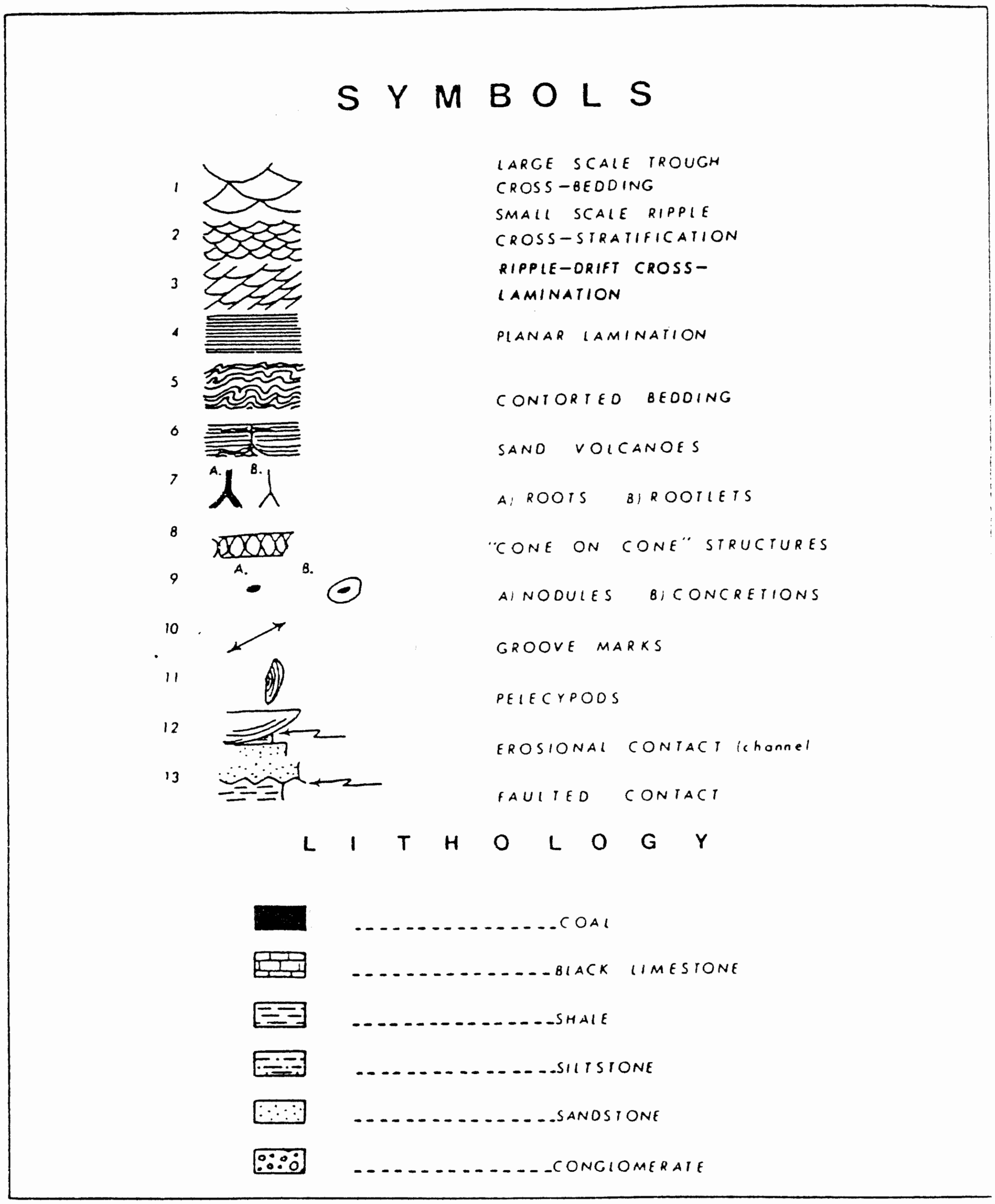


Fig. 3.2a List of Symbols for Stratigraphic Column

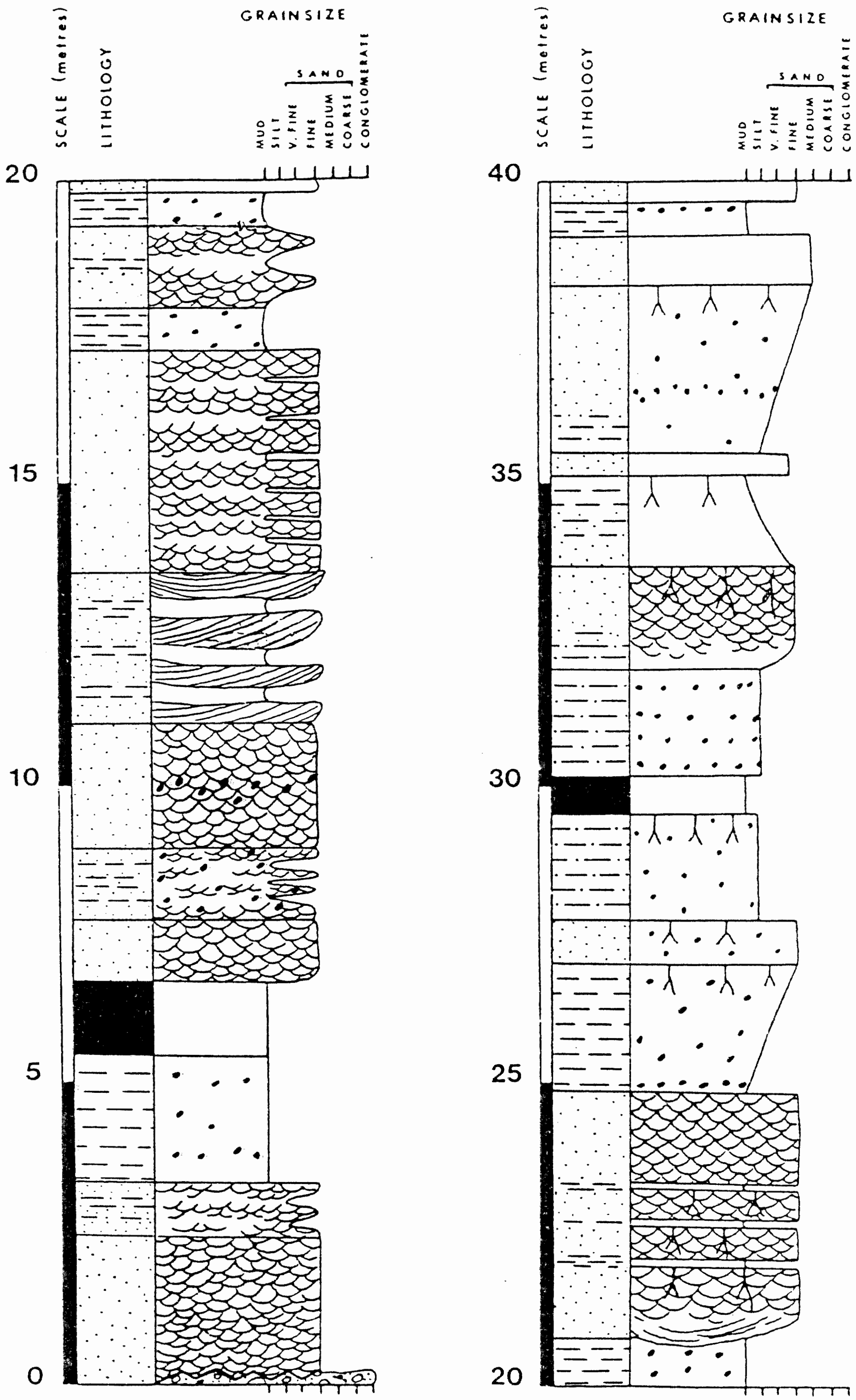
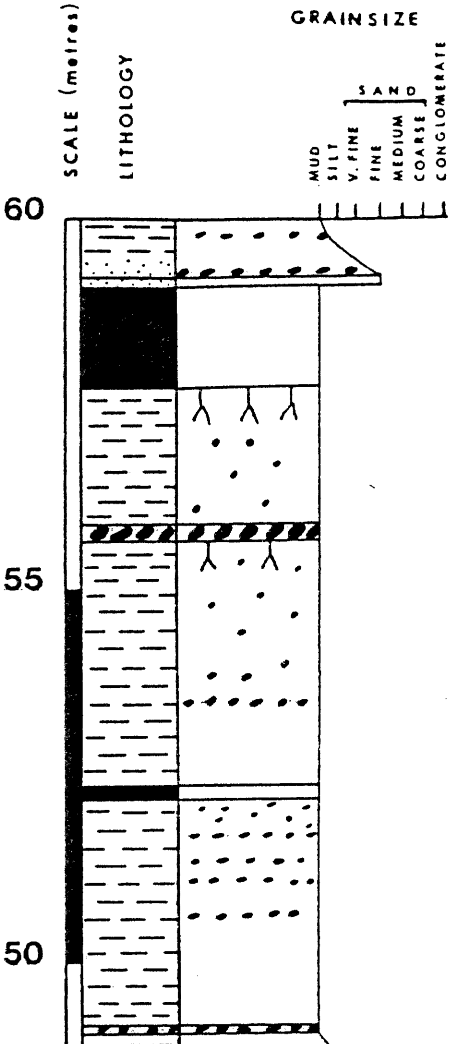


Fig. 3.2 Detailed Stratigraphic Column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MUD
SILT
V. FINE
FINE
MEDIUM
COARSE
CONGLOMERATE
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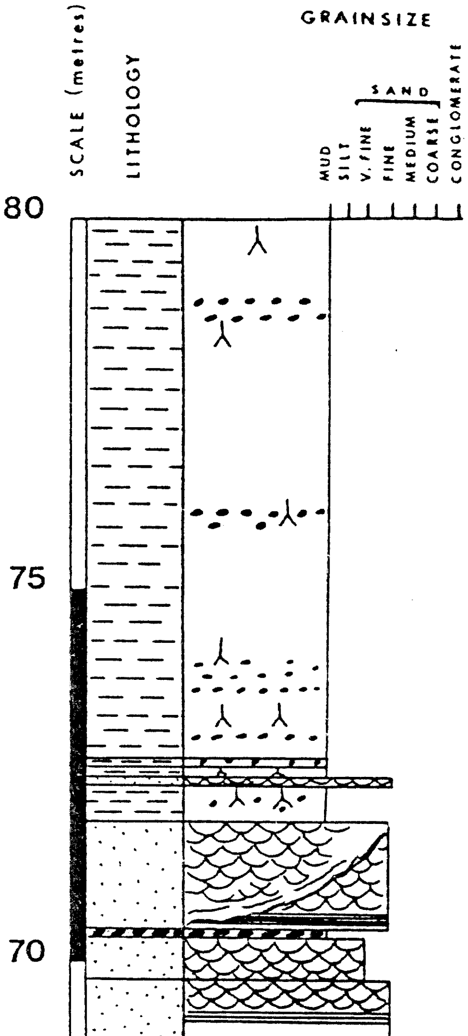
55
50
45
40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SILT
V. FINE
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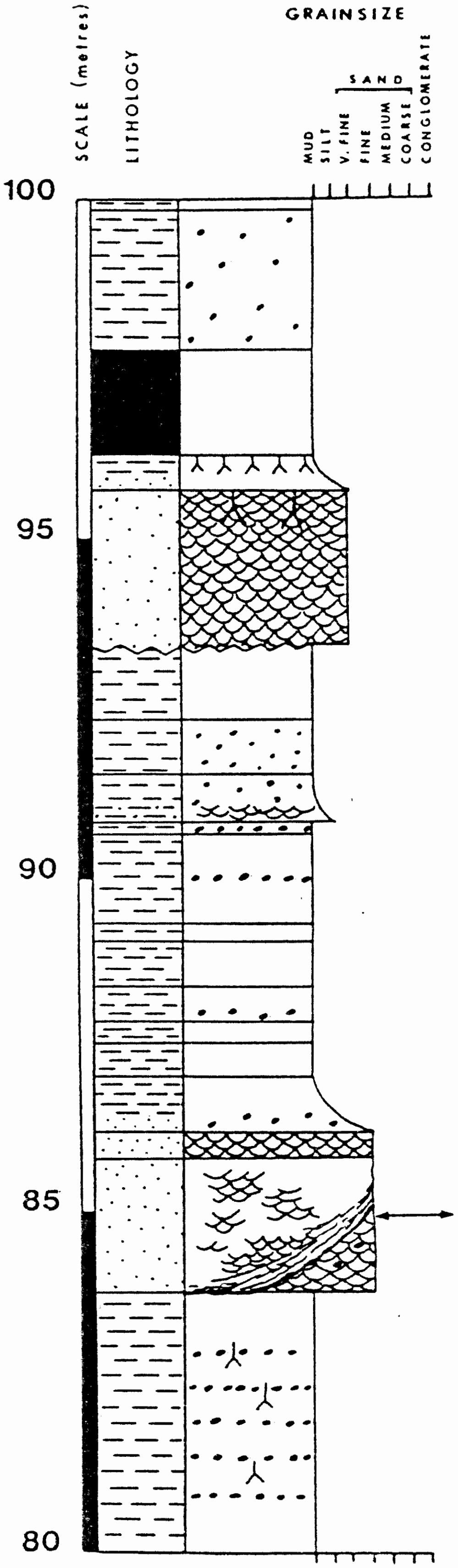
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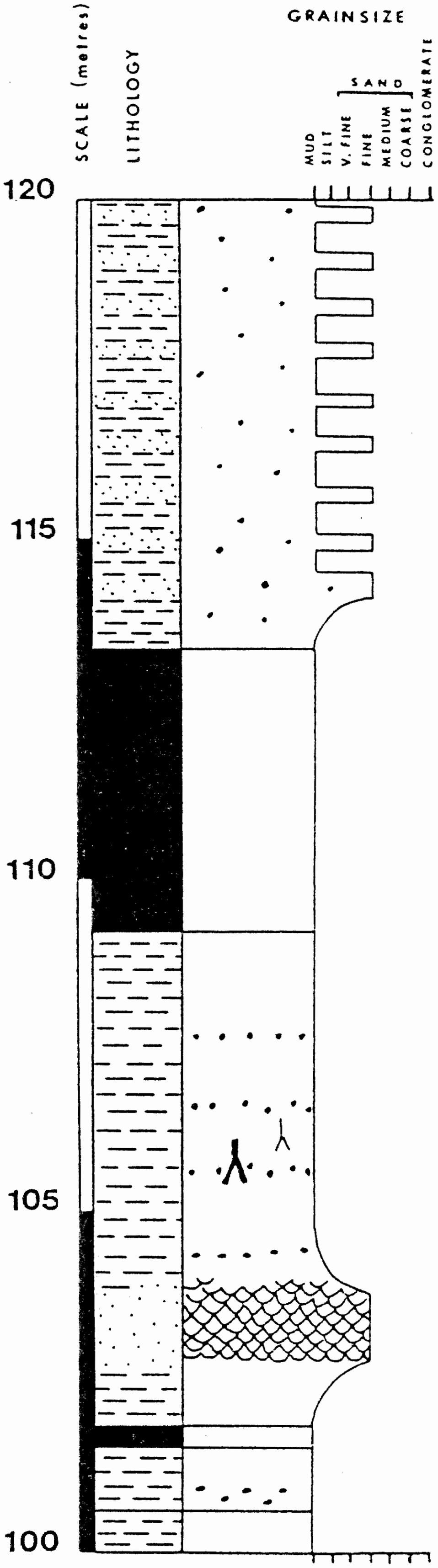
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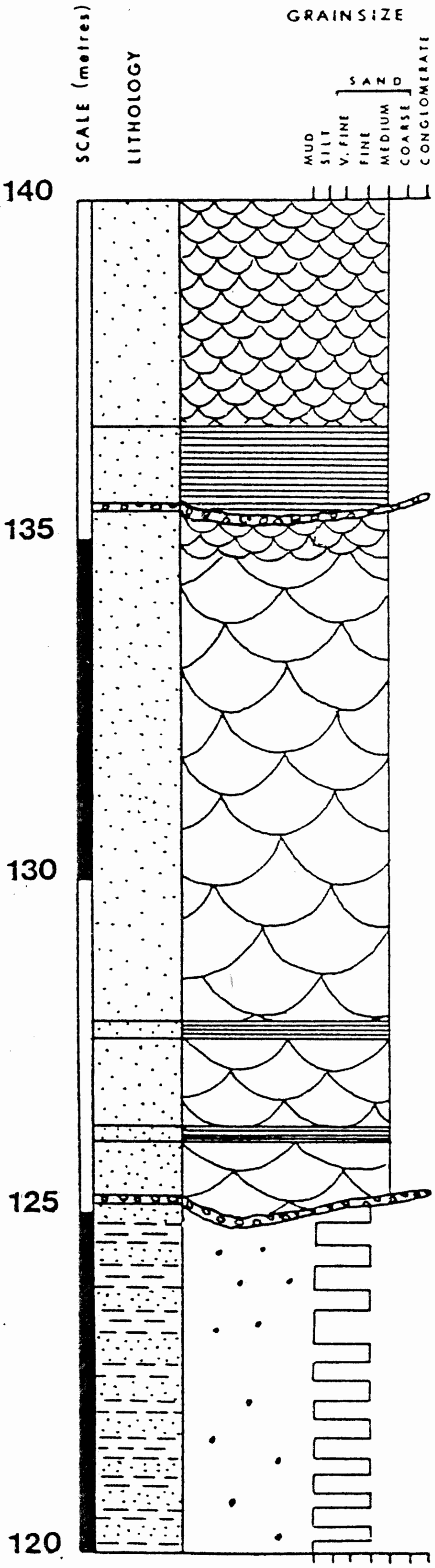
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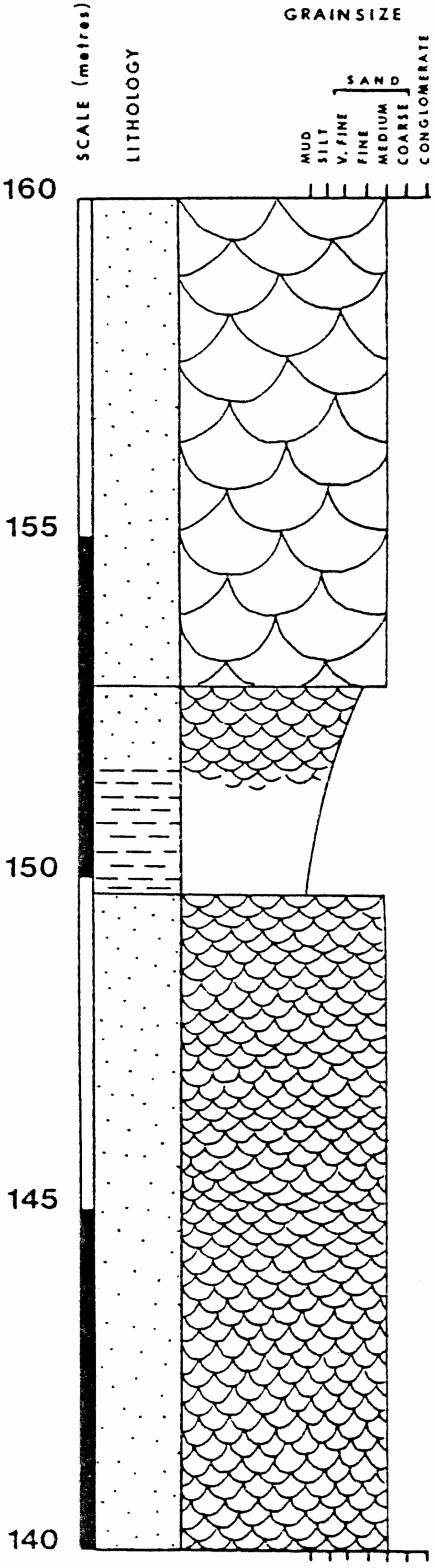
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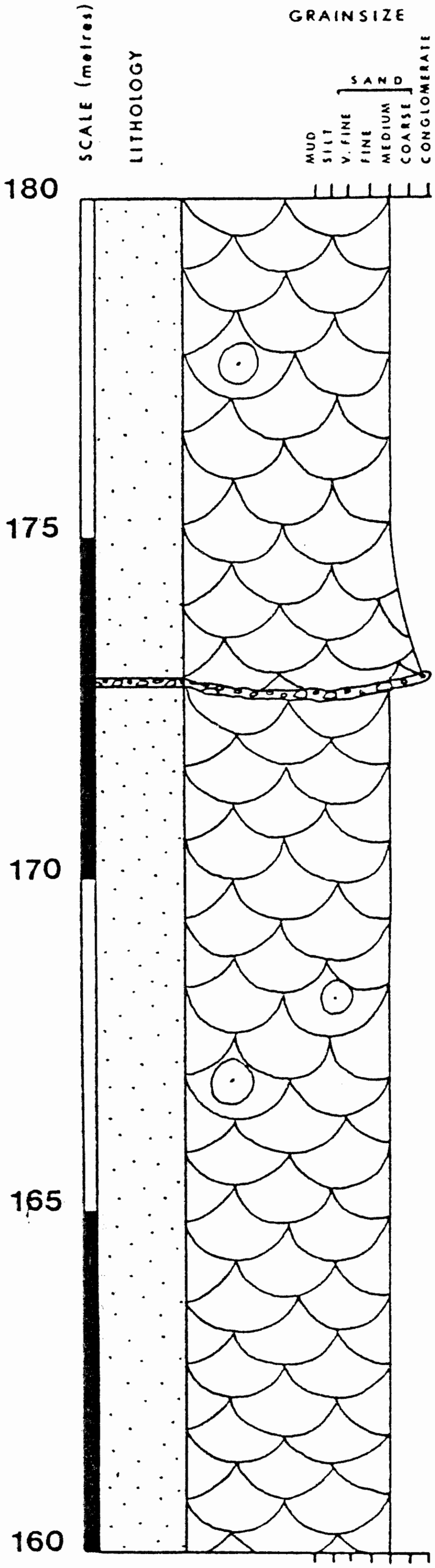
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V. FINE
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MEDIUM
COARSE
CONGLOMERATE
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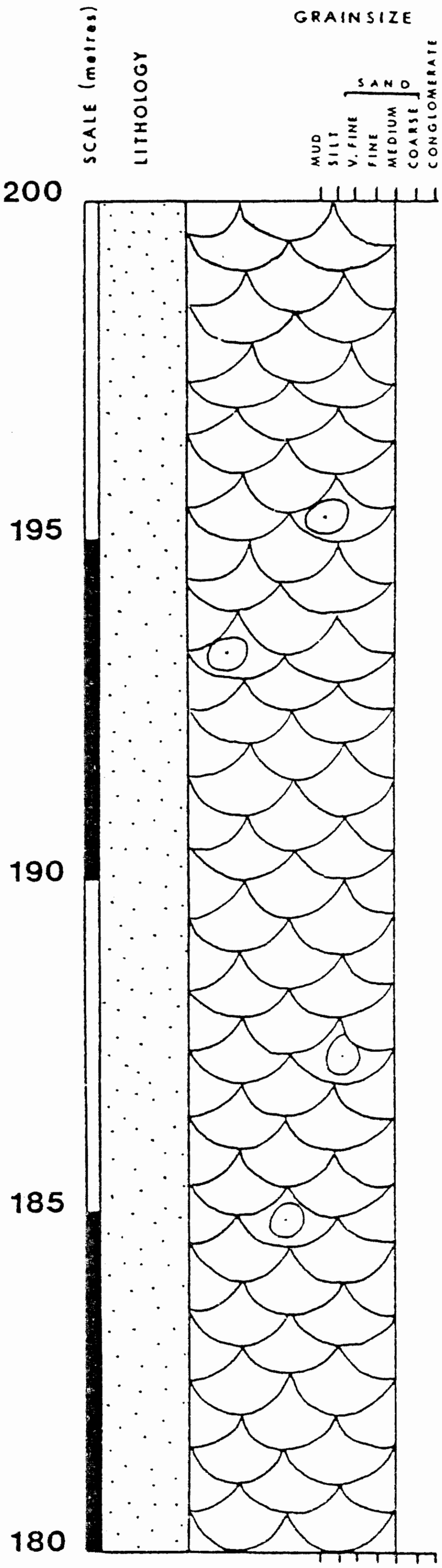
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V. FINE
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COARSE
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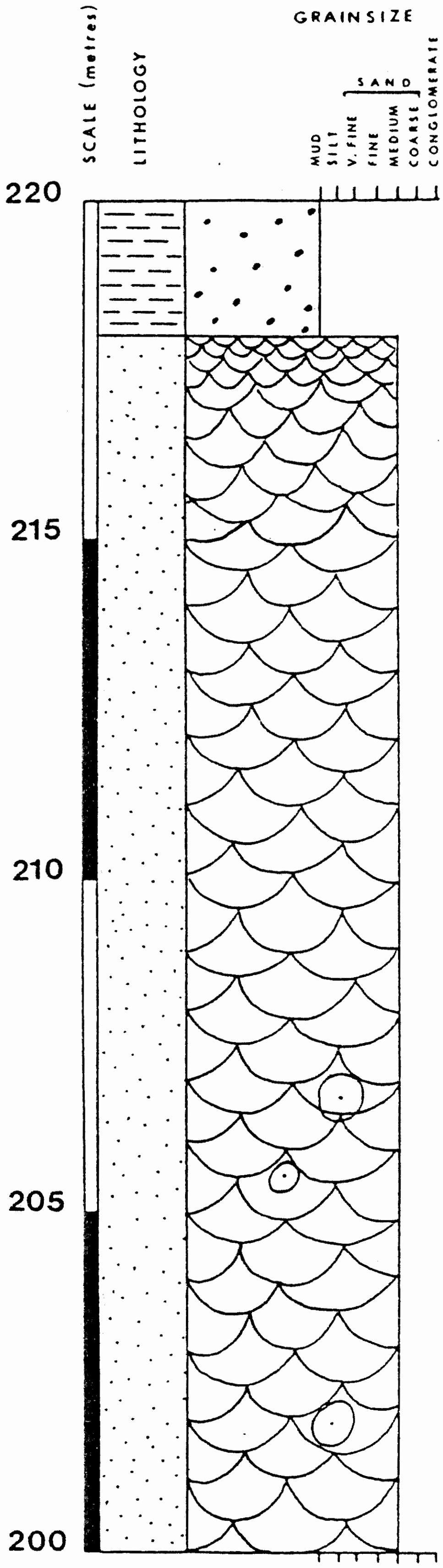
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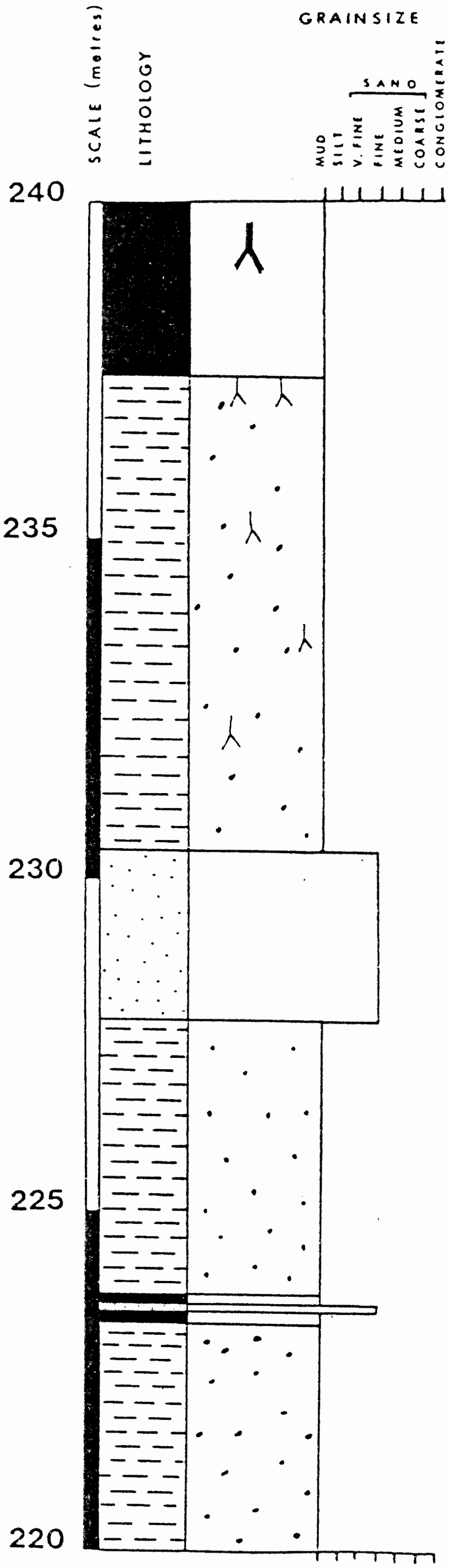
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SILT
V. FINE
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MEDIUM
COARSE
CONGLOMERATE
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225
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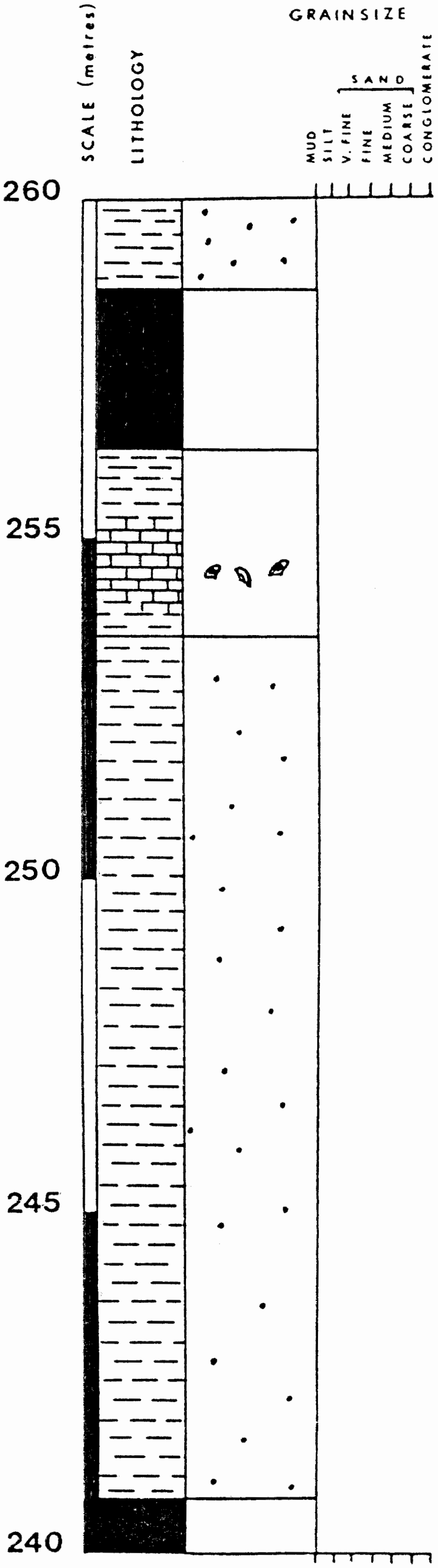
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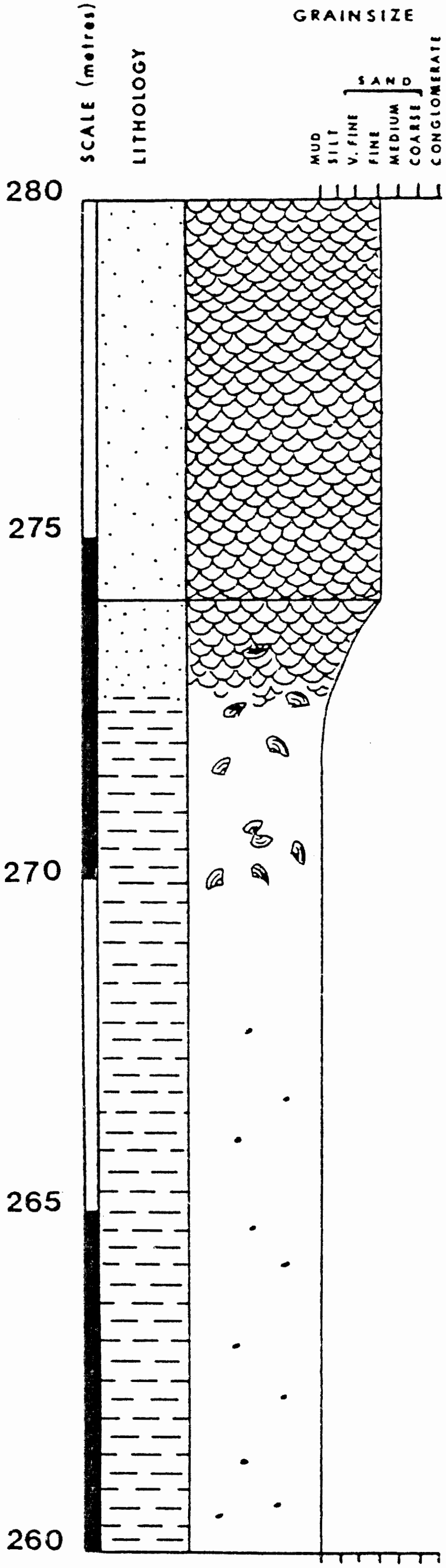
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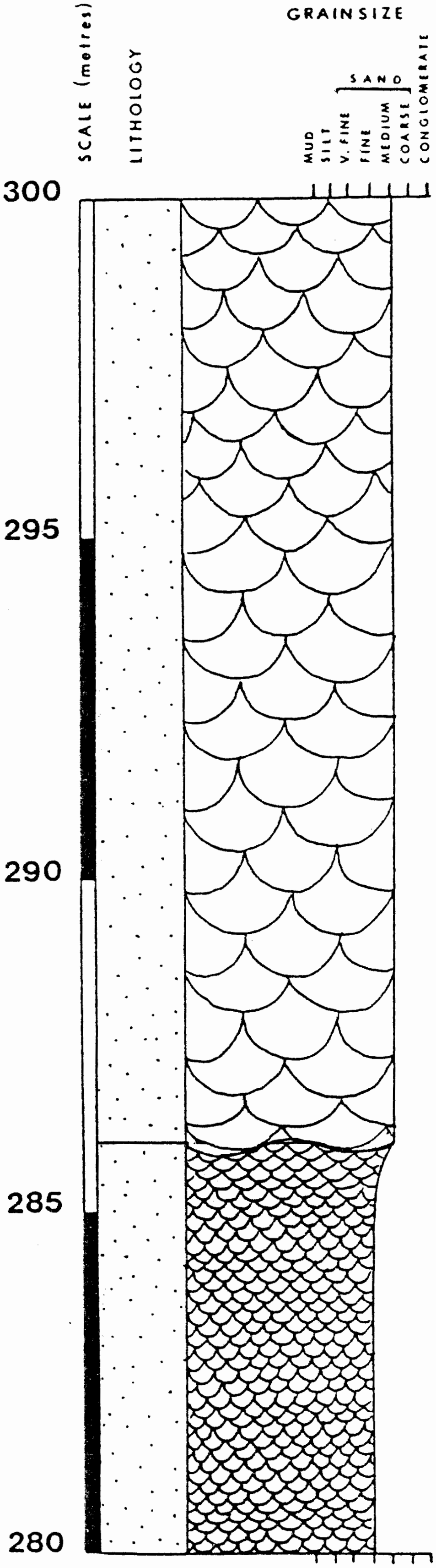
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MEDIUM
COARSE
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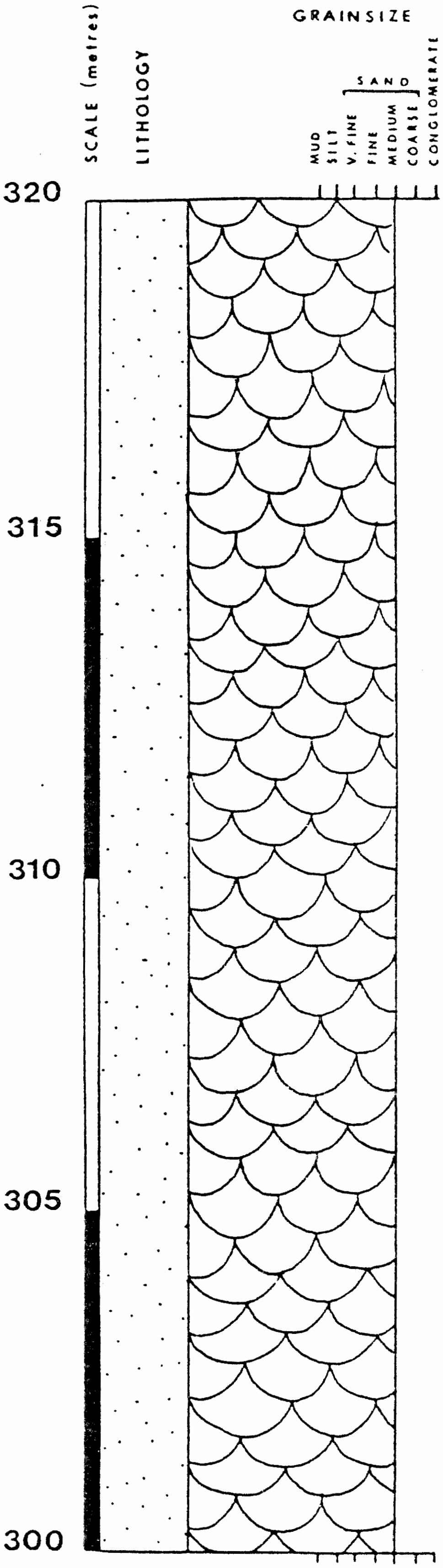
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GRAINSIZE
SAND
MUD
SILT
V. FINE
FINE
MEDIUM
COARSE
CONGLOMERATE
320
315
310
305
300

3.2 Correlation Within the Basin

Hacquebard (1962) correlated the coal seams of Coal-mine Point to those of Finlay Point on the basis of microlithotypes and spore assemblages. The 7' and 8' seams of the Coal-mine Point section were correlated to coal horizons in onland and offshore boreholes and to the 2' seam at Finlay Point. The 15' seam was correlated to the 5' seam of Finlay Point and an 11' seam present offshore was projected to an inferred position in the Coal-mine Point section. Using borehole and outcrop data, Hacquebard (1962) correlated the cliff section of Coal-mine Point to that of Finlay Point. The Eagle Sandstone and the upper shale member thin toward Finlay Point until they merge to form the Point Sandstone, according to Hacquebard (1962). The coal seam correlations are assumed to be correct, however, a detailed sedimentologic study of the Finlay Point section shows a thick sandstone unit immediately below the 2' seam (Deal, in progress). The correlations of Hacquebard (1962) between the two major outcroppings of Pictou Group strata in the Mabou Mines region show a major thinning trend of the Eagle Sandstone and the upper shale member. A major thinning trend is also seen in the 15' seam, where it becomes the 5' seam of Finlay Point. Due to the extremely poor nature of the outcrop northeast of Coal-mine Point and the fact that it is faulted, plus the fact that the sandstone units seen in core and in outcrop do not agree with the data of Hacquebard (1962), it is assumed that fault action displaced the Eagle Sandstone from where it should have been exposed in the cliff section northeast of Coal-mine Point. This agrees much more strongly with present sedimentological evidence than does the interpretation that the Eagle Sandstone simply pinches out. In summary, the Stack Sandstone correlates with a sandstone unit above the 2' seam at Finlay Point. Also, the Eagle Sandstone correlates with another sandstone above the Finlay Point 5' seam. As facies are similar for all of these sandstone units, all of these sandstone bodies have erosional lower contacts, and the intervening shale unit (upper shale member) pinches out laterally toward Finlay Point, it is reasonable to assume that the Eagle and Stack Sandstones merge somewhere beyond Finlay Point and essentially become a single unit. This agrees with the correlations of Hacquebard (1962).

Based on these correlations, it has been possible to suggest a three-dimensional correlation with outcrops and offshore boreholes. Using the Stack Sandstone as a correlatable horizon (this is the reflector horizon for the Mabou offshore seismic survey) in the basin, several three-dimensional sandstone sheets have been delineated (Hacquebard, in press). The Stack Sandstone and coal seam correlations of Hacquebard (in press) have been projected to other sandstone bodies within the basin in order to obtain a three-dimensional view of the basin lithosomes. Some of the correlations are tenuous, however, the strong evidence of the coal seam correlations plus those of the two Mabou Mines

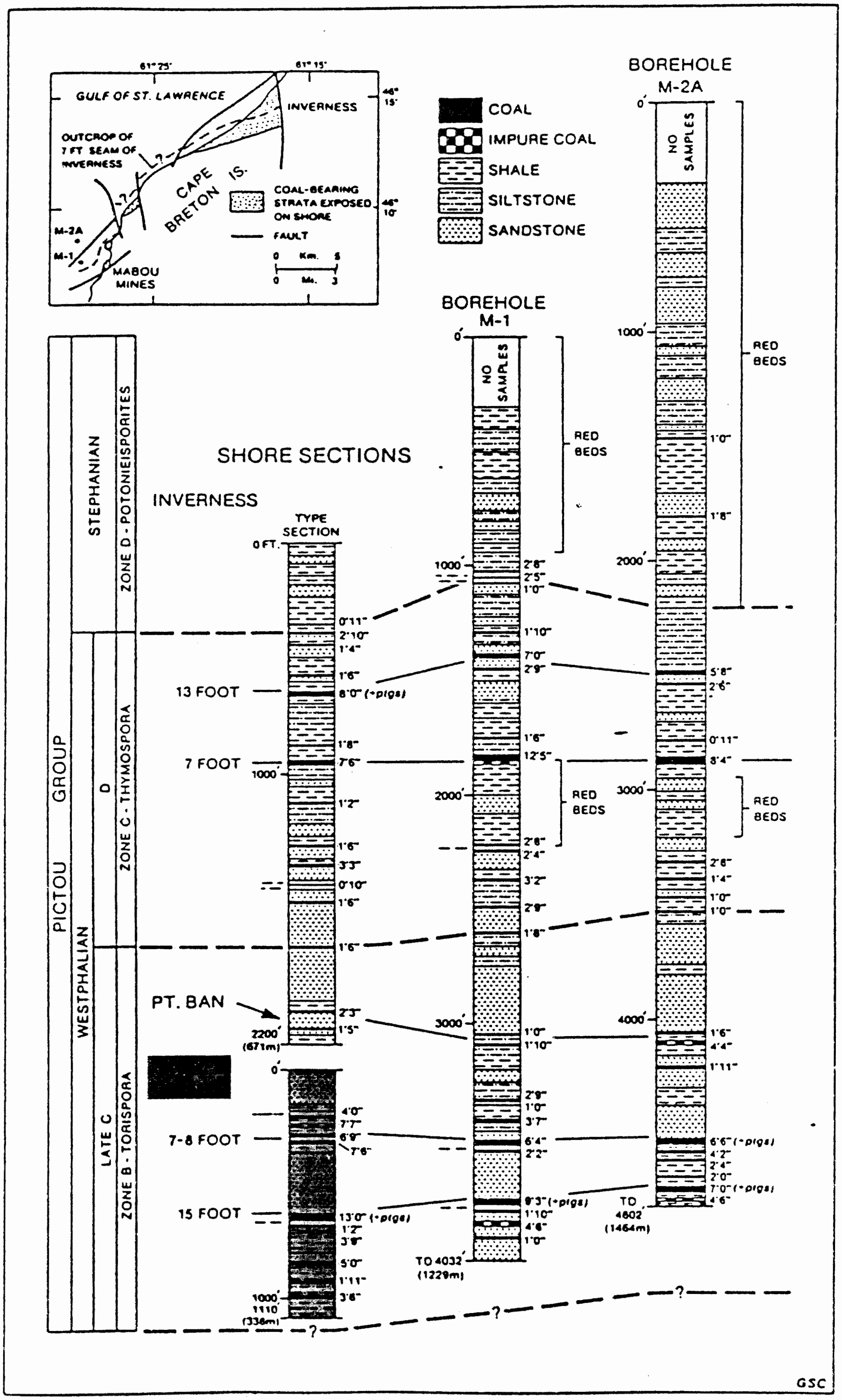
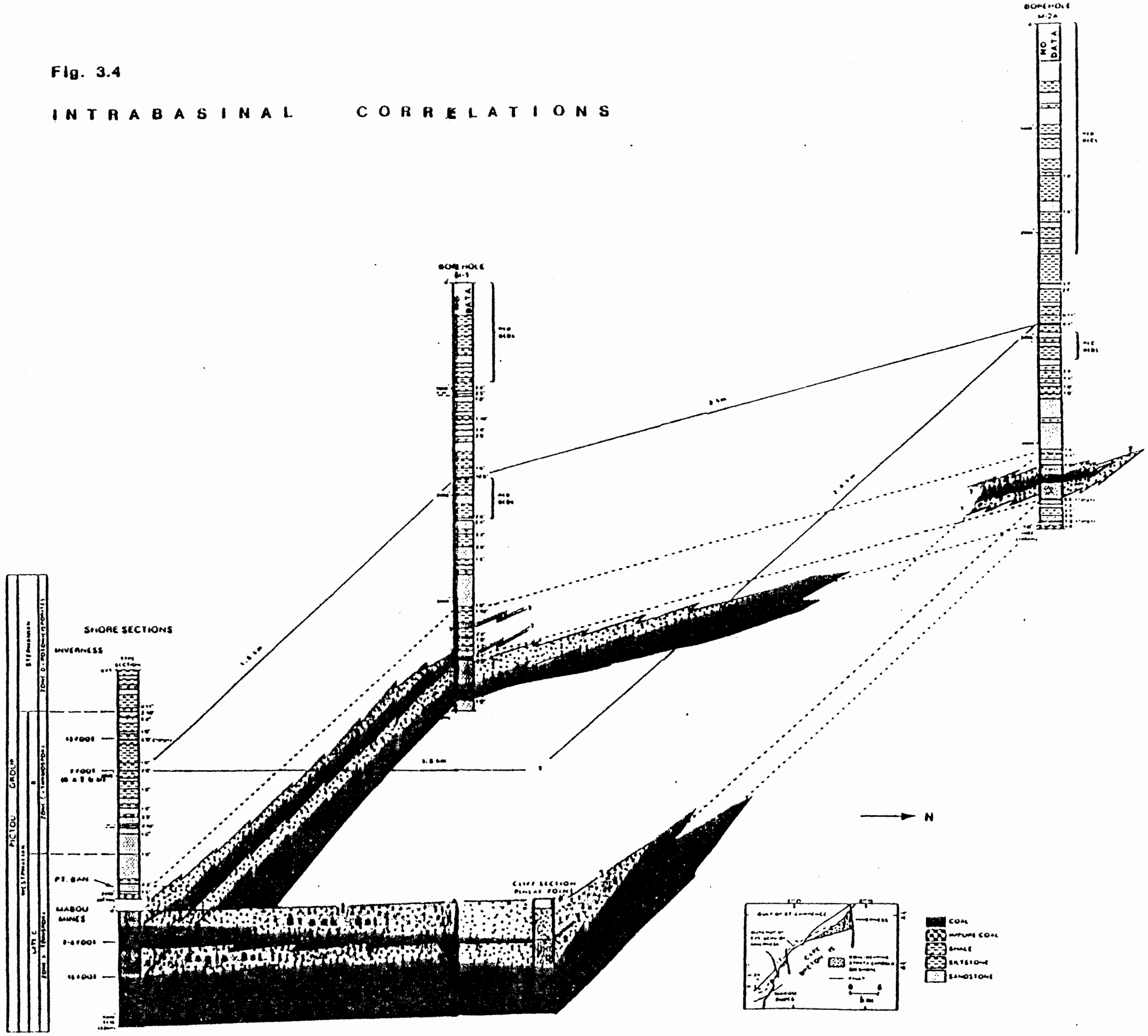


Fig. 3.3 Correlations of Seams in Offshore Boreholes with Seams in the Mabou Mines Section (From Hacquebard, in press).

Fig. 3.4

INTRABASINAL CORRELATIONS



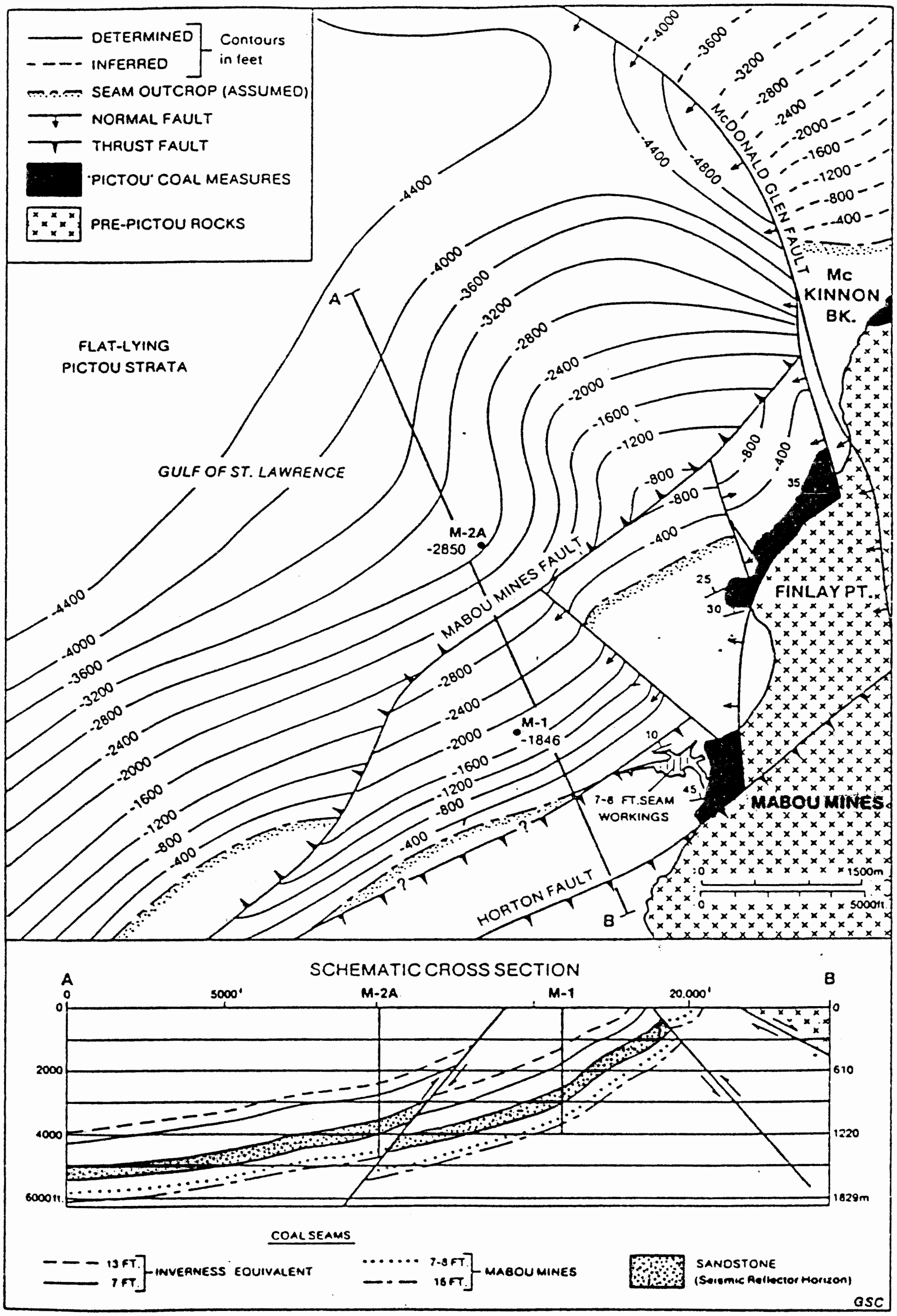


Fig. 3.5 Structural Reconstruction of the Mabou Mines Area (From Hacquebard, in press).

outcrops indicates that these projected correlations are reasonable based on the available data (See Figs. 3.3, 3.4).

The effect that a three-dimensional correlation into the basin has on the interpretation of these units will be dealt with later in the text.

Based on the seam correlations and coal ranks, Hacquebard (in press) attempted a structural history of the Mabou Mines region. According to the data (Fig. 3.5), the 7'-8' seam section is much farther offshore at Finlay Point than at Coal-mine Point and might be interpreted as being older at a glance. This is simply the effect of thrust-faulting having affected the Coal-mine Point section while the Finlay Point section was dropped as part of a normal faulted block (See Fig. 3.5).

The result of the correlations places much of the Mabou Mines strata at a lower stratigraphic level than those of the Inverness coalfield (Hacquebard, in press) and the major portion of the two offshore boreholes. Finlay Point is of comparable age to Coal-mine Point and very probably represents deposition from the same system in Westphalian time.

The data indicates that the strata dip steeply seaward close to shore at Mabou Mines, with the dip angle decreasing gradually farther out into the basin until the strata are nearly flat-lying (Hacquebard, in press). The continuous nature of the strata make the Gulf of St. Lawrence Coal Basin the largest in eastern Canada, with an area exceeding

46 620 km^2 (Hacquebard, in press).

The coal seams increase in quality toward the basin center reflected by a decrease in sulphur and ash content. More data will be presented on the coal in a later chapter.

CHAPTER FOUR

LITHOFACIES

4.1 Introduction

Each bed in the cliff section at Mabou Mines can be assigned to one of nine states. These states, or lithofacies, are recognized on the basis of lithology, grain size, sedimentary structures, fossil content and colour. Each lithofacies results from a different set of sedimentary processes, including sediment load and transport, compaction and dewatering, and assemblages of flora and fauna in situ or as organic debris.

The lithofacies have been assigned symbols according to a classification scheme devised by Miall (1978) for the analysis of fluvial systems. This code can be applied to all of the Mabou Mines facies except for the black limestone and the organic-rich planar-laminated sandstone. In these two cases, additional codes were devised by the author.

The relative abundance of facies at Coal-mine Point is displayed in Table 2.

4.2 Lithofacies Descriptions

1) COAL AND CARBONACEOUS SHALE (Figs. 4.1, 4.2)

Facies Code: C

Grain Size: N/A

Colour: Black

Sedimentary Structures: None

Fossils: Generally unidentifiable plant debris. In the 8' seam very large roots (up to 18cm diam.) are present. Roots and rootlets are present beneath coal seams. Bivalves and ostracods, present in interbeds of black limestone, are found rarely within the seams themselves.

Nodules: None

Other: Disseminated pyrite with associated Fe-staining is present. In the carbonaceous shales, leaves and twigs from _Neuropteris_ and _Cordaites_ can be distinguished. Coals are of bituminous C rank.

Interpretation

Roots and seat-earths point to an autochthonous origin for the coal seams. Carbonaceous shales contain compressed pinnules and tiny stems, suggesting that there was a large contribution of woody material. The general interpretation of this facies is that it represents _in situ_ floral growth within a swamp environment.

2) BLACK LIMESTONE (Fig. 4.3)

Facies Code: Lst

Grain Size: N/A

Colour: Dark grey to black

Sedimentary Structures: Some planar lamination is defined by bivalves and rare, isolated pinnules of _Neuropteris_.

Fossils: This facies consists of 75% to 80% shell fragments and complete valves of bivalves and ostracods within a limestone matrix. Tiny coalified plant fragments are locally abundant and generally increase in concentration gradually toward the top or base of the facies.

Nodules: None

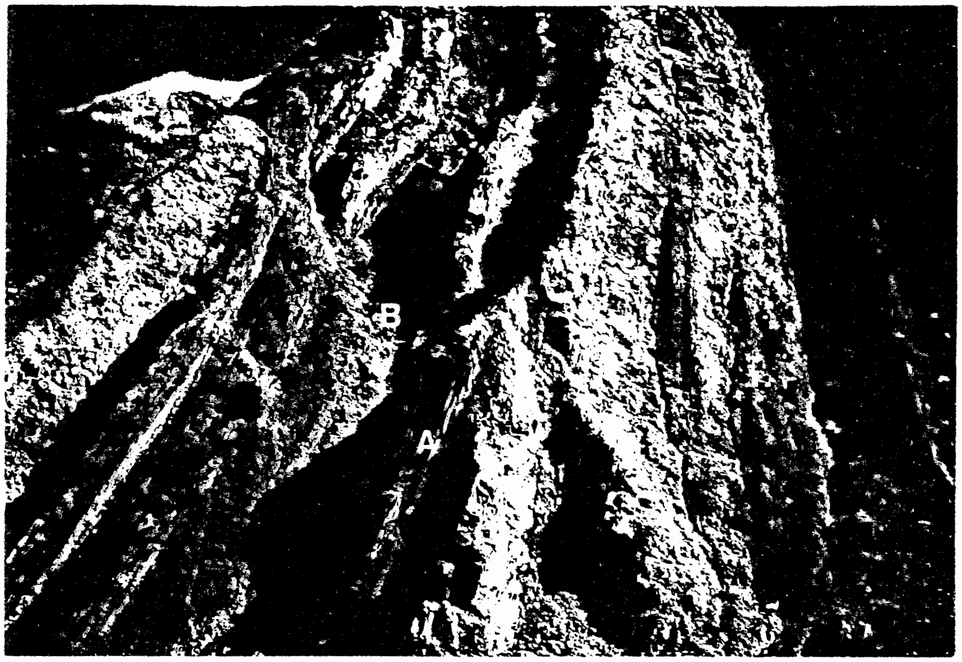


Fig. 4.1: Facies C:A: 5' seam B: Minor fault

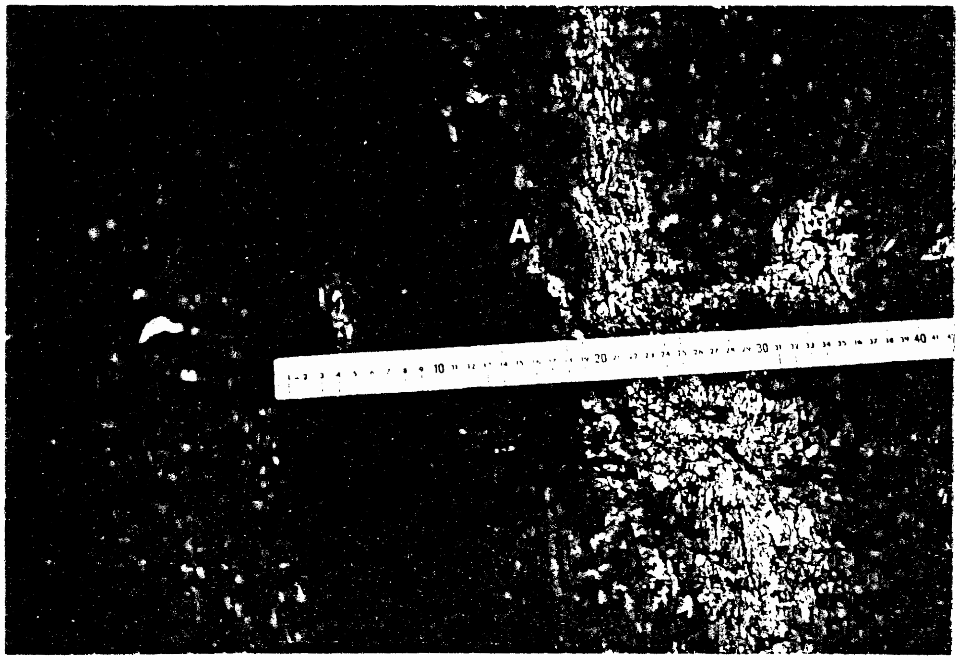


Fig. 4.2: Facies C:A: Thin band of durain and fusain

Fig. 4.3 Facies Lst : Abundant bivalves Anthraconauta phillipsii

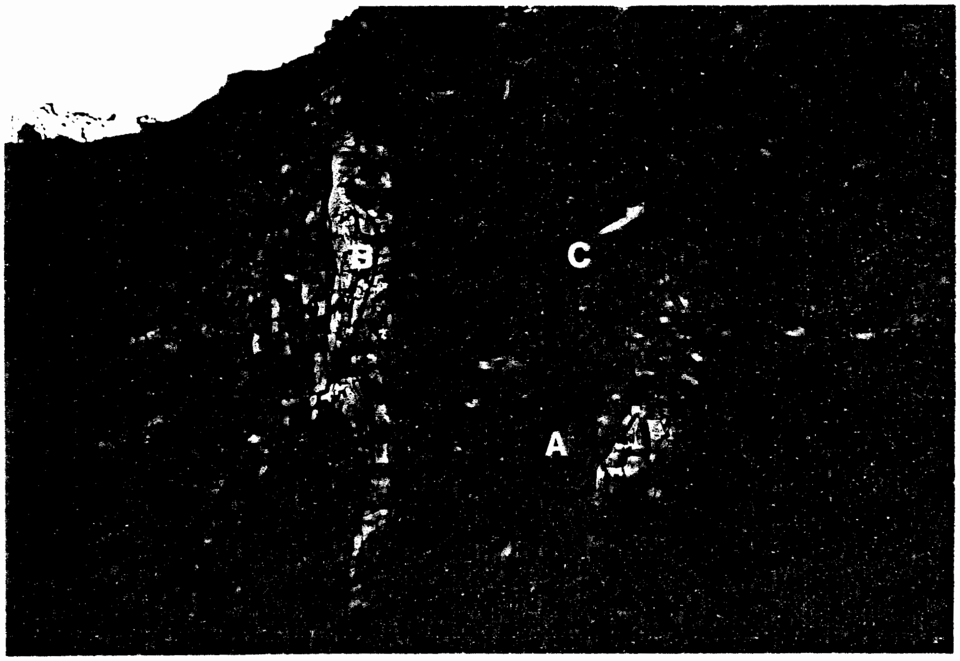


Fig. 4.4 Facies Fsc, Sr: A: Facies Fsc B: Small channel in Facies Sr sandstones C: Minor fault

Other: This facies rarely exceeds thicknesses of 10 to 15cm without being separated by partings of carbonaceous shale. Diagenetic cone-in-cone structures are fairly common.

Interpretation

The faunal assemblage indicates a shallow lacustrine system. Increasing plant material points to an increasingly toxic system resulting in the death of the faunal community and re-establishment of peat growth. A decrease in plant material suggests that flooding "drowned" the peat and established a shallow lake in which a faunal community became established.

3) SHALE AND SILTSTONE (Fig. 4.4)

Facies Code: Fsc

Grain Size: Clay to silt

Colour: Light to dark grey, depending on organic content. Rarely brown or brown-purple.

Sedimentary Structures: Massive; rarely small-scale ripple cross-lamination is present in silty layers.

Fossils: Stigmarian roots and rootlets are very abundant, particularly directly beneath coal seams. Neuropteris tenuifolia and Cordaites principalis (Bell, 1944) are common as debris rather than as in situ growth.

Nodules: Nodules are extremely abundant in this facies and possess a great variety of shapes and sizes. They are common in rooted horizons, often preserving rootlets, uncompressed, in three dimensions.

Other: Bioturbation is extremely common and is identified by rootlets or inferred from conchoidal fracturing (Gibling, personal communication).

Interpretation

The fine grain size and absence of sedimentary structures implies that this facies was deposited from suspension in ponding water. Roots and rootlets plus excessive amounts of foliage as debris indicate a thick vegetative cover. This facies is indicative of sedimentation resulting from overbank flooding of a low-energy fluvial system (Coleman, 1966).

4) GREY, CROSS-LAMINATED FINE SANDSTONE (Figs. 4.5, 4.6, 4.8)

Facies Code: Sr

Grain Size: Fine sand (interbeds of clay to silt)

Colour: Light grey

Sedimentary Structures: Small-scale ripple cross-stratification predominates. Rare ripple-drift cross-lamination (Fig. 4.6), contorted bedding and sand volcanoes are present also. Interbeds of shale are frequent.

Fossils: Stigmarian roots are present but rare. *Calamites*, *Neuropteris* and *Sphenopteris* are the major flora present but are rarely *in situ*.

Nodules: The nodules in this facies are commonly smaller, rounder and more spherical than in the other facies.

Other: Ripple-drift cross-lamination is present between sequences of cross-laminated snadstone at rare occurrences. Sand volcanoes are present over contorted bedding. Fining-upward sequences are common.

Interpretation

Small-scale ripple cross-stratification indicates unidirectional current flow. Lower flow regime conditions prevailed, evident from the sedimentary structures. Ripple-drift cross-lamination is indicative of low velocity - high sediment load deposition. Contorted bedding and sand volcanoes formed from dewatering of rapidly-deposited sand. Fining-upward sequences give evidence for several pulses of sedimentation with waning flow strength (Harms *et al.*, 1982).

5) GREY, MASSIVE TO PLANAR-LAMINATED SANDSTONE (Fig. 4.7)

Facies Code: Sh

Grain Size: Fine to medium sand

Colour: Light grey to pale yellow

Sedimentary Structures: This facies is commonly massive, but planar lamination with primary current lineation is common also.

Fossils: These units are conspicuously devoid of fossil material.

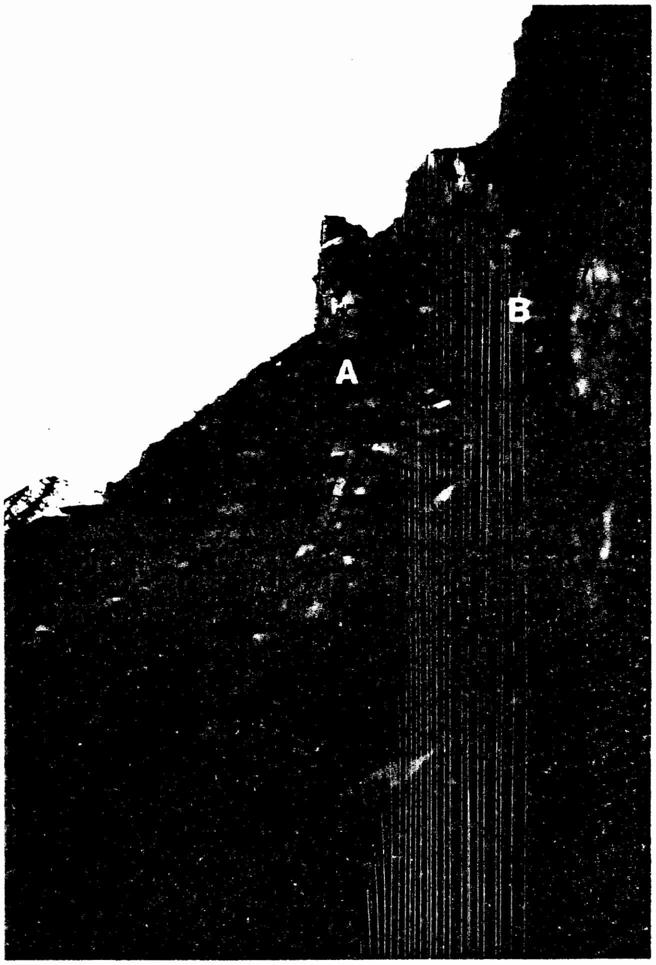


Fig. 4.5 Facies Sr: A: Minor channel, B: Interbedded sandstone/shale

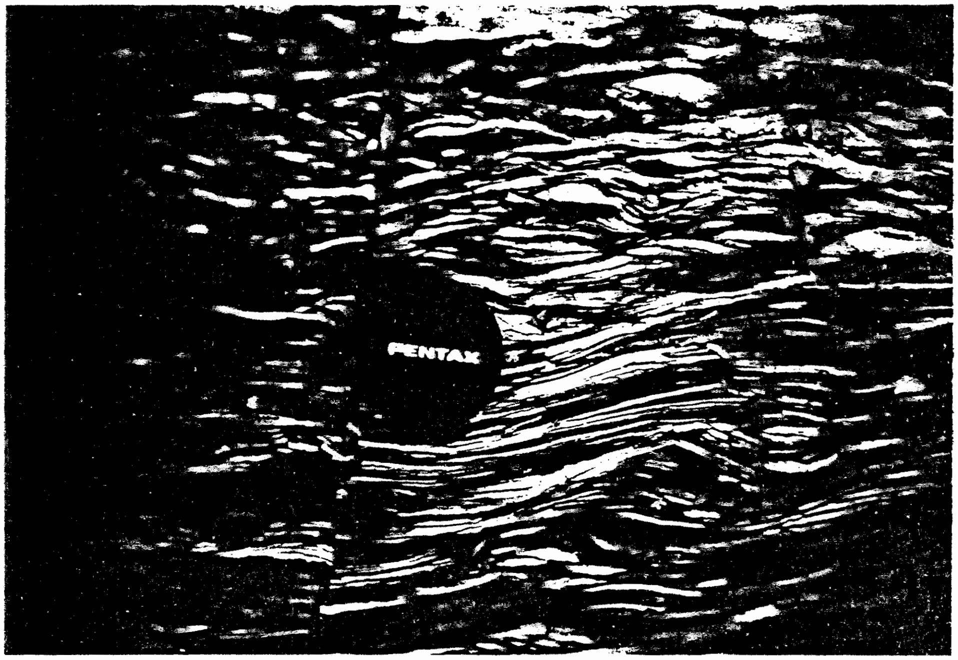


Fig. 4.6 Facies Sr: Ripple-drift cross-lamination

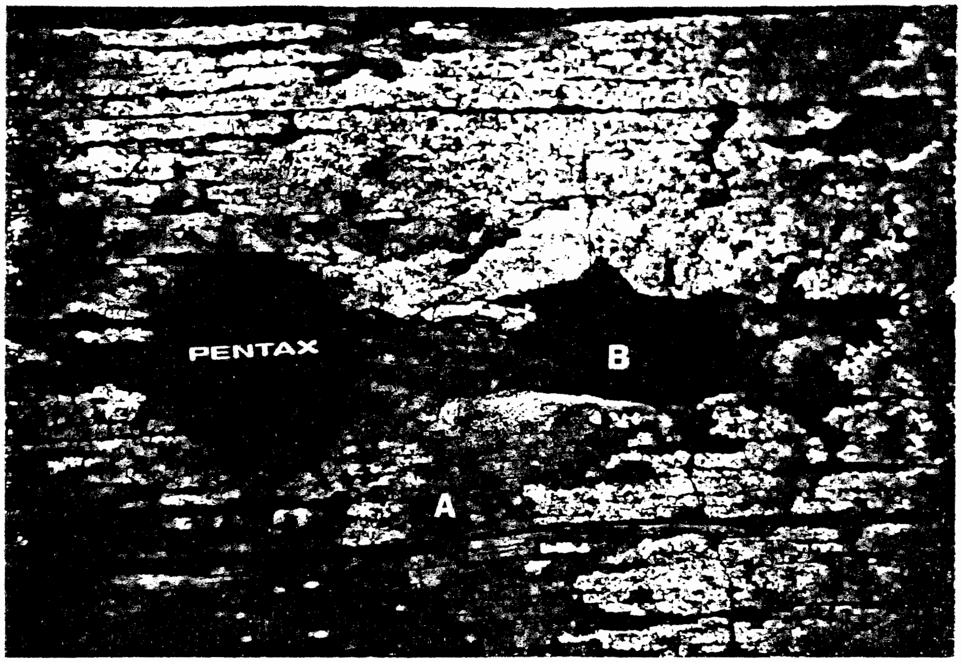


Fig. 4.7 Facies Sh: A: Planar lamination B: Mud chip

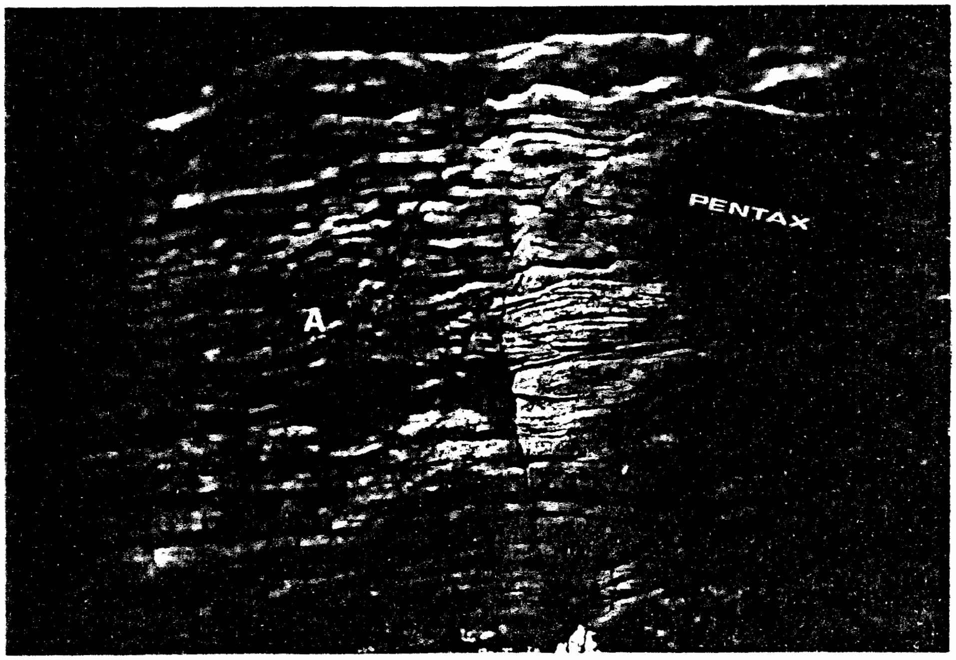


Fig. 4.8 Facies Sr: A: Sand volcanoes and contorted bedding

Nodules: None

Other: This facies is often extremely well-indurated.

Interpretation

The presence of primary current lineation implies upper flow regime conditions. This type of structure plus the lack of any clay, silt or fossil debris is indicative of rapid-flow deposition. "Massive" sandstone may not have any well-defined laminae due to a lack of fine clastics or organic material. Another possibility is that it was deposited as a rapid flow that suddenly encountered a body of standing water with the result that the sand carried by this flow was suddenly deposited as if from suspension by the very sudden decrease in flow strength (Harms et al., 1982).

6) SIDERITE BANDS (Fig. 4.9)

Facies Code: P

Grain Size: N/A

Colour: Light brown

Sedimentary Structures: None

Fossils: None

Nodules: Some siderite bands may be intergrown nodules, however, the vast majority are discreet bands.

Other: These bands are laterally continuous and of uniform thickness, rarely exceeding 5cm. In one case, a contorted and undulatory siderite band is present and follows a similarly deformed underlying sandstone.

Interpretation

Siderite generally forms diagenetically as nodules (Franks, 1969) but the solid bands are unexplained. These are assumed to be diagenetic as well (Calder, 1986, personal communication). As there is a very strong correlation between siderite nodules and roots at Coal-mine Point, there may also be a connection between siderite bands and "mats" of vegetation. These mats may be either autochthonous or allochthonous and be formed as very thin horizons of thickly intergrown roots or simple accumulations of floral debris. The undulatory nature of at least one siderite band is indicative of plastically-deformable material susceptible to soft-sediment deformation. The great abundance of sideritic horizons and root zones points to a high level of carbonate in the depositional system.

Fig. 4.9: Facies P: A: Siderite bands

Fig. 4.10 Rooted horizons

7) TROUGH CROSS-BEDDED SANDSTONE (Figs. 4.11, 4.12, 4.13)

Facies Code: St

Grain Size: Medium sand

Colour: Light grey with abundant red (hematite) colouration

Sedimentary Structures: Large-scale trough cross-beds are the dominant structure. Set thickness ranges from 0.8 to 1.2m. Cross-beds are inclined roughly 15 to 18 degrees to the bedding plane. Rarely, planar lamination separates trough sets.

Fossils: Rare, unidentifiable coalified plant fragments, generally twigs up to several cm long, are present. Casts of Calamites and Sigillaria trunks up to 50cm diam. are invariably found in clusters, but are never in situ.

Nodules: None

Other: "Cannonball concretions" from 0.5 to 1.0m diam. and of a spherical nature are present.

Interpretation

The large size of the bedforms places them within the megaripple-dune classification, indicative of the upper part of the lower flow regime and also suggesting abundant sediment supply. Clusters of "tree" trunks lead to the conclusion that they were eroded out of the river bank and, at one point in time, grew in a forest that likely was situated on a floodplain.

8) PEBBLE CONGLOMERATE

Facies Code: Gm

Grain Size: Pebbles in a matrix of medium sand

Colour: Dependent upon individual clast lithology, but generally dark to reddish brown

Sedimentary Structures: Flat pebbles are commonly imbricated along the basal scour surface.

Fossils: None

Nodules: None

Other: The pebble conglomerate always marks a large scour surface and rarely exceeds 10cm in thickness except in the Stack Sandstone where it contains, at one location, roughly 30 to 40cm of medium- to well-sorted pebbles in a muddy

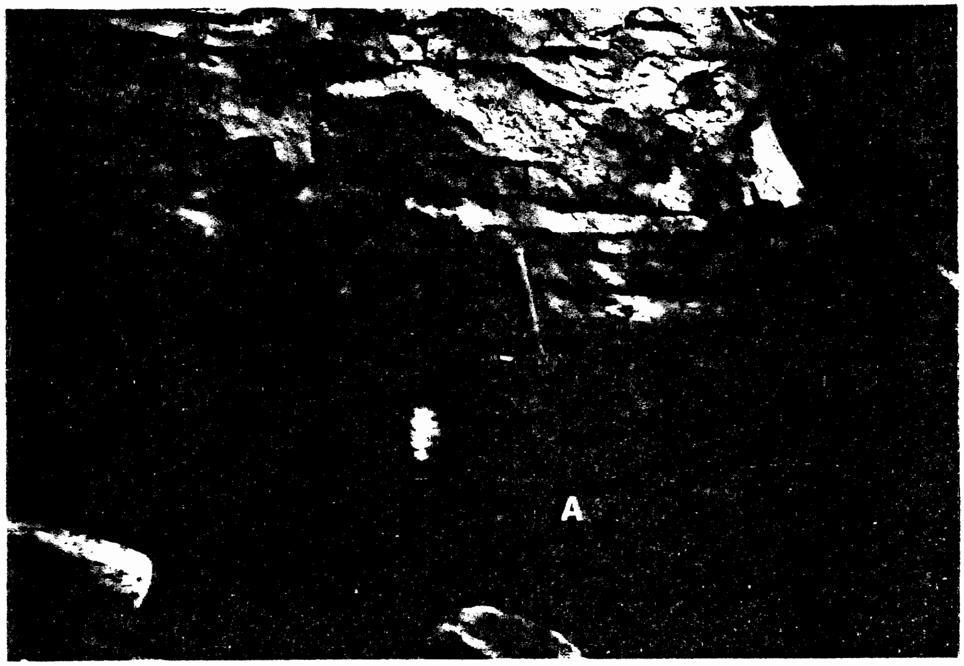


Fig. 4.11 Large-scale trough cross-bedding. A: Lag conglomerate

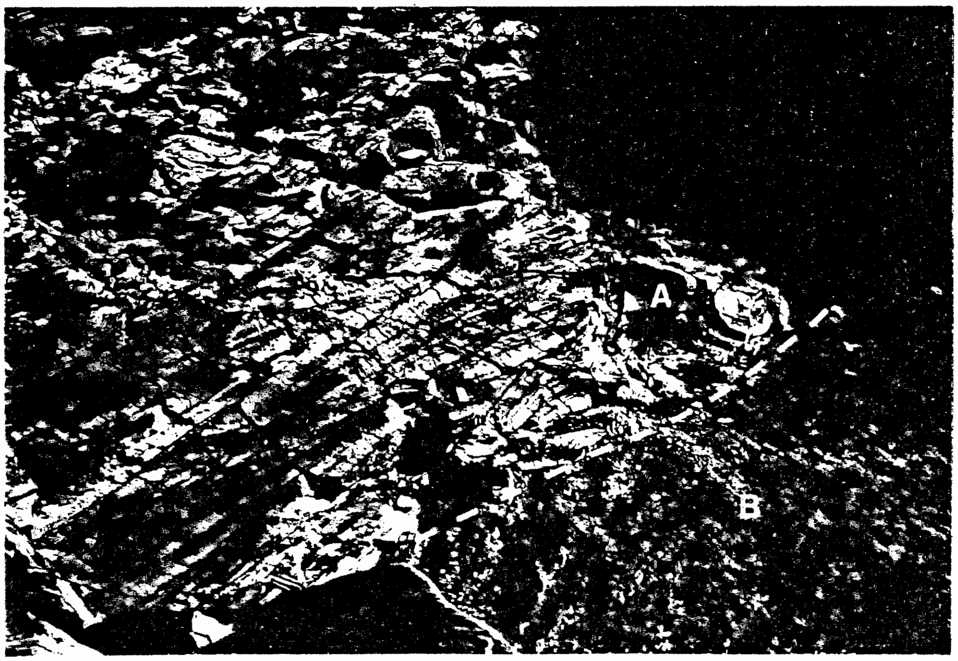


Fig. 4.12 Eagle Sandstone: A: Trough cross-bedding B: Facies Fsc, lower shale member

Fig. 4.13 Large-scale trough cross-bedded sandstone (Facies St)

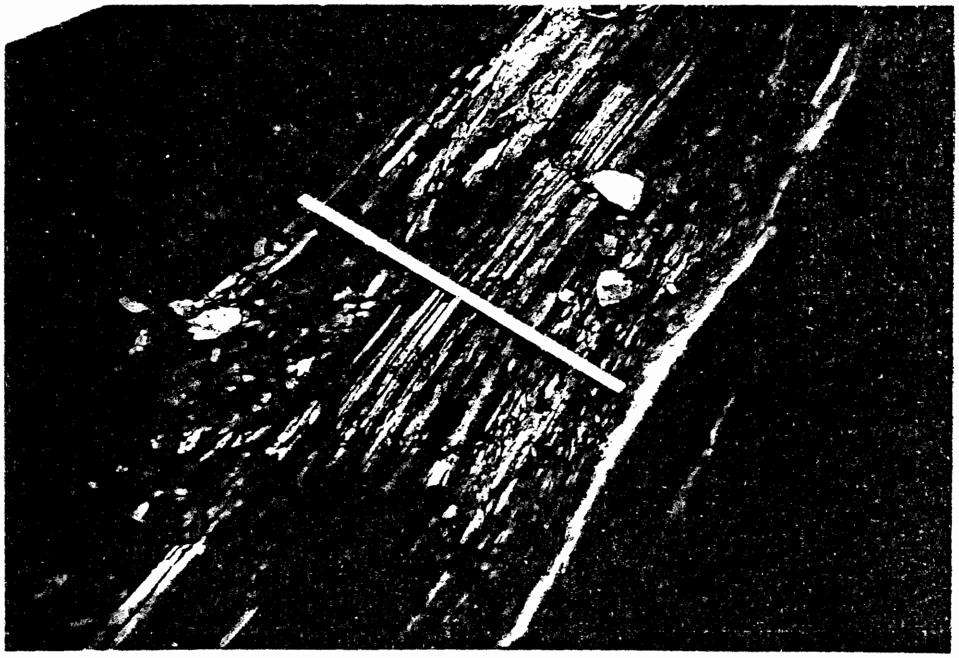


Fig. 4.14 Lensoid body of Sho facies sandstone.

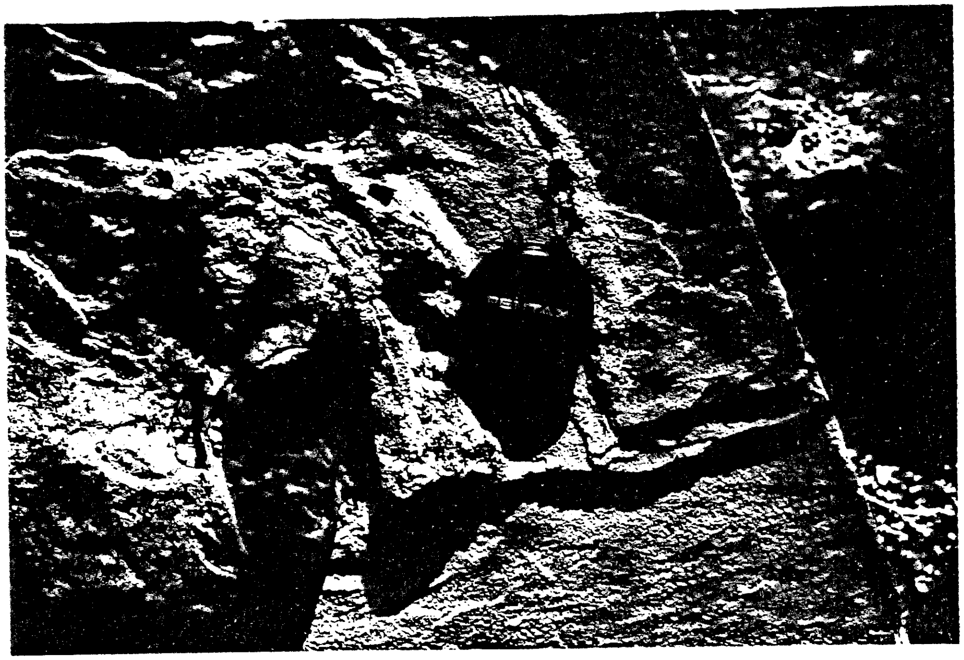


Fig. 4.15 Siderite nodule in Sr facies sandstone.

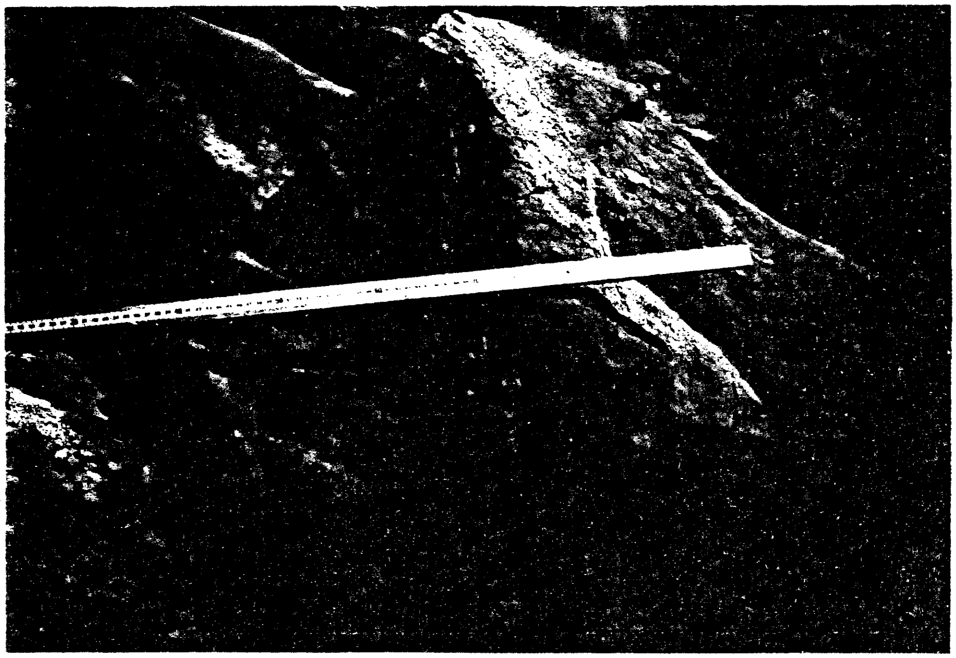


Fig. 4.16 *Sigillaria* in facies St sandstone.

sandstone matrix. The pebbles are typically a combination of mudstone and extrabasinal metamorphic and granitic clasts. The mudstone pebbles are the more common clast type.

Interpretation

The presence of very large scours overlain by coarse-grained facies with appropriate bedforms attests to the fact that they are channel features. The pebble conglomerate is only found along the base of these channel features which agrees with a fluvial channel system where the most rapid flow is along the channel thalweg where the coarsest sediment is transported (Miall, 1982). Facies Gm, therefore, represents the channel base lag conglomerate.

9) ORGANIC-RICH PLANAR-LAMINATED SANDSTONE (Fig. 4.14)

Facies Code: Sho

Grain Size: Fine to medium sand (rare clay)

Colour: Light grey alternating with very dark grey layers coloured by abundant coalified plant material.

Sedimentary Structures: Planar laminae of alternating sandstone/mudstone and organic-rich sandstone of 0.5 to 2.0 cm thickness. The individual laminae tend to pinch out at both ends over a distance of 2 to 3m.

Fossils: Rare, coalified plant fragments are scattered in the lowermost section of this facies.

Nodules: None

Other: The "pinching-out" trend of the laminae results in an overall lensoid geometry.

Interpretation

The lensoid nature of this facies plus abundant, fine, coalified plant detritus indicates deposition in low-energy conditions which allowed sediment to be "draped" over the substrate, probably infilling scours. The difference in scale between these features and both megaripple troughs and channel bases plus the fact that they only occur in the Eagle and Stack Sandstones points to a fluvial channel scour-fill origin.

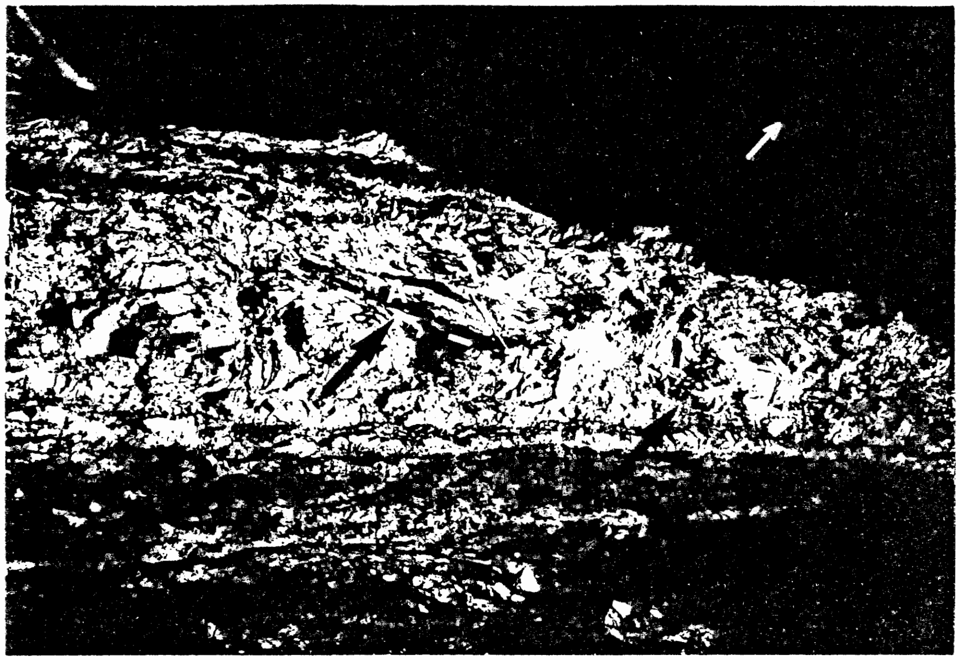


Fig. 4.17 A: Feeder channels in cliff-section.
Arrow shows "right way up" for orientation.

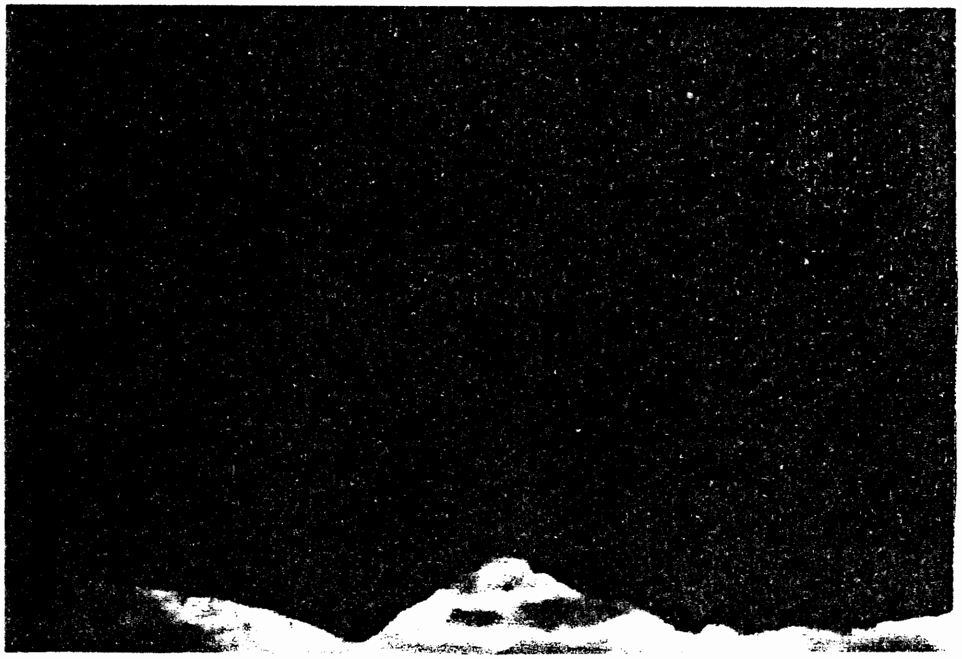


Fig. 4.18 Vegetated crevasse-splay (Columbia R., British Columbia)

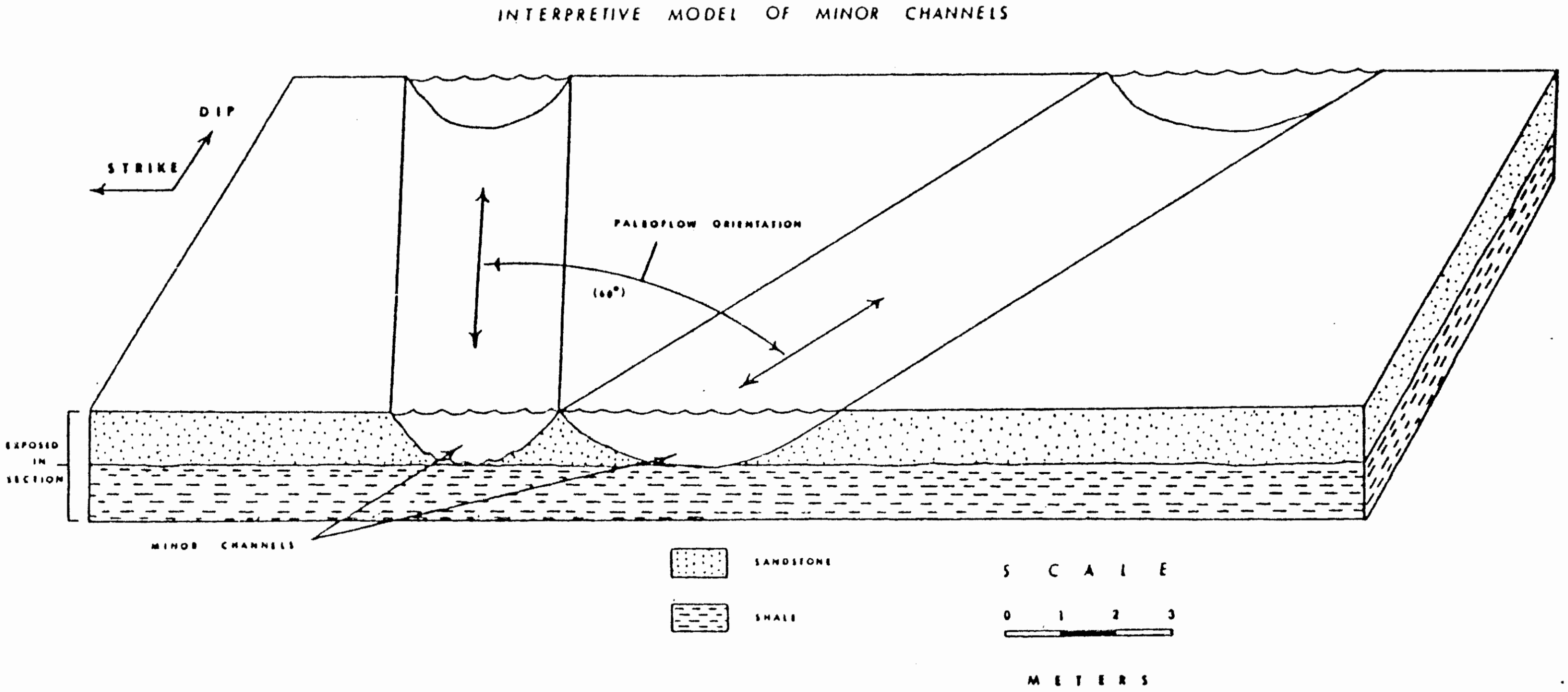


Fig. 4.19 Crevasse-splay Feeder Channels
Small-scale channels present in the lower shale member (See Fig. 4.17) are interpreted as crevasse-splay feeder channels.

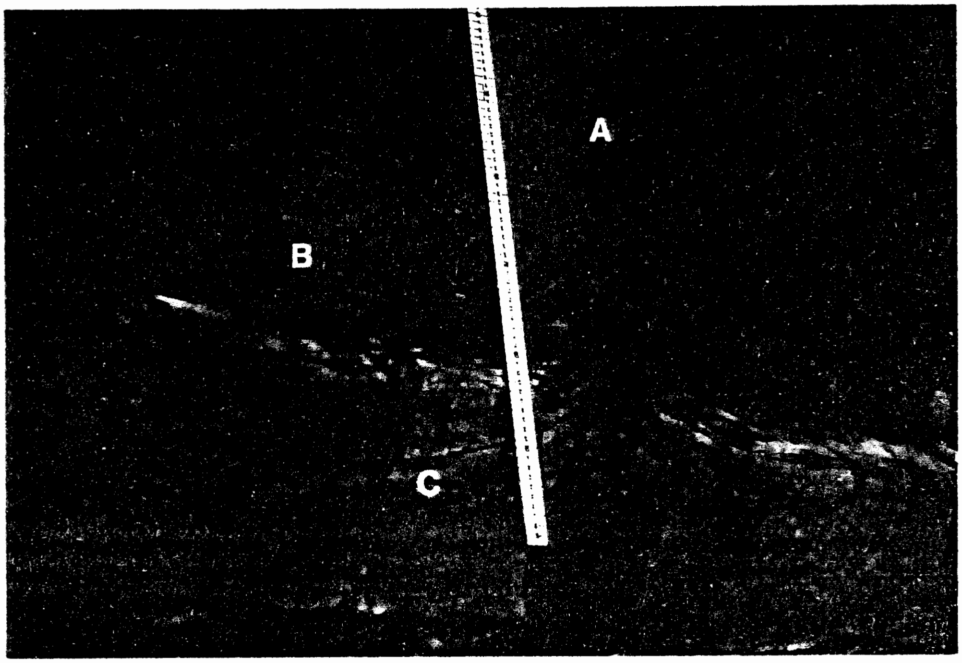


Fig. 4.20 Root System A: Branching root of *Stigmaria*

B: Sideritic band (facies P)

C: Sr facies sandstone containing rootlets from main root

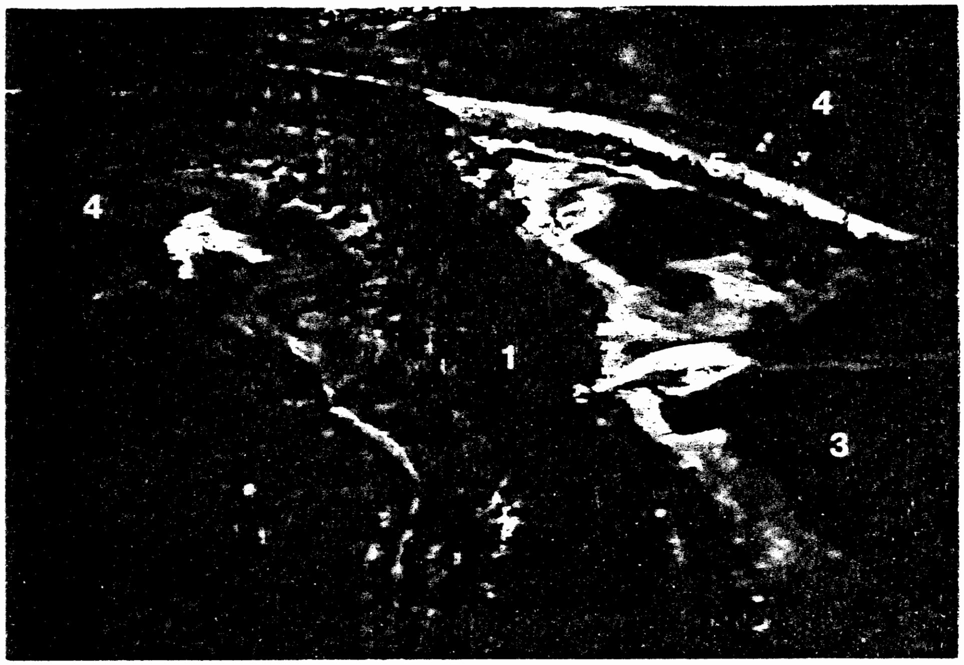


Fig. 4.21 (1) Main channel (2) Crevasse-splay (3) Shallow lake (4) Peat swamp (5) Abandoned channel [Columbia River, B.C.] -Red colour due to infrared film used.

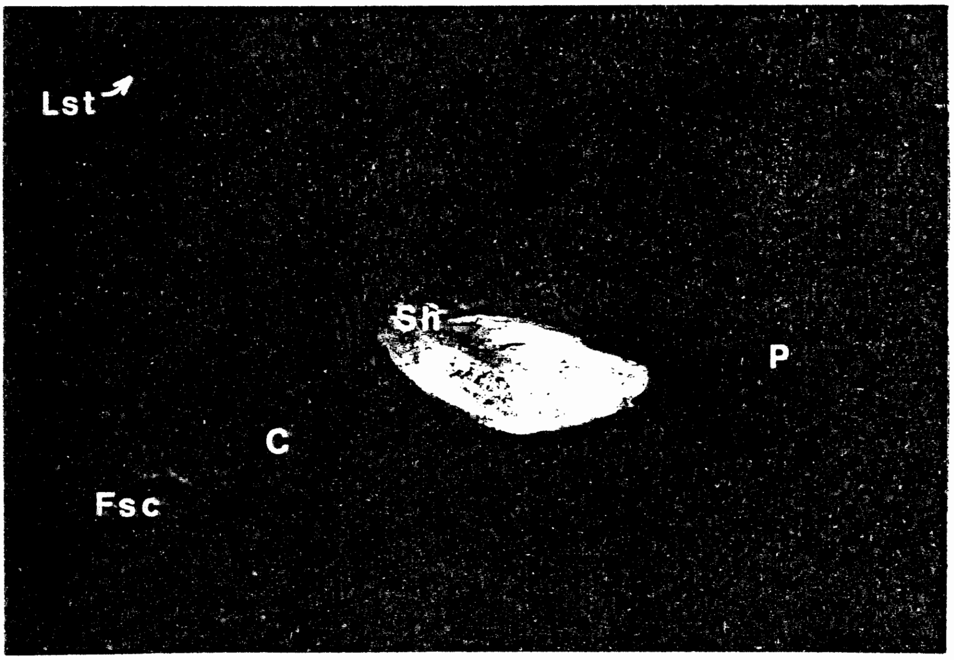


Fig. 4.22 Floodplain facies of Mabou Mines applied to a modern facies-assemblage analog- The Columbia River, B.C.

TABLE 1

PALEOCURRENT DATA

FACIES	FEATURE	PALEOFLOW (Degrees Azimuth)
St	Large trough cross-beds	128
		130
		130
		120
		120
		130
		120
		110
		115
	N=9	Mean=123
Sr	Groove Marks (Crevasse-splay feeder channels)	a150(330)
		a150(330)
		a150(330)
	a=channel a	b210(030)
	b=channel b	b210(030)
	Total N=5	Mean=174(354)
Sr	Primary Current Lineation	200
		N=1 Mean=200

Paleocurrents of major bedforms indicate a SE flow direction. Smaller features, such as groove marks and primary current lineation (in shale member sandstone beds) show flow direction at a high angle to this trend (see Interpretations- Chapter 10).

[Paleocurrents were corrected for structural rotation by using a stereonet]

CHAPTER FIVE

MARKOV CHAIN ANALYSIS

5.1 The Markov Test

In order to ascertain which sedimentary processes operate when particular lithofacies assemblages are deposited, it is important to determine if the sedimentation occurs as regular, cyclic events or if it is episodic. The most useful and simplest of statistical techniques for determining cyclicity is the Markov Chain Analysis. It determines the probability of the appearance of a particular state in the record by knowing the preceding state.

5.2 Procedure

The procedure for using this mathematical tool consists of the following steps. The states, or lithofacies in this case, are defined as discrete units and each represents a particular type of sedimentation. In a stratigraphic column, such as the one produced for the Mabou Mines section, each bed is placed into an appropriate lithofacies.

All the transitions from one state to the overlying one are recorded upward through the section. Transitions between units of the same lithofacies are not counted as they indicate similar processes. The data are then arranged into a two-dimensional array (transition-count matrix) where transition couplets are represented by the row number (lower bed) and the column number (upper bed) (Miall, 1982). Transitions are independent of unit thickness. An independent trials matrix is then constructed to test the probability of the random transition of one state to another, based only on their proportions. A transition probability matrix determines actual probabilities of particular transition occurrences. Finally, a difference matrix tests the difference between the predicted and the observed probabilities and indicates which transitions have occurred with greater than random frequency (Miall, 1973; 1982).

Positive values exceeding 0.1 are usually considered significant (Miall, 1973). Once data have been tabulated, the results are placed in a flow chart.

The Markov analysis was performed on the lower shale member at Mabou Mines. This section represents flood-plain sedimentation associated with fluvial flood-stage cycles (see Interpretations, Chapt. 10) and the Markov analysis should reflect this cyclicity. Subtle changes in the processes could be masked by the inclusion of thick channel deposits that do not represent cyclic sedimentary processes on this scale (Gibling, 1986, personal communication).

5.3 Results

The matrices of the Markov Chain Analysis (Fig. 5.1) resulted in a flow chart graphically depicting facies interrelationships on the Carboniferous flood-plain (Fig.

5.2). As is readily observed, there is a strong tendency for all facies types to be superposed by facies Fsc (shale, siltstone). An unexpected result is the apparent lack of statistical transitional trends between the other facies, even though field observations suggested otherwise.

Sedimentation on this Carboniferous alluvial floodplain probably had a rather constant style, with an overwhelming abundance of shale which points to frequent breaching of river banks by floodwater bearing suspended fine clastics. Periodic and random events occurred: inundation from the main channel creating crevasse-splays; periodic ponding allowing peat growth or, with deeper water, shallow lakes; see later interpretations (Chapt. 10). The only different facies is P (siderite bands), but these are a diagenetic rather than a depositional feature.

TRANSITION COUNT MATRIX

	C	LST	FSC	Sr	SH	P	
C	—	0	5	1	1	0	7
LST	0	—	7	1	0	1	9
FSC	7	9	—	11	1	4	32
Sr	0	0	15	—	1	0	16
SH	0	0	3	0	—	0	3
P	0	0	3	2	0	—	5
							72
	7	9	33	15	3	5	

TRANSITION PROBABILITY MATRIX

	C	LST	FSC	Sr	SH	P
C	—	0.00	0.71	0.14	0.14	0.00
LST	0.00	—	0.78	0.11	0.00	0.11
FSC	0.22	0.28	—	0.34	0.03	0.12
Sr	0.00	0.00	0.94	—	0.06	0.00
SH	0.00	0.00	1.00	0.00	—	0.00
P	0.00	0.00	0.60	0.40	0.00	—

INDEPENDENT TRIALS PROBABILITY MATRIX

	C	LST	FSC	Sr	SH	P
C	—	0.14	0.51	0.23	0.05	0.08
LST	0.11	—	0.52	0.24	0.05	0.08
FSC	0.18	0.22	—	0.38	0.08	0.12
Sr	0.12	0.16	0.59	—	0.05	0.09
SH	0.10	0.13	0.48	0.22	—	0.07
P	0.10	0.13	0.49	0.22	0.04	—

DIFFERENCE MATRIX

	C	LST	FSC	Sr	SH	P
C	—	-.14	.20	-.09	.09	-.08
LST	-.11	—	.26	-.13	-.05	.03
FSC	.04	.06	—	-.04	-.05	0.00
Sr	-.12	-.16	.35	—	.01	-.09
SH	-.10	-.13	.52	-.22	—	-.07
P	-.10	-.13	.11	.18	-.04	—

Fig. 5.1 Matrices of the Markov Chain Analysis (performed on the lower shale member, Mabou Mines) (After Miall, 1982).

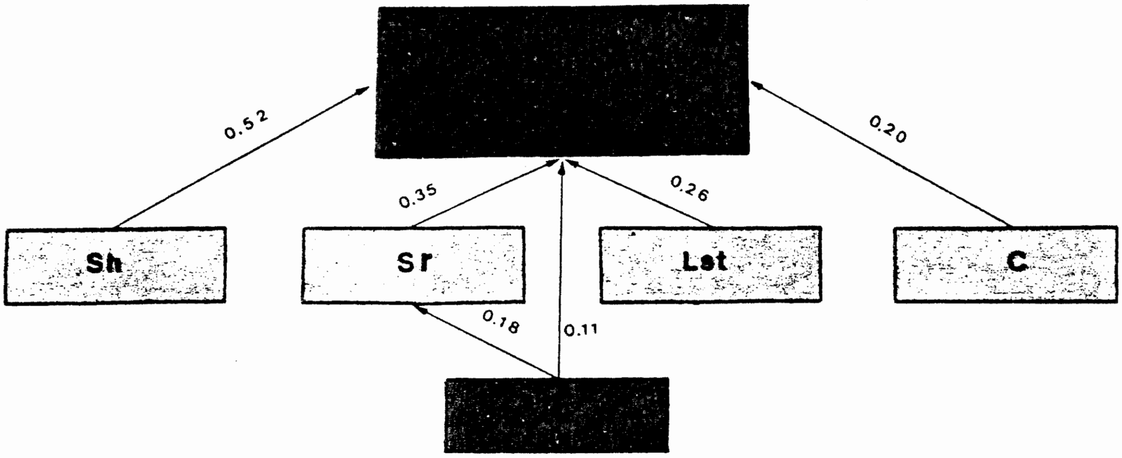


Fig. 5.2 Flow Chart - Markov Chain Analysis

As can be deduced from the chart, trends from one state to another are designated by arrows. The numbers beside the arrows refer to the probability that the underlying state will be conformably overlain by the upper state (See text) (After Miall, 1973).

CHAPTER SIX

PETROGRAPHY

6.1 Procedure

Several samples of sandstone were systematically collected at selected stratigraphic positions in the section. These were later thin-sectioned at Dalhousie University and mounted without cover slips in preparation for staining. The staining technique, as described by Friedman (1959), tests for the presence of calcite. The Alizarin Red S/ Potassium Ferricyanide solution turns calcite pink in a positive test for calcite and also stains some dolomite blue-purple when present. Careful study under a standard petrographic microscope followed, with detailed descriptions being made of each sample. These results are listed in Appendix B.

6.2 Results

The sandstones present in the shale members are chemically and texturally immature sandstones with predominantly calcite cement. Where calcite, dolomite or hematite was not seen, silica cement was inferred. No silica overgrowths were observed except in polycrystalline quartz grains. The clasts are dominantly quartz, commonly exhibiting a polycrystalline nature and undulatory extinction. Plagioclase and K-feldspar grains are also common, although plagioclase is the more abundant of the two. Plagioclase is commonly partially altered to clay and appears, in some instances, to have been partly altered to calcite. The lithic clasts are very tiny and appear to be metamorphic although they may be of volcanic origin. Their small size prevented accurate identification.

These sandstones constitute lithofacies Sh (planar-laminated sandstone) and Sr (cross-laminated, interbedded sandstone with minor shale) in the shale members and do not show any petrographic differences.

The sandstones constituting the Eagle and Stack Sandstones are represented by lithofacies St (trough cross-bedded sandstone) and the sandy matrix of facies Gm (pebble conglomerate). These show differences from the sandstones present as "packets" within the shale members. In the case of each sandstone member, the sandstones are chemically and texturally immature, medium-grained, and have a hematite cement. No carbonate is present. Some clay matrix is present, however, there is a higher grain to matrix ratio than in the sandstones of the shale members. Some quartz grains are polycrystalline with undulatory extinction, and plagioclase is often highly altered. Several quartz grains, as with those of the shale member sandstones, are very elongate. Facies Sho (organic-rich planar-laminated sandstone) is also restricted to the Eagle and Stack Sandstones. It differs from facies St in that there are clay-rich bands of coalified debris alternating with fine-grained, immature sandstone. The mineralogy is essentially the same as that of St, and the cement is hematite as well.

Petrographic study points toward a metamorphic source for all the samples. This explains the irregular nature of many of the quartz grains (see Appendix B), the highly altered nature of many of the plagioclase grains (although this may be a diagenetic feature), and the presence of metamorphic lithic grains. The relative abundance of muscovite and biotite suggests a metamorphic source also. Clay present as matrix is likely to have been derived from chemical alteration of the feldspar grains at the source. The shale member sandstones are invariably cemented with varying amounts of calcite. Conversely, the sandstone members contain no calcite whatsoever and are cemented by hematite.

The overwhelming abundance of calcite cement in sandstones, the presence of the black limestone facies (Lst) and extreme abundance of siderite as nodules and bands in the shale members points to a very high concentration of carbonate within the flood-plain system. The sandstone members contain no carbonate and are, instead, cemented by hematite. This indicates an oxidizing system as compared to a generally reducing system for the flood-plain.

TABLE 2

ANALYSIS OF Fsc FACIES SHALES

SAMPLE	KAOLINITE	ILLITE	QUARTZ	CALCITE
1	36%	8%	56%	-
2	27%	15%	50%	8%
3	35%	5%	60%	-

1 - Unconsolidated seat-earth (5' coal seam)
2 - Shale; Not associated with coal
3 - Shale; Not associated with coal

Only three samples of shale were collected in the field. Analysis was by X-ray diffraction. A brief description of this technique is given in Chapter 9.

CHAPTER SEVEN

BIOTA

7.1 Fauna

The faunal assemblage at Mabou Mines is completely restricted to the black limestone lithofacies (Fsc) (Fig. 4.3). These units are characterized by a restricted fauna of ostracods and bivalves. Similar units present north of Finlay Point (Fig. 1.2) also contain fish spines, bones and scales, but it is uncertain if these units are actually part of the correlatable Westphalian age Finlay Point strata due to the presence of several major faults and the fact that parts of the section are hidden by talus. However, if they are part of the same section, this suggests that large lakes were present and were able to support a vertebrate community. As a result, the lakes must have been of a permanent nature.

Bivalves of the species Anthraconauta phillipsii (Williamson) (Cox *et al.*, 1969; Vasey *et al.*, 1983; 1985) occur as rarely articulated whole shells, but predominantly as intact single valves and crushed shell fragments. The high proportion of intact to broken shells, their generally concave-up orientation in the substrate, and the lack of detrital quartz suggests a life assemblage (Eagar, 1960). An influx of detrital quartz or the development of toxicity through organic decay and peat growth killed off the community where the black limestone is seen to grade to carbonaceous shales.

Anthraconauta phillipsii has been identified in the Sydney coalfield of Nova Scotia where it is present in association with coal seams. It has been found in the Morien Group (Pictou equivalent) strata at Sydney, and has been dated as ranging from upper Westphalian C to Stephanian (or possibly Permian) age (Vasey *et al*., 1985) and occurs in bivalve-ostracod assemblages between the Harbour and Hub seams and above the Phalen seam. These assemblages also contain rare *Anthraconauta tenuis* (Davies and Trueman) and *Antraconaia* aff. *arenacea* (Dawson) which have not been identified in the Mabou coal measures. The fauna present at Mabou were identified by the author using references by Cox *et al*. (1969) and Vasey *et al*. (1983; 1985). The assemblages were also compared to those of the British coal measures (Eagar, 1960) and those of the Cumberland Group at Joggins, Nova Scotia (Duff *et al*., 1973). The ostracods also present at Mabou were identified as *Carbonita sp*. by Vasey *et al*. (1983; 1985) in the Sydney Basin.

A peculiarity of the black limestone lithofacies is its association with coal seams. At Mabou, Sydney and also in the Cumberland Basin (Calder, 1986), this facies is found in close proximity to coal. At Mabou, coal is locally interbedded with these fossiliferous limestones. This might be more easily explained had the matrix been terrigenous, however, it is calcite and raises questions about the Eh -

pH conditions of the depositional environment (see Interpretions, Chapt. 10). Often the upper and/or lower contact of these units is gradational, that is, the carbonaceous shale gradually decreases in plant material while simultaneously increasing in bivalves until the bed is composed entirely of limestone, including the matrix. Most often, these limestone beds increase in carbonaceous shale upward and sometimes grade into a coal stringer or seam. In one case at Mabou Mines, this entire transition occurs within a seam.

In the Sydney Basin and at Joggins, thin black limestone beds have been attributed to the sudden flooding of the peat swamp to form lakes. Later lowering of the water table enabled peat growth to resume, creating a toxic environment for the invertebrates (Duff et al., 1973; Vasey et al., 1985). Duff et al. (1973) and Vasey et al. (1983; 1985) suggest that brackish conditions prevailed in these floodplain lakes on the basis of the invertebrate fauna. The fact that the faunal assemblage displays lower diversity (only two taxons are present) points to harsh environmental conditions. In an aqueous natural system, this invariably implies relatively high salinity. Only certain taxa can withstand more unfavourable conditions and so have little or no competition for a particular niche. As a result, these taxa are very prolific. This appears to be the case of the fauna in the black limestone facies at Coal-mine Point. Scott et al. (1980) discovered the same trends in foraminiferal assemblages through studies of brackish salt-marsh ecosystems.

7.2 Flora

The macrofloral remains at Mabou Mines range from poor impressions in sandstone to petrified wood and casts of transported <u>Calamites</u> and <u>Sigillaria</u>. In many instances, the preservation of the plant fossils has been sufficient to permit only identification to the genus level. Identification was carried out using descriptions by Bell (1938; 1944) for comparison with the specimens collected at Mabou Mines. The resulting specimen names were next compared to a range chart for the Carboniferous flora of Nova Scotia (Bell, 1944) in order to put higher confidence on the identification. This is valid as the spore assemblages of Hacquebard (1962) place very good dates on the Mabou coal measures.

<u>Calamites</u> is abundant, particularly in the facies St of the sandstone members as unaligned debris, and in the fine sandstones (facies Sr) of the shale members as debris but also as <u>in situ</u> growth. <u>Sigillaria</u> is also predominant within the St facies of the Eagle and Stack Sandstones but is absent elsewhere. The <u>Calamites</u> and <u>Sigillaria</u> within the sandstone members are very large (up to 0.5m diam.) and occur as clusters of logs at random intervals. Most abundant within lithofacies Fsc are individual pinnules from

Neuropteris tenuifolia (Schlotheim), occurring in random orientation within the shales. *Cordaites principalis* (Germar) and *Sphenopteris sp*. are also common in shales as coalified impressions. Rootlets of unknown affinity are extremely common, as are complete stigmarian root systems (Fig. 4.18). These imply a highly vegetated flood-plain (see Chapt. 10). *Stigmaria* has been interpreted as the root system for *Lepidodendron* (Hacquebard, 1985), however, no stem debris of *Lepidodendron* was seen at Mabou Mines. It must be noted that *Stigmaria* was once thought to be a distinct species, and the term *Stigmaria* may even now refer to root systems of a variety of plant species of the Carboniferous flood-plain. The presence of large root systems within thick sandstone beds of the shale members provides evidence that the floodplain was very stable for long periods of time. This time span was at least equal to that required for a root system of a very large plant (tree) to become established.

In general, the floral community was extremely rich as is demonstrated by the presence of highly fossiliferous units, extremely abundant roots and rootlets and thick coal seams. Pinnules and other plant debris accumulated in shallow lakes or floodponds, being incorporated into the sediment and preserved where they fell or drifted. *Sigillaria* and *Calamites*, found as large transported stems in clusters within the Eagle and Stack Sandstones, suggests transport from a source upstream because only small

Calamites and no Sigillaria were found in the flood-plain facies assemblage.

Scott (1979) described an example of the British Carboniferous swamp ecosystem where particular plants occupied niches presently held by angiosperms in modern systems. In general, he found that Sigillaria and Lepidodendron tended to grow in drier areas with Calamites common in wetter parts of the flood-plain, such as along the perimeters of crevasse-splays and lakes. This fits well with the assemblages of Coal-mine Point, where most of the plant material of the flood-plain is found preserved in the shale members, while plants foreign to the same part of the flood-plain were transported from upriver and are present in the sandstone members.

Based upon descriptions of the flood-plain environment of the Atchafalaya River Basin (southern United States), the floral community of this system correlates ecologically with that of the Mabou coal measures (Coleman, 1966).

TABLE 3

FLORAL DISTRIBUTIONS

	Calamites	Sigillaria	Neuropteris	Stigmaria	Sphenopteris
C	0	0	4	2	0
Lst	0	0	4	0	0
Fsc	0	0	1,4	2	3
Sr	2,4	0	3	2	3
Sh	0	0	0	0	0
P	0	0	0	0	0
Gm	0	0	0	0	0
St	4	4	0	0	0
Sho	5	5	0	0	0

FACIES

C=Coal, carbonaceous shale
Lst=Black limestone
Fsc=Shale, siltstone
Sr=Interbedded fine sandstone-shale
Sh=Planar-laminated fine sandstone
P=Siderite bands
Gm=Pebble conglomerate
St=Large-scale trough cross-bedded sandstone
Sho=Organic-rich planar laminated sandstone

CODE

0 - Not seen
1 - Extremely abundant
2 - Abundant
3 - Rare
4 - Common as debris
5 - Rare (as debris)

CHAPTER EIGHT

SIDERITE NODULES

8.1 Field Relations

One of the most noticeable features of the shale member part of the Mabou coal measures is the extreme abundance of nodules within the shale beds (facies Fsc). Nodules are extremely common as separate entities within discrete horizons, and very often these horizons coincide with identifiable root zones (see Fig. 4.10). Roots commonly are surrounded by nodules and, in some cases, are found in three-dimensional preservation without any evidence of compaction within the nodules. This means that nodules precipitated around the roots of in situ, probably living, plants. Very large concretions (up to 1.0m diam.) containing Stigmaria are present in the coalfields of Pennsylvania (Gibling, 1986, personal communication). At Mabou Mines the size of nodules ranges from a few millimetres to roughly 30cm in diameter. Shapes are extremely variable and range from spherical to irregular, although the smaller nodules tend to be more spherical and more rounded than the larger ones, which are morphologically much more irregular. There is no evidence of compression in most of the nodules, although some appear as discs. Some Stigmaria casts are of a sideritic composition and possibly point to a gradual replacement of roots during decomposition.

8.2 X-Ray Diffraction Analysis

XRD tests were run on twelve samples using powder from crushed nodules mixed with acetone to make smear slides. Samples were run for approximately 50 minutes each using CuK alpha radiation. The resulting X-ray diffractograms were compared with known two-theta values for commonly-occurring minerals and subsequent identifications were made. The final step consisted of calculating the peak areas and multiplying by the intensity for each mineral in order to obtain relative proportions. Percentages were calculated and placed in a table (Table 4). The procedure followed that suggested by Cook et al. (1975) and, unfortunately, is semiquantitative only, although sufficiently accurate for determining relative mineral abundances.

Resulting data from the samples showed the nodules to be dominantly sideritic with abundant quartz and trace quantities of kaolinite and mica. Two samples confirmed the presence of calcite, infilling radial shrinkage cracks infhand-specimens. This is therefore of later-diagenetic origin. The same trend is seen in Jurassic carbonate nodules of the Oxford Clay in England (Hudson, 1978).

Electron microprobe analysis of two polished thin-sections provided generally inconclusive results on the relative proportions of siderite/calcite from the nodule cores to rims. It was originally thought that this technique might be useful for this purpose, but as it turned out, the fine-grained nature of the siderite prevented a very accurate assessment of general trends. The electron microprobe did, however, allow constraints to be placed on the mineralogy of bands within one of the thin-sectioned nodules. The bands are on the order of 0.5 to 1.0mm wide and are perpendicular to a coalified root, thus allowing the interpretation that the bands are parallel to bedding. Alternating light and dark coloration of the bands turned out to be the result of alternations of calcite and siderite. As stated above, the banding is most likely representative of laminae of the confining bed. This quality points to concretion growth soon after the deposition of the surrounding beds (Raiswell, 1971).

8.3 Interpretation

The siderite nodules of the shale members at Mabou Mines are of a diagenetic origin. Evidence for this is provided by the presence of three-dimensional preservation of roots within nodules and parallel laminae within nodules. A definite correlation between organic material and nodule precipitation can be drawn. Nodules occur associated with, or surrounding, roots and rootlets within shale beds. Nodules within marine formations in England of varying ages surround well-preserved and undeformed fish and invertebrate fossils (Hodgson, 1966; Raiswell, 1971; Hudson, 1978). The undeformed nature of these fossils points to concretion growth before sediment compaction and thus, to an early diagenetic origin (Raiswell, 1971). As a result, mineralogical changes across the nodules can be used to indicate changes in Eh-pH trends with time (pre-lithification) (Raiswell, 1971). In this light, the nodule from Mabou Mines with alternating siderite-calcite bands may reflect Westphalian peat swamp groundwater chemistry trends. Further evidence for this is provided by shrinkage cracks infilled by later-diagenetic calcite in siderite nodules (early diagenetic), and the general trend of siderite bands occasionally alternating with cone-in-cone calcite bands in the shore section at Mabou Mines. There is evidence that some of the nodules lithified gradually, beginning at the outer rim and later affecting the entire nodule, resulting in shrinkage cracks (Hudson, 1978). These cracks then filled with later-stage calcite. Calcite precipitation within sandstones (shale members only) as cement also reflects a later-stage diagenesis.

Concretion-rich horizons at Mabou Mines and those described in the literature are invariably associated with organic-rich material, present either as marine organisms or plant material (Hodgson, 1966; Raiswell, 1971; Hudson, 1978). Residual organic matter, consisting of humic acids (common in peat swamps) and other organic materials are subject to attack by anaerobic bacteria and subsequent decarboxylation (Hodgson, 1966). This process releases CO_2 which can then combine with CaO, if present, under suitable Eh and pH conditions to precipitate calcite. As groundwater

Eh and pH fluctuates with the seasonal hydrologic budget, the alternations of siderite and calcite might be indicators of seasonal Eh-pH flux and hence, subtle variations in floodplain groundwater chemistry.

TABLE 4

X-RAY DIFFRACTION DATA

SAMPLE	TYPE	SIDERITE	QUARTZ	CALCITE	CLAYS
5	1	77%	8%	5%	10%
6	1	90%	10%	-	trace
8	1	73%	27%	-	trace
12	1	67%	33%	-	trace
3	2	70%	30%	-	trace
4	2	60%	35%	trace	5%
9	2	20%	55%	-	25%
10	2	52%	41%	-	7%
2	3	90%	3%	7%	trace
11	3	67%	22%	11%	trace
7	4	71%	25%	4%	trace
1	5	89%	11%	-	trace

Mean Siderite=69%
Mean Quartz=25%

TYPE 1 NODULE: In facies Fsc (shales)
TYPE 2 NODULE: In facies Sr (Sst./shale)
TYPE 3 NODULE: Facies P (siderite bands)
TYPE 4 NODULE: In facies Lst (black limestone)
TYPE 5 NODULE: Replaced Stigmarian root

NOTE:

1) Type 3 nodules enriched in calcite
2) Type 2 has less siderite/more clays
3) Type 5 (root): no difference from nodules

CHAPTER NINE

COAL

9.1 Seams at Mabou Mines

The Mabou coal measures contain eight seams in outcrop. These are the 3', 1', 4', 5', 15', 8', 7' and 11' seams, six of which are of mineable thickness (more than 1m) (Hacquebard, 1985). The 11' seam (thickness taken from borehole data) is present in outcrop as a thin bed of black limestone and carbonaceous shale roughly 30 to 40cm thick. Also, there are five seams beneath the exposed section at Coal-mine Point (Hacquebard, in press). All seams are autochthonous, evidence for which is provided by the presence of roots extending from the coal directly into underclays. This is exceptionally well-defined in the 5' seam. Spore assemblages from the 7', 8' and 15' seams were used to date the coal measures. The coals fall into the _Torispora_ spore zone (spore zone B) of Late Westphalian age (Hacquebard, 1962) which is correlatable to European coal measures. All of these coals are classed as high volatile "C" bituminous with generally high, but variable, sulphur and ash content (Hacquebard, 1962).

The Mabou coals are similar to those of the Sydney Basin, being normal banded coals with durain bands that can be traced long distances. Those in the 15' seam can be traced to Finlay Point and lend a higher level of confidence to the correlation of Coal-mine Point to Finlay Point (Hacquebard, 1980).

9.2 Coal Quality

The fact that the coals are classed as high volatile "C" bituminous rank plus the great abundance of carbonaceous shale within the seams prevents their utilization in coking for the steel industry (Hacquebard, 1985). Partings within the seams are shale or "fire-clay", rarely exceeding 5-10cm in thickness (Norman, 1935). The 15' seam contains very few partings, none of which are particularly thick, and total only 10cm thickness compared with the more than 4m thickness of the seam.

Sulphur and ash content of the seams varies within the section. All of the coals stratigraphically beneath the Eagle Sandstone have significantly higher percentages of sulphur than those in the upper shale member (Norman, 1935). The 8' seam is conspicuously lower in sulphur and ash than all of the other seams, including the 7' seam which is only one metre from the 8' seam (See Fig. 1.2). The 7' seam is much higher in ash, sulphur and impure durain and fusain. In general, sulphur content is high in all of the coals, ranging from 1.8% to 6.5%, and reaching a maximum in the 15' seam (Hacquebard, 1980; Norman, 1935). Ash content is high as well, ranging from 7% to 30% on a dry basis (Hacquebard, 1980). Further data is provided in table 5. The highest quality coal comes from the 11' seam (from borehole data) which contains less sulphur and ash than all of the other seams. Also, there is a general increase in coal quality farther out into the basin (Hacquebard, 1962; 1980) and as a result, these seams should be of economically mineable quality, although the rank restricts the use of this coal to thermal power generation (Hacquebard, 1985). Seams in the strata overlying those correlatable to the Mabou coal measures (equivalent to the 7' and 13' seams of the Inverness coalfield) are of sub-economic quality (Hacquebard, 1980).

9.3 Sulphur in Coal

The most economically-limiting feature of the Mabou coals is the high sulphur content. Sulphur content greater than about 2% usually makes a coal uneconomic (Hacquebard, 1985), therefore, the conditions responsible for the presence of abundant sulphur should be determined in order to predict trends within coal basins for the purpose of mining economically-sound resources.

Hacquebard (1972; 1985) suggested that the Sydney and Mabou coalfields are part of a very large paralic basin, mainly because all major coal deposits around the world are related to such systems. There are, however, no marine beds present anywhere in the Sydney or Gulf of St. Lawrence Coal Basins, indicating that these coals formed higher up on the alluvial plain where they would not be subjected to a marine influence. High sulphur content in coal has usually been related to the introduction of marine sulphate into the peat swamp during its development (Williams et al., 1963; Hacquebard et al., 1970; McCabe, 1984). Obviously, there must be a non-marine source of sulphur for the coals of Sydney and Mabou. In answer to this problem, Bell (1927) postulated that Windsor Group evaporites, probably exposed as bedrock near the peat swamps in Westphalian time, contributed sulphate and carbonate ions to the groundwater system through dissolution. Hacquebard et al. (1970) pursued this problem for a seam in the Sydney Basin and agreed with the idea put forward by Bell (1927). Gibling et al. (1986) suggested that, following these ideas, sulphur isotope ratio comparisons between coal seams of the Sydney Basin and the Windsor Group evaporites could substantiate this claim. The data do not provide conclusive evidence, but there is enough confidence in the results to support the hypothesis. Gibling (1986, personal communication) also noted that the Morien Group (Pictou equivalent) at Sydney is locally unconformably overlying Windsor gypsum and anhydrite, suggesting that the evaporites did occur as outcrop when the peat swamps were forming. At Mabou Mines, the presence of Windsor group strata in close proximity to the Pictou Group points to the probability that processes enriching swamps of the Morien Group in sulphate were also operative in those of Mabou Mines during Westphalian time.

9.4 Future Mining Potential

The roof beds for the Mabou Mines seams are generally the Fsc facies grey shales or Sr facies interbedded fine sandstone and shale. Shales make stable roof beds, but thin sandstones (10-20cm) would have to be bolted into place to prevent roof collapse (Horne _et_ _al_., 1978). Eagle and Stack Sandstones come very close to several of the seams and may cause problems in mining. Interfaces between shale and thick, coarser-grained units often result in slipping between the different lithologies and cause severe roof cave-ins (Horne _et_ _al_., 1978).

In light of this data, the shale members at Mabou Mines are suitable for stable drifts. Due to the thinness of some of the sandstone beds of facies Sr, parts of the roof would have to be bolted for added stability. Seams in close proximity to the Eagle or Stack Sandstones (or similar lithosomes) could be a serious threat to mine roof-stability.

Other mining difficulties would be encountered where the fluvial sandstones erosionally overlie coal-bearing strata. Syndepositional "wash-outs" could terminate a seam and make it uneconomic (Hacquebard, 1985). The highly faulted and fractured nature of the strata in the Mabou Mines region combined with the fact that mining must occur offshore (inland seam continuity is lacking) suggests that flooding of the mine is a strong possibility (Hacquebard, 1962; 1980; in press).

9.5 Interpretation

The thickness of the coal seams indicates long periods of steady peat growth, only periodically disturbed by an influx of clay. Using a 10:1 compaction ratio for peat during coalification (McCabe, 1984; Hacquebard, 1985), original peat thicknesses reached more than 40m (maximum-present in the 15' seam). Citing a general buildup rate for peat of 0.305m every 300 years (Fisk, 1960), it can be suggested that the peat swamp on the flood-plain was completely undisturbed by any major depositional events for periods up to 40 000 years long.

The high sulphur content of the coal (present as disseminated pyrite) is probably the result of dissolution of gypsum/anhydrite bedrock, from which sulphate was flushed into the swamp. High ash values may be the result of clay minerals incorporated into the peat through floods (McCabe, 1984).

Based on various studies and previous mining activities, mining would be restricted to the offshore part of the coalfield at Mabou Mines. Due to high sulphur and ash content and the low grade of the coal, plus the fact that a tunnel over 3km long would have to be constructed, these coals are considered uneconomic.

TABLE 5

MINING POTENTIAL

COAL:

Age: Late Westphalian C (Torispora- spore zone B)

Seams: 3', 1', 4', 5', 15', 8', 7', 11' (offshore), (plus five others in an underlying fault block)

Rank: High volatile bituminous C

Ash: 7% to 30% (dry basis)

Sulphur: 1.8% to 6.3%

Btu/lb: 10 000 to 12 000 btu's/lb (dry basis)

Moisture: 2.10% to 2.85%

Fixed Carbon: 49.55% to 56.40%

Combined Volatile Matter: 34.25% to 37.50%

Seam Thickness: 0.9 to 4.5m (in cliff exposure)

Partings: Generally very thin shale or clay

Roof-beds: Generally shale or interbedded shale/sandstone; possibly sandstone members in locations offshore.

GENERAL:

Transportation: Present roads could be improved to handle trucks, however, this would be a very expensive mode of transport for the coal. The fact that a future mine would be on the coast suggests that transport by barge would be the most reasonable choice.

Tunnels: Tunnels in the basin would have to be very long in order to reach the best coal.

(Data from: Norman, 1935; Hacquebard, 1962; 1980; 1985; in press)

CHAPTER TEN

INTERPRETATION

10.1 Eagle and Stack Sandstones

The Eagle and Stack Sandstones consist of three lithofacies. St is the predominant facies and represents fluvial channel deposition. Supporting evidence includes the medium-grained sandstone lithology, large-scale trough cross-beds (rarely grading upward to smaller bedforms), transported trunks of Sigillaria and Calamites and the association with facies Gm. This second facies consists of commonly-imbricated intrabasinal pebbles along large, concave-upward erosional surfaces. The erosional contact is always directly beneath the conglomerate which is, in turn, always overlain by facies St. Facies Gm is therefore interpreted as channel lag material. The third facies present within the sandstone members is Sho. Finer grain size, abundant coalified detritus plus rhythmic banding of alternating sandstone/coaly shale attest to a low-energy deposition. It is restricted to the sandstone members. The lateral discontinuity and lensoid geometry suggest facies Sho represents the infilling of a channel scour when that part of the channel became dominated by low-energy deposition. These three facies (Gm, St, Sho) indicate deposition in a fluvial system. The association of syndepositional floodplain deposits (see Fig. 10.1) including palludal, lacustrine and crevasse-splay facies assemblages (see section 10.2) with the sandstone members which display erosional lower contacts and non-erosional upper contacts provides further evidence for a fluvial depositional environment with an associated flood-plain.

A notable feature of the interpreted channels is the fact that they commonly are present in aggrading sets of up to three channel bodies. Actual channel depths were calculated in the field, giving four rough estimates of 10-15m depth by measuring one basal channel scour surface to the next. Another quantitative method utilizes megaripple size, a feature controlled more by sediment supply and water depth than by current strength (Allen, 1968). The formula:

$$H=0.086d^{1.19} \quad (1)$$

gives the relationship between the height of the bedforms and channel depth, where "H" is the height of the megaripple and "d" is the depth of the channel. This equation was originally formulated to describe channels in meandering systems, however, as it uses only current strength and bedload, it will be assumed as reasonable for the features at Coal-mine Point even though it has not been established that the system was actually a meandering one. From megaripples in the Eagle and Stack Sandstones (facies St) with a "minimum" bedform height (i.e. the <u>preserved</u> thickness of the cross-bed sets) of 0.8 to 1.2m, a channel depth of at least 6 to 9m is calculated using equation (1) from Allen (1968). Further equations from Allen (1968) could be used to predict channel width and meander wavelength, but these have not been used due to the fact that it has not yet been established that Mabou Mines strata were deposited by a meandering river.

10.2 Shale Members

The facies comprising the shale members are more completely described in Chapter 4 and will not be repeated here. Instead, an interpretation of the depositional environment will be discussed.

Autochthonous coal seams and stringers with associated carbonaceous shale and shale partings (facies C) represent thick buildups of peat and assorted flood-plain vegetation. Original thicknesses may have reached over 40m (10:1 compaction during coalification) (McCabe, 1984; Hacquebard, 1985). Generally few major clay or shale partings within seams suggests a stable swamp where clay influx was minimal until a major inundation halted peat growth. This may be a result of a laterally migrating river which had little effect on the swamps until it was fairly close. Extensive durain bands show that swamps were areally extensive for at least a few kilometres, based on correlations to Finlay Point (Hacquebard, 1962). Disseminated pyrite in the coal and generally high sulphur content point to an influx of sulphate into the swamp (see Chapter 9) from some external source.

The black limestones (facies Lst) occur intimately associated with coal seams and stringers. Faunal associations point to a non-marine, probably brackish, shallow lake environment. The brackish quality of the lakes is supported by the fauna and lack of diversity in this small ecosystem. The abundance of minute particles of coalified plant material suggests that these shallow lakes were closely associated with swamp peat buildup, where too much water would flood the peat and prevent further growth, whereby the faunal groups would become established. Increased plant growth due to decreased water levels would have then built up toxicity and, as a result, killed off the fauna.

Sandstone packets (facies Sh and Sr) in the shale members show trends typical of crevasse-splays. The sedimentary structures, in situ small Calamites (Scott, 1979) and minor channels, interpreted as crevasse-splay feeder channels, support this idea. The relation of these sandstone packets to the surrounding shale beds indicates episodic deposition, supported by the Markov chain analysis (after Miall, 1973; 1982). Paleocurrents trend at high angles to the paleoflow attitude of the main river channel (Table 1), as would be expected for a crevasse-splay.

Facies Fsc (shale) is the predominant facies of the shale members. It contains abundant plants and roots in situ and as debris. Basing the presence of conchoidal fracture patterns and numerous siderite nodules on a root-related origin, these features, in conjunction with actual visual roots (in outcrop), point to a very heavily vegetated flood-plain with root systems stabilizing the soil. Clay and silt were deposited from suspension and reflect the flood-stage cycle of the river. The flooding may also have provided abundant sulphate to the peat swamps. The abundant sulphur was soon incorporated into the peat (coal) as syngenetic pyrite (Coleman, 1966).

Siderite bands (facies P) and cone-in-cone limestone, both diagenetic features (Franks, 1969) are present in great quantities at Coal-mine Point. There must have been a large amount of carbonate in the groundwater, a possible source being the dissolution of Windsor Group carbonate/evaporite strata. Alternating cycles of calcite and siderite diagenesis may reflect alternating trends in flood-plain water chemistry.

In summary, the shale members represent sedimentation on a highly vegetated flood-plain. The autochthonous coal seams, large permanent root systems and abundant vegetation point to the fact that the overbank region was not significantly affected by the main river for very long periods of time. Flood-plain facies of the Atchafalaya River Basin are almost identical to those at Mabou Mines. The shale member facies assemblage correlates well with the poorly-drained swamp facies of the Atchafalaya Basin (Coleman, 1966). The large-scale interpreted morphological features are very close to those present in the Columbia

River, British Columbia (Gibling, 1986, personal communication).

10.3 Synthesis

The formulation of a "model" for a depositional system is very difficult to do with confidence because it consists of interpreting data collected from a two-dimensional cliff section and projecting to a three-dimensional system that accumulated over time (a fourth dimension). Following, however, is an attempt to reconstruct the depositional system responsible for the strata at Mabou Mines in Westphalian C time.

The data point to a dominantly sandy fluvial system with a thick, very richly vegetated alluvial flood-plain (Fielding, 1985) studded with shallow lakes.

Based on the correlations of Hacquebard (1962; in press) the geometry of the sandstone members is sheet-like rather than elongate and "ribbon-like", thus ruling out the possibility that the river was anastomosing (Smith and Smith, 1980; Smith et al., 1980).

The Eagle and Stack Sandstones are many tens of metres in thickness. A comparison with a 10-15m channel depth points to "stacked" channels which are, in fact, visible in outcrop. This is a feature common to braided rivers (Cant, 1978) but also occurs in meandering rivers where highly rooted levees repulse erosion and result in an entrenched river which is forced to build upward until avulsion takes place (McCabe, 1984). Facies models for braided and meandering rivers show that the facies assemblage of the

Stack and Eagle Sandstones, which is mainly St and minor Gm and Sho, is very similar to that of a South Saskatchewan -type braided river (Cant, 1978; Jackson, 1978; Miall, 1978; Miall, 1982). The lack of lateral accretion sets, variation in paleoflow, fining-up sequences or clay plugs plus the fact that the sandstones are immature texturally and mineralogically attests to a non-meandering river origin for the Mabou strata. Also, channel sandstone bodies on the order of 50-100m thick are unlikely to form in a meandering river (Gibling, 1986, personal communication). On the other hand, thick coals and overbank strata are not commonly associated with braided rivers and crevasse-splays are associated with meandering systems (Miall, 1978; Smith and Smith, 1980; Smith et al., 1980).

The depositional environment for the strata at Mabou Mines was a river with an associated flood-plain. The river was probably braided, closely resembling the contemporary South Saskatchewan River in Western Canada in both lithology and facies assemblages (including flood-plain facies) (Miall, 1982). The Carboniferous river of Mabou Mines was entrenched in its own channel system due to the heavily vegetated (root-stabilized) banks that restricted lateral migration by being difficult to erode (McCabe, 1984). The river built up vertically, occasionally breaching weak parts of the bank, which resulted in crevasse-splays. The aggradation of the channel body continued until the river reached an unstable height above the flood-plain, at which point avulsion took place, just as in a meandering system (Cant and Walker, 1984). While vertical accretion of channel facies took place, vertical buildup of flood-plain facies occurred simultaneously. Lateral migration of the river is evident, based on correlations between Coal-mine Point and Finlay Point (Hacquebard, 1962) in addition to erosional bases and non-erosional surfaces of the sandstone members. Incorporation of peat as "coal mats" in channel sandstones above the 2' seam at Finlay Point (Deal, in progress), the pinching out of the upper shale member and the linking of the Eagle and Stack Sandstones to form the Point Sandstone of Finlay Point all attest to the lateral migration of the river channel across the flood-plain (see Fig. 10.1) (Hacquebard, 1962). Paleoflow points to flow toward the southeast, <u>away</u> from the Gulf of St. Lawrence Basin. This may indicate that these strata are late-stage basin-fill.

The system interpreted from the sedimentary features in the cliff exposure at Coal-mine Point does not fit either a meandering or braided river model perfectly, and as a result, is not strictly classified as either but is more likely a system governed by processes found in both of these depositional environments.

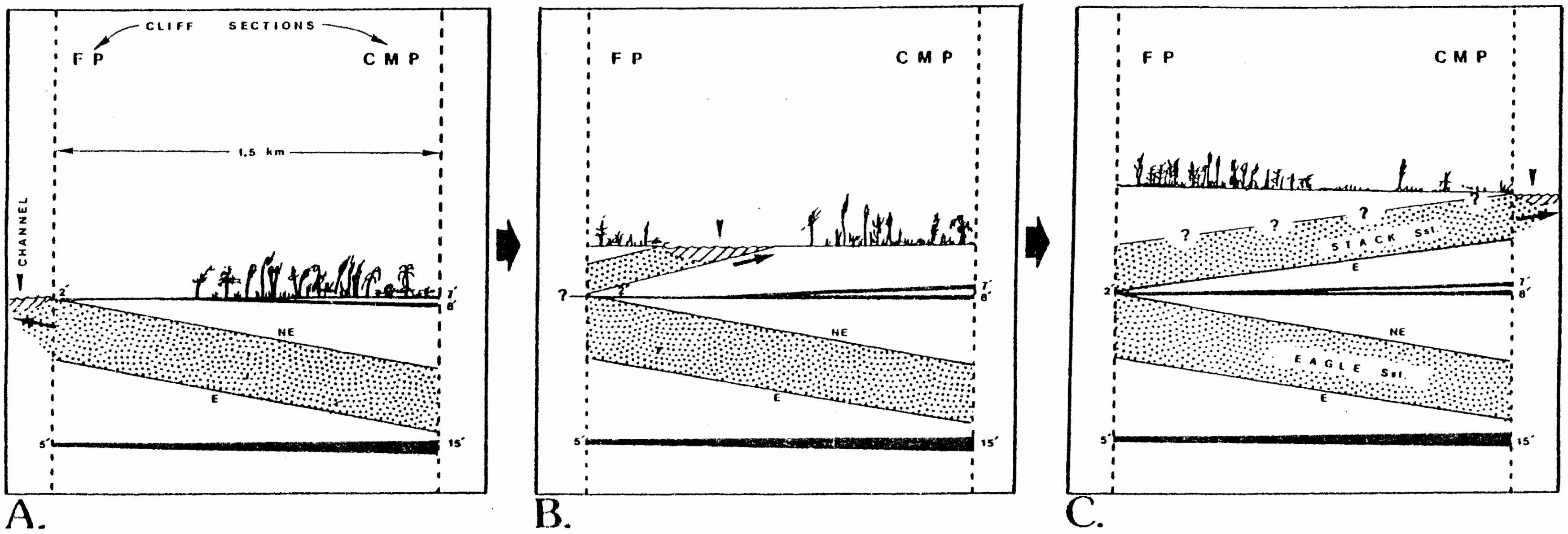


FIG. 10.1 Migration of Sandstone Members

This diagram shows the lateral migration of the Stack/Eagle Sandstones through time.

E=erosional surface
NE=non-erosional surface

5' (etc.)=five-foot coal seam

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APPENDIX A

STRATIGRAPHIC SECTION - MABOU MINES

The shore exposure at Coal-mine Point was systematically measured and described from the base upward. These measurements correspond to a graphic log displayed in Chapter 3. Where coal seams were missing due to drift collapse, seam thicknesses listed by Norman (1935) were used.

Cumulative Thickness (m)	Thickness (m)	Description
0-3.55	3.55	Grey, fine sst. with plant fossils, cross-lamination.
-4.33	0.78	Same as above, only with shale interbeds.
-6.33	2.0	Dark grey, fissile shale
-7.55	1.2	3' Coal seam. 20cm black shale at base going to alt. dull and bright bands.
-8.55	1.00	Grey, fine to med. sst. with cross-lamination
-9.70	1.15	Same as above with shale interbeds and abundant nodules.
-11.75	2.05	Same as above.
-14.25	2.50	Same as above with small channel features.
-17.85	3.60	Same as above minus channel features.
-18.55	0.70	Grey, fissile shale;

		abundant nodules.
-19.90	1.35	Grey, fine sst. with cross-stratification and shale interbeds. Some coarsening/fining sequences.
-21.25	1.35	Dark grey-black shale with nodules. Sst. interbed.
-25.40	4.15	Interbedded sst./shale. Lower contact is erosional; Channel features present. Cross-lamination.
-27.98	2.58	Grey, conch. fractured shale. Rooted, nodularized, Fe-oxide bands, coarsens upward.
-28.33	0.35	Grey, massive fine sst. Heavily rooted; nodules.
-29.47	1.14	Grey, rooted siltstone with conch. fracturing.
-30.07	0.60	1' coal seam. Alt. coal/ shale (coal=clarain)
-31.87	1.80	Grey, conch. fractured siltstone with nodules.
-33.52	1.65	Grey, fine sst. with cross-lamination. Plant debris; roots.
-35.05	1.53	Dark grey shale. Plant fossils (debris).
-35.45	0.40	Grey, massive, fine sst. with fine plant debris.
-38.25	2.80	Grey, conch. fractured siltstone; nodules.
-39.15	0.90	Yellow, hard, massive med. sst.
-39.75	0.60	Brown, grading to grey, shale. Nodules up to

		20cm diam.
-44.25	4.50	Grey, massive fine sst. interbedded with shale. Plant debris and cross-stratification.
-44.85	0.60	Dark grey shale with roots; bioturbation.
-45.15	0.30	Black lst. with bivalves.
-45.21	0.06	Dark grey shale.
-45.45	0.24	Grey shale.
-45.65	0.20	Black lst. with bivalves.
-45.75	0.10	Black lst. with bivalves and cone-in-cone str.
-46.15	0.40	Dark grey shale with thin lst. band (cone-in-cone str.)
-46.52	0.37	Black lst. with bivalves.
-47.94	1.42	Grey shale; nodules.
-48.04	0.11	Siderite band.
-49.47	1.42	Grey shale coarsening to fine sst. and fining back to shale. Planar lam. in sst.
-49.52	0.05	Siderite band.
-52.52	3.00	Grey shale. Common plant debris; nodule/root zones.
-52.67	0.15	Coal stringer. 3 clarain bands separated by 2 durain bands. Thin lst. with cone-in-cone interbedded.
-54.87	2.17	Dark grey fossiliferous shale; roots and nodules.
-55.04	0.20	Siderite band.
-56.84	1.80	Grey, fossiliferous shale; nodules.

-58.24	1.40	4' coal seam. Alternating carbonaceous shale/coal. 1 shale parting of 7cm.
-58.31	0.07	Grey, massive, med. sst.
-60.31	2.00	Grey shale. Rare bivalves in thin lst. horizons. Nodules common.
-60.74	0.43	Grey, very fine sst. with shale interbeds. Sst. is massive.
-61.84	1.10	Grey shale coarsening upward to fine sst.
-65.59	3.75	Grey fine sst. fining to siltstone in top few cm. Bottom 55cm is massive; next 40cm is planar lam.; rest of unit has cross-stratification with plant debris.
-66.19	0.10	Grey, fine sst. with ripple-drift cross-lamination. Contorted beds near top.
-66.31	0.60	Grey, massive shale.
-66.38	0.07	Grey, massive fine sst. with rare cross-lamination.
-67.68	1.30	Grey shale. Purple/brown colour near centre. Nodules common.
-67.92	0.24	Grey shale.
-69.57	1.65	Black lst. grading to shale. Shale has rare bivalves.
-69.61	0.04	Siderite band.
-71.61	1.00	Grey, fine sst. with cross-stratification. Nodule zones; undulating siderite band.
-72.41	0.80	Grey, medium sst. with planar lamination. Cross-strat. near top.

-73.01	0.60	Grey shale. Rare cross-strat. within sandy layers. Rootlets
-73.05	0.04	Siderite band.
-74.55	1.50	Grey, fine sst. with shale interbeds. Cross-lamination. Channel feature 12m wide and 1.5m deep. Root system very well-preserved.
-75.02	0.47	Grey shale with abundant roots; nodules.
-75.08	0.06	Grey, fine sst. with cross-lamination.
-75.33	0.25	Grey, conch. fractured and rooted shale.
-86.43	11.10	Grey shale. Root/nodule horizons common.
-88.73	2.30	Grey, fine sst. with cross-lamination. Two small channel features present.
-89.03	0.30	Grey, fine sst. fining up. Cross-lamination.
-89.93	0.90	Grey shale. Roots; nodules.
-90.33	0.40	Black lst. Bivalves and plant debris.
-90.63	0.30	Grey shale. Fe-stained bands.
-91.19	0.56	Black lst. Abundant plant debris, decreasing upward.
-91.79	0.60	Grey shale.
-92.04	0.25	Black lst. Carbonaceous shale at base.
-93.24	1.20	Grey shale. Fe-stains; rare nodules.
-93.44	0.20	Grey shale; nodules.
-94.04	0.60	Grey siltstone; rare cross-lamination; nodules.

-94.79	0.75	Grey shale. Nodules; Fe-stained bands.
-95.79	1.00	Black lst. interbedded with black shale. Cone-in-cone str. in lst.
-97.39	1.60	Grey, fine sst. with cross-lamination. Heavily rooted with plant debris.
-97.89	0.50	Grey, rooted clay (non-lithified).
-99.45	1.56	5' coal seam. Interbedded carbonaceous shales/durain bands. Black lst. interbeds within the seam.
-101.45	2.00	Grey shale. Conch. fracture; nodules.
-102.10	0.65	Black lst./shale interbeds containing plant debris.
-102.90	0.80	Grey shale with interbedded carbonaceous shale at top.
-103.31	0.31	Coal stringer. Carbonaceous shale with a durain interbed.
-110.31	7.00	Grey shale interbedded with fine sst. containing cross-stratification and roots.
-114.57	4.26	15' coal seam. Collapsed drift; cliff obscured.
-125.57	11.00	Grey shale with fine sst. interbeds at 0.5-1.0m intervals. Cross-lamination and nodules.
-125.67	0.10	BASE OF EAGLE SST. Pebble conglomerate lining large erosional surface.
-135.57	9.90	Grey, Fe-stained trough cross-bedded med. sst. Organic debris. Smaller cross-beds at top of unit.

-135.67	0.10	Pebble conglomerate (erosional base)
-136.87	1.20	Dark grey, poorly-indurated planar-laminated med. sst. Laminae ave. 1mm thick. Unit is lensoid with pinching out laminae. Common coalified debris.
-149.87	3.00	Grey, med. sst. with large trough cross-beds. "Cannonball" concretions.
-152.87	12.00	Interbedded fine sst./shale. Abundant planar laminae of coalified plant material.
-172.87	20.00	Grey, Fe-stained trough cross bedded sst. Fossil logs; concretions up to 1.0m diam.
-172.92	0.05	Pebble conglomerate.
-217.92	45.00	Grey. Fe-stained large trough cross-bedded sst. Small cross-stratification in top 4.0m.
-223.22	5.30	BASE OF UPPER SHALE MEMBER Grey shale. Nodules; roots in nodules uncompressed.
-223.62	0.40	Coal stringer. Clarain bands separated by 20cm of sst.
-227.72	4.10	Grey shale with nodules and plant fossils.
-230.22	2.50	Grey, massive, fine sst. Scoured base.
-237.62	7.40	Grey shale. Abundant nodules and roots. Roots preserved in three-dimensions.
-240.97	3.35	8' coal seam. Section hidden due to collapse of drift.
-253.67	12.70	Grey/brown colour-banded shale. Grey bands are ~5cm and brown bands are ~1cm. Nodules very common and tend

		to be small.
-256.37	2.70	Black lst. with bivalves and ostracods; increasing plant material upward. Upper part is carbonaceous shale.
-258.73	2.36	7' coal seam. Interbedded black lst, thick clarain, shaley coal, and durain.
-274.23	15.50	Grey/brown banded shale. Grey bands ~5cm thick; brown bands ~1cm thick. Bands constant through the bed. Small nodules common.
-286.23	12.00	Previous unit coarsens up to grey, fine sst. with cross-lamination.
-326.23	40.00	BASE OF STACK SANDSTONE Erosional base. Grey, Fe-stained med. sst. with large trough cross-beds. Abundant logs in clusters.

APPENDIX B

PETROGRAPHY

SAMPLE: CMP240485-10

FACIES: Sr

POSITION IN SECTION: 29.47m

ROUNDING: Subangular   SORTING: Poor

QUARTZ: 30%   PLAGIOCLASE: 15%
K-FELDSPAR: 5%   BIOTITE: 2%
MUSCOVITE: 5%   LITHIC: 3% (metamorphic)

CLASTS (%): 60%   MATRIX (%): 20%   TYPE: Clays
CEMENT (%): 20%   TYPE: Calcite

SAMPLE: A12

FACIES: Sr

POSITION IN SECTION: 33.52m

ROUNDING: Angular/subangular   SORTING: Poor

QUARTZ: 25%   PLAGIOCLASE: 15%
K-FELDSPAR: 5%   BIOTITE: 2%
MUSCOVITE: 3%   LITHIC: 10% (metamorphic - ?)

CLASTS (%): 60%   MATRIX (%): 30%   TYPE: Clays
CEMENT (%): 10%   TYPE: Calcite

SAMPLE: B14

FACIES: Sr

POSITION IN SECTION: 35.45

ROUNDING: Ang. to subrounded SORTING: Moderate to poor

QUARTZ: 20% PLAGIOCLASE: 15%
K-FELDSPAR: 5% BIOTITE: 2%
MUSCOVITE: 5% LITHIC: 3%

CLASTS (%): 50% MATRIX (%): 30% TYPE: Kaolinite
CEMENT (%): 20% TYPE: Possibly quartz

-Plagioclase often altered

-Quartz commonly elongate

SAMPLE: C15

FACIES: Sh

POSITION IN SECTION: 39.15

ROUNDING: Subangular SORTING: Poor

QUARTZ: 30% PLAGIOCLASE: 20%
K-FELDSPAR: 5% BIOTITE: 0%
MUSCOVITE: 5% LITHIC: 0%

CLASTS (%): 65% MATRIX (%): 15% TYPE: Clays
CEMENT (%): 20% TYPE: Calcite

SAMPLE: D15

FACIES: Sr

POSITION IN SECTION: 44.25m

ROUNDING: Subangular SORTING: Poor to moderate

QUARTZ: 15% PLAGIOCLASE: 25%
K-FELDSPAR: 10% BIOTITE:0%
MUSCOVITE: 5% LITHIC: 0%

CLASTS (%): 60% MATRIX (%): 20% TYPE: Clays
CEMENT (%): 20% TYPE: Calcite

-Many of the plagioclase grains are partly altered to clay

SAMPLE: CMP300485-03

FACIES: Lst

POSITION IN SECTION: 91.19m

ROUNDING: N/A SORTING: N/A

QUARTZ: - PLAGIOCLASE: -
K-FELDSPAR: - BIOTITE:-
MUSCOVITE: - LITHIC: -

CLASTS (%): Shells MATRIX (%): 20% TYPE: Calcite
CEMENT (%): TYPE:

-Clasts are bivalve and ostracod shells surrounded by a calcite matrix.

SAMPLE: CMP300485-18

FACIES: St

POSITION IN SECTION: 135.57m

ROUNDING: Subrounded SORTING: Poor to moderate

QUARTZ: 40% PLAGIOCLASE: 15%
K-FELDSPAR: 5% BIOTITE: 5%
MUSCOVITE: - LITHIC: -5%

CLASTS (%): 70% MATRIX (%):25% TYPE: Clays
CEMENT (%): 5% TYPE: Hematite

SAMPLE: CMP300485-21

FACIES: Sho

POSITION IN SECTION: 152.87m

ROUNDING: Subangular SORTING: Poor

QUARTZ: 25% PLAGIOCLASE: 15%
K-FELDSPAR: - BIOTITE: 3%
MUSCOVITE: 2% LITHIC: 2%

CLASTS (%): 50% MATRIX (%):30% TYPE: Clays
CEMENT (%): 20% TYPE: Hematite

SAMPLE: L30

FACIES: St

POSITION IN SECTION: 172.87m

ROUNDING: Subangular
SORTING: Moderate

QUARTZ: 40%
K-FELDSPAR: 5%
MUSCOVITE: 2%
PLAGIOCLASE: 20%
BIOTITE: 3%
LITHIC: max. 1%

CLASTS (%): 70%
CEMENT (%): 20%
MATRIX (%): 10%
TYPE: Clays
TYPE: Hematite

SAMPLE: CMP300485-22

FACIES: St

POSITION IN SECTION: 172.92m

ROUNDING: Subangular
SORTING: Poor

QUARTZ: 30%
K-FELDSPAR: -
MUSCOVITE: Max. 1%
PLAGIOCLASE: 20%
BIOTITE: 5%
LITHIC: 15% (metamorphic - ?)

CLASTS (%): 70%
CEMENT (%): 10%
MATRIX (%): 15%
TYPE: Clays
TYPE: Hematite

SAMPLE: CMP300485-23

FACIES: St (grades to Sr)

POSITION IN SECTION: 217.92m

ROUNDING: Subangular SORTING: Moderate to poor

QUARTZ: 40% PLAGIOCLASE: 20%
K-FELDSPAR: 5% BIOTITE: 2%
MUSCOVITE: 3% LITHIC: 10%

CLASTS (%): 80% MATRIX (%): 15% TYPE: Clays
CEMENT (%): 5% TYPE: Quartz

SAMPLE: T

FACIES: Sh

POSITION IN SECTION: 230.22m

ROUNDING: Subangular SORTING: Poor

QUARTZ: 25% PLAGIOCLASE: 5%
K-FELDSPAR: - BIOTITE: -
MUSCOVITE: 5% LITHIC: 5%

CLASTS (%): 40% MATRIX (%): 20% TYPE: Clays
CEMENT (%): 30-40% TYPE: Calcite

APPENDIX C : COAL

Eight-foot Seam

	Ft.	Ins.
Shaly coal	1	0
Coal with shale	1	5
Clay	..	2
Coal and shale	..	6
Soft fire-clay	1	0
Coal	3	3
Fire-clay	..	3
Coal, hard	..	9
Coal	3	6
	11	10

Fifteen-foot Seam

	Ft.	Ins.
Shaly coal	2	0
Coal	3	6
Clay	.	1
Shaly coal	..	6
Coal	2	6
Shale	..	2
Coal	1	3
Shale	..	1
Coal	4	0
	14	1

Five-foot Seam

	Ft.	Ins.
Coal	2	6
Canneloid coal	1	6
Coal	2	0
	6	

The following measurements were made on the shore outcrops of the remaining lower seams:

Four-foot Seam

	Ft.	Ins.
Shale with thin sandstone interbeds	10	0
Coal	2	0
Coal and shale	1	7
Fire-clay	..	6
Coal and shale	..	6

One-foot Seam

	Ft.	Ins.
Coal	1	0
Carbonaceous shale	1	0

Three-foot Seam

	Ft.	Ins.
Soft, grey, carbonaceous shale	8	0
Coal	..	6
Shale	..	5
Coal and shale	2	6

The following analyses of the upper seams are given by Gilpin (50):

—	Vol. comb. matter	Fixed carbon	Ash	Sulphur	Moisture
Seven-foot seam	35·90	53·30	8·70	1·88	2·10
Eight-foot seam	34·25	56·40	6·95	1·85	2·40
Fifteen-foot seam	37·50	51·20	9·05	5·77	2·25
Five-foot seam	35·65	49·55	11·95	5·20	2·85

(Norman, 1935)

APPENDIX D

FACIES DISTRIBUTION AT MABOU MINES

FACIES	% LOWER SHALE MMBR.	% TOTAL SECTION
C	7.6	4.6
Lst	4.4	2.4
Fsc	54.6	35.0
Sr	31.6	15.8
Sh	1.4	1.3
P	0.4	0.1
Gm	-	0.1
St	-	39.5
Sho	-	1.2

FLOODPLAIN FACIES (C, Lst, Fsc, Sr, Sh, P) = 59.7% total section

CHANNEL FACIES (St, Gm, Sho) = 40.3% total section

APPENDIX E

BRAIDED RIVER FACIES (Miall, 1982)

Name	**Environmental setting**	**Main facies**	**Minor facies**
Trollheim type (G_I)	proximal rivers (predominantly alluvial fans) subject to debris flows	*Gms, Gm*	*St, Sp, Fl, Fm*
Scott type (G_{II})	proximal rivers (including alluvial fans) with stream flows	*Gm*	*Gp, Gt, Sp, St, Sr, Fl, Fm*
Donjek type (G_{III})	distal gravelly rivers (cyclic deposits)	*Gm, Gt, St*	*Gp, Sh, Sr, Sp, Fl, Fm*
South Saskatchewan type (S_{II})	sandy braided rivers (cyclic deposits)	*St*	*Sp, Se, Sr, Sh, Ss, Sl, Gm, Fl, Fm*
Platte type (S_{II})	sandy braided rivers (virtually non cyclic)	*St, Sp*	*Sh, Sr, Ss, Gm, Fl, Fm*
Bijou Creek type (S_I)	Ephemeral or perennial rivers subject to flash floods	*Sh, Sl*	*Sp, Sr*