STRATIGRAPHIC ANALYSIS AND POSSIBLE TIDAL INFLUENCE IN THE THORBURN MEMBER AND COAL BROOK MEMBER, STELLARTON FORMATION, NOVA SCOTIA

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Abstract

The Late Carboniferous Stellarton Basin is located in central Nova Scotia. It is bounded by the Cobequid Fault to the north and the Hollow Fault to the south. Dextral movement on these faults during the Carboniferous formed the 6 km by 18 km pull-apart Stellarton Basin. The basin-fill is composed of approximately 2600 m of coal- and oil shale-bearing strata of the Stellarton Formation. The intervals studied are within the Thorburn and Coal Brook Members of the Stellarton Formation. They include a range of lithofacies from proximal to distal with respect to the sediment source. The fissile and torbanite oil shales were deposited under quiet, anoxic, sediment starved conditions. Massive and laminated grey mudstones formed in a sediment deprived environment with limited current action indicated by small scale cross-stratification. An increase in biological activity including burrowing implies a move to oxygenated bottom waters. A lithofacies consisting of interlayered sandstone and mudstone shows an increased proximal component with unsteady current flow exhibited by sandy cross-beds overlain by mudstone drapes. Weakly stratified sandstone were deposited during periods of high sediment load and energetic water movement. A coal facies as well as a paleosol facies is encountered locally in the Thorburn interval. These indicate sub-aerial or near-sub-aerial exposure and form the proximal end-member of the facies range.

Horizontal and vertical lithofacies variations are found in the two studied intervals. The Thorburn interval shows an overall coarsening-upward grain size trend in cycles approximately 10 to 20 m thick, from oil shale to medium-grained sandstone. The coarsening-upward cycle is overlain by a minor fining-upward cycle that includes paleosols. The Coal Brook interval ranges from 11 to 20 m thick and shows an overall coarsening-upward grain-size trend. The interval also exhibits lateral thickening of units and an increase in coarse-grained units towards the inferred sediment source in the southeastern portion of the study area. The overall coarsening-upward trend in the intervals implies deposition in standing bodies of water with prograding coarse-grained deposits.

Paired mudstone drapes, considered characteristic of tidal influence, were identified in the interlayered sandstone and mudstone of the Thorburn interval. The mudstone drapes cap sandy climbing and truncated cross-sets of approximately 3 cm thickness. Although not all mudstone drapes in the facies are paired, individual sets show as much as 50% pairing. Mud drape deposition is inferred to occur during the slackwater period of tidal reversal. The pairing is associated with thickness differences in the sandstone cross-sets implying differences in current strength and direction between a dominant and a subordinate tide. The low-sulphur coals and lack of strictly marine fossils indicate that the tidal influence was not accompanied by increased salinity. Supporting marine influence has been documented in other Upper Carboniferous areas of Atlantic Canada including Sydney, Joggins, and Port Hood. This is the first documentation of marine influence in the Upper Carboniferous strata of the Stellarton Basin.

Key Words: Carboniferous, Stellarton Basin, Nova Scotia, lithofacies, lacustrine, delta, progradation, standing water, oil shale, tidal influence, cyclicity

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I dedicate this thesis to my family and friend, and especially my parents for all of the support they have given me over the years.

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CHAPTER 1: INTRODUCTION

1.1 General Statement

This study involves the description of two intervals, bounded by oil shales, within the Thorburn and Coal Brook Members of the Stellarton Formation. Oil shales are rocks that contain solid organic matter in proportions high enough to produce oil when distilled (Hutton et al., 1980). The primary objective of the thesis is to study and trace the various lithofacies within the two oil shale-bounded intervals through drill-core in order to determine the vertical and lateral variability. This is of importance because, although extensive study of the oil shales within the formation has taken place, very little work has been conducted on the enclosed clastics. Based on observation of the various facies within the intervals, an examination of structures suggestive of periodic tidal influence is described. An interpretation of the depositional environment of the interval based on the examination of the various facies relationships and the tidal influence concludes the study.

1.2 Geological Background

1.2.1 The Stellarton Basin

The Stellarton Basin is located in central Nova Scotia. It forms part of the extensive Maritimes Basin and is located between the Cobequid and the Antigonish Highlands. The basin is 6 km X 18 km and is bounded on the north by the Cobequid Fault and on the south by the Hollow Fault (Fig. 1-1).

The formation of the Stellarton Basin resulted from movement on its two bounding faults. The Cobequid Fault underwent dextral movement during the Late Carboniferous

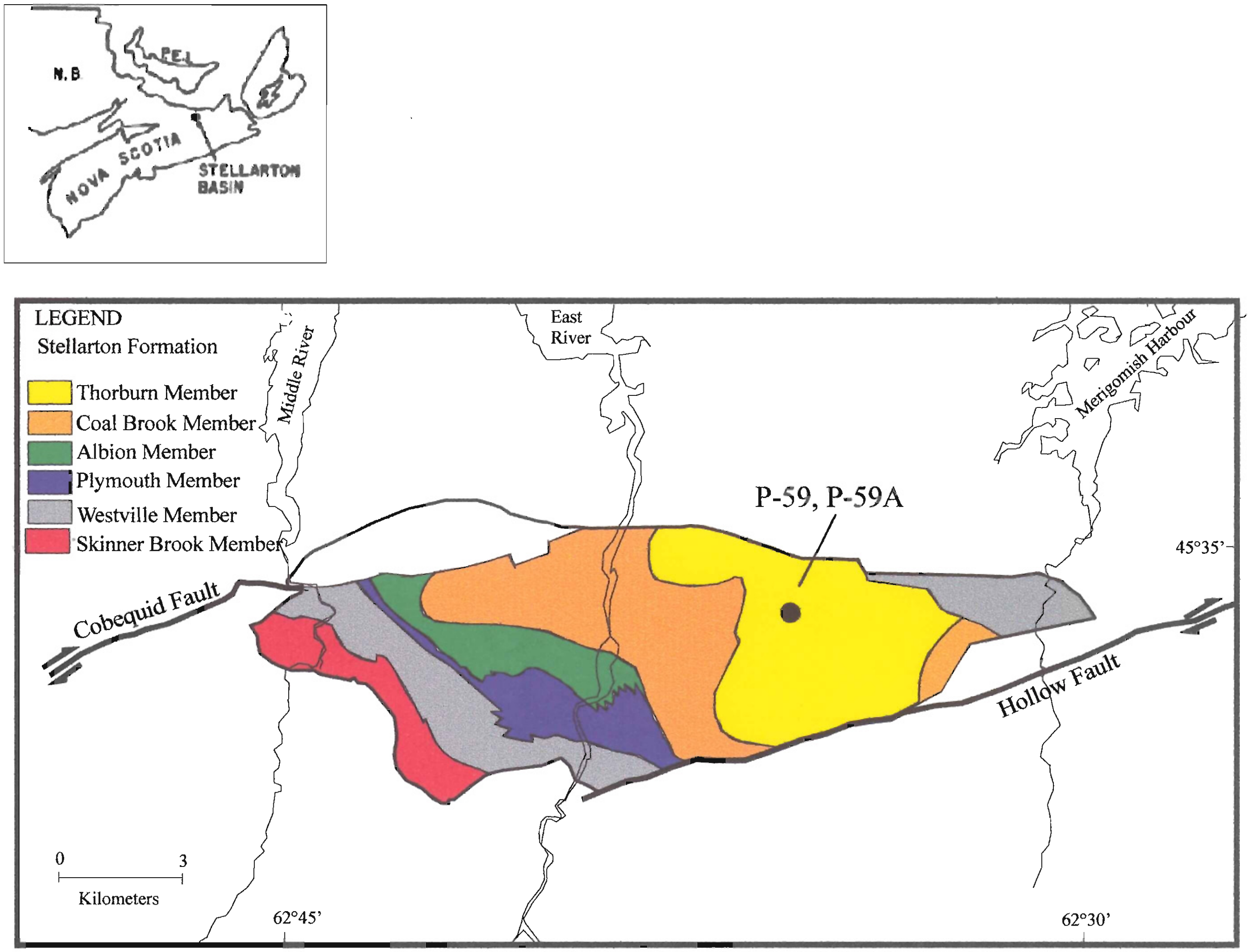


Figure 1-1. Setting map of the Stellarton Basin (Naylor et al., 1989; Kalkreuth and MacAuley, 1991).

from Westphalian B through Stephanian time (Eisbacher, 1967; Yeo and Ruixiang, 1986) (approximately 311 to 306 Ma: Okulitch, 1999). Dextral movement was also suggested by several workers (Eisbacher, 1967, 1969; Webb, 1969; Benson, 1974; Fralick, 1980; Fralick and Schenk, 1981) for the Hollow Fault. Extension in the area between the two faults formed the pull-apart Stellarton Basin (Yeo and Ruixiang, 1987).

During its formation in the Late Carboniferous the Stellarton Basin was located near the paleo-equator (Fig. 1-2). As a part of Pangea this region was undergoing a seasonal climate with aridity (Parrish, 1993). To the east, the Paleo-Tethys Sea existed with an inferred extension, namely the Mid-Euramerican Sea, into the Maritimes Basin (Calder, 1998). Strong evidence for a marine influence at this time is evident in Nova Scotia (Wightman et al., 1993, 1994; Archer et al., 1995; Allen, 1998; Gibling et al., 1989, 1999; Naylor et al., 1998).

1.2.2 The Stellarton Formation

The approximately 2600 m of coal-bearing strata found in the Stellarton Basin makes up the Stellarton Formation. The formation comprises six members (Fig. 1-3): the Skinner Brook, Westville, Albion, Plymouth, Coal Brook, and Thorburn Members. The basal Skinner Brook Member is composed of up to 655 m of red beds containing mudstones, sandstones, and minor conglomerates. It has been attributed to deposition on small alluvial fans and floodplains (Yeo and Ruixiang, 1987). The overlying Westville Member encompasses up to 544 m of lacustrine delta deposits including oil shales, coals, and mudstones (Naylor et al., 1992). Overlying the Westville is another 620 m thick oil shale and coal-bearing unit, the Albion Member. The Plymouth Member interfingers

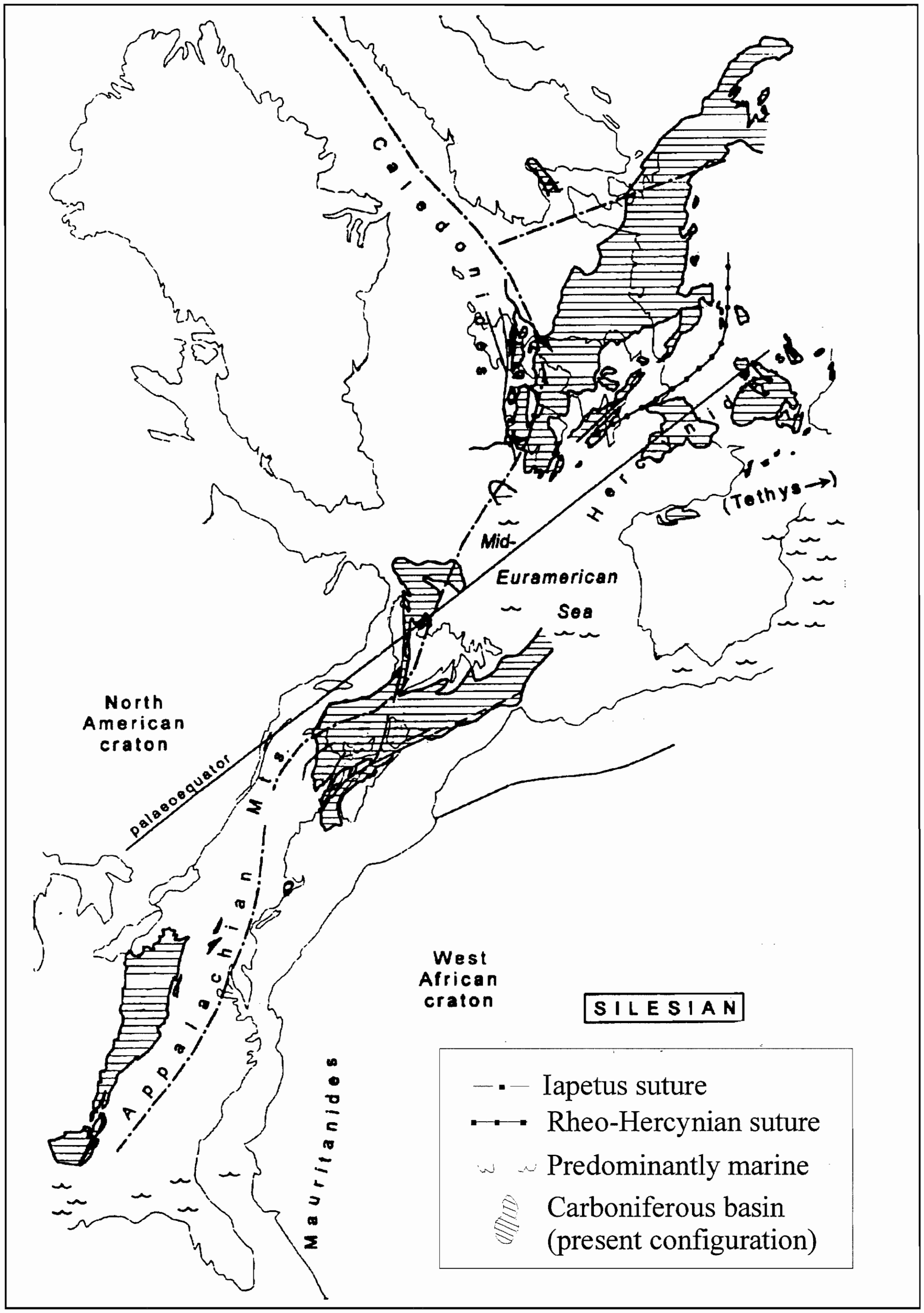


Figure 1-2. Map of the Euramerican Basin during the Silesian (Calder, 1998).

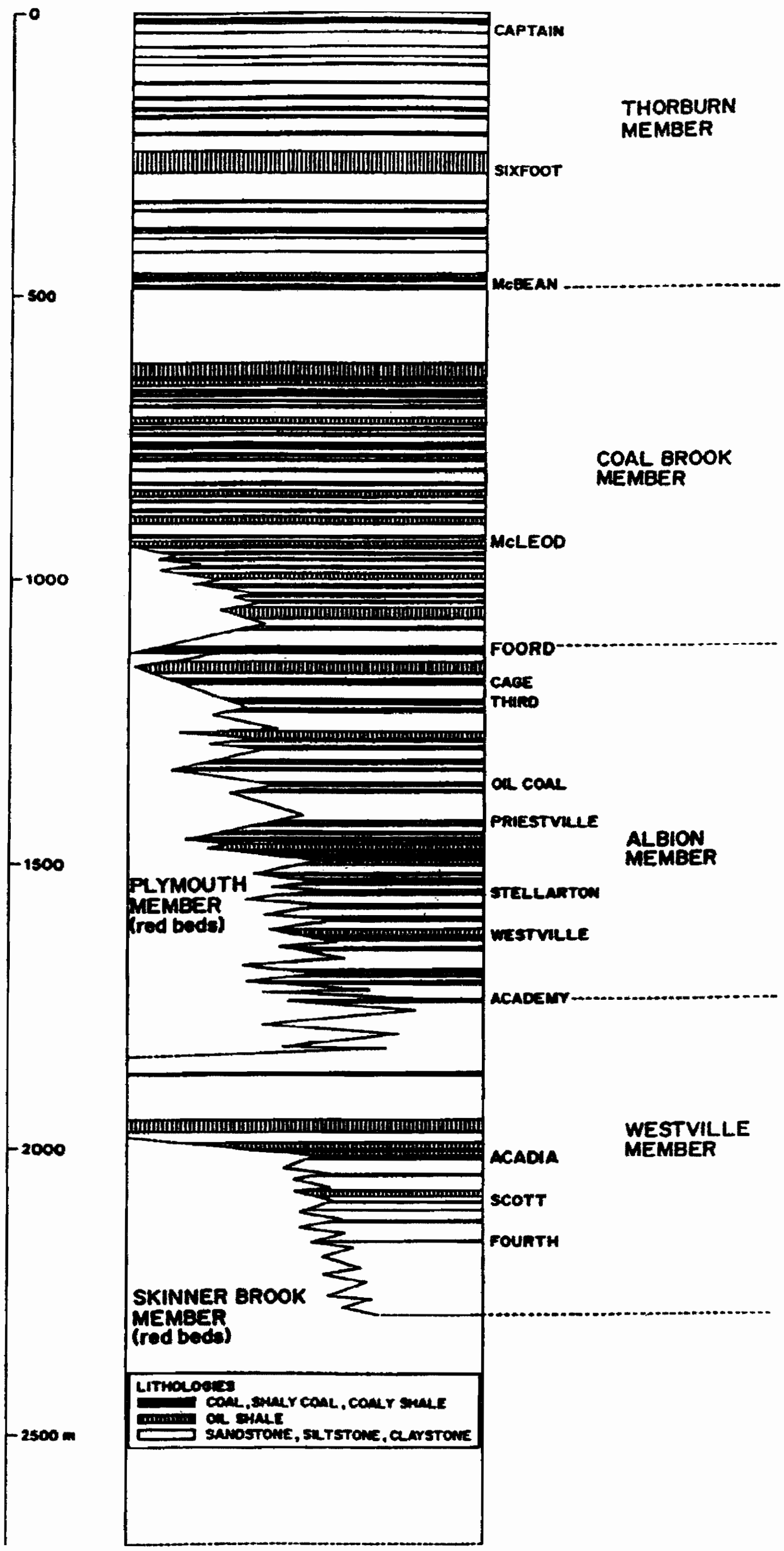


Figure 1-3. Stratigraphic column of the Stellarton Basin showing coal seams and oil shales (Naylor et al., 1989).

with both the Westville and Albion Members. It comprises as much as 295 m of alluvial red beds (Yeo and Ruixiang, 1987.) The upper two units, the Coal Brook and Thorburn Members, are also oil shale- and coal-bearing. The Thorburn and Coal Brook Members are the focus of this study and are discussed in greater detail below. Each member is found in outcrop within the basin (Fig. 1-1) beginning with the Skinner Brook to the west with progressively younger beds eastward. The Stellarton Formation was deposited from the Westphalian B through early D (Naylor et al., 1989), about five million years (Okulitch, 1999). Therefore the entire 2600 m of the Stellarton Formation was deposited within a small area over a short timespan.

1.2.3 The Coal Brook Member

The first interval studied is found in the Coal Brook Member. The Coal Brook Member ranges from 500 m to 900 m in thickness (Naylor et al., 1989). There are approximately 30 oil shales within the member (Fig. 1-4). These occasionally grade laterally into thin coals towards the basin margin. Mudrocks, With apparent rhythmic lamination, constitute a large proportion of the Coal Brook Member. These mudrocks grade laterally into interlaminated fine-grained sandstones and mudrocks. Towards the basin margin there are minor pebbly conglomerates which rapidly thin and disappear basinward.

The Coal Brook Member has traditionally been interpreted to be comprised primarily of lacustrine deltaic deposits (Naylor et al., 1989). Coal formed in peat mires that developed close to the basin margin. Oil shales formed from organic-rich muds that accumulated in a quiet environment with a restricted sediment supply. The rhythmically

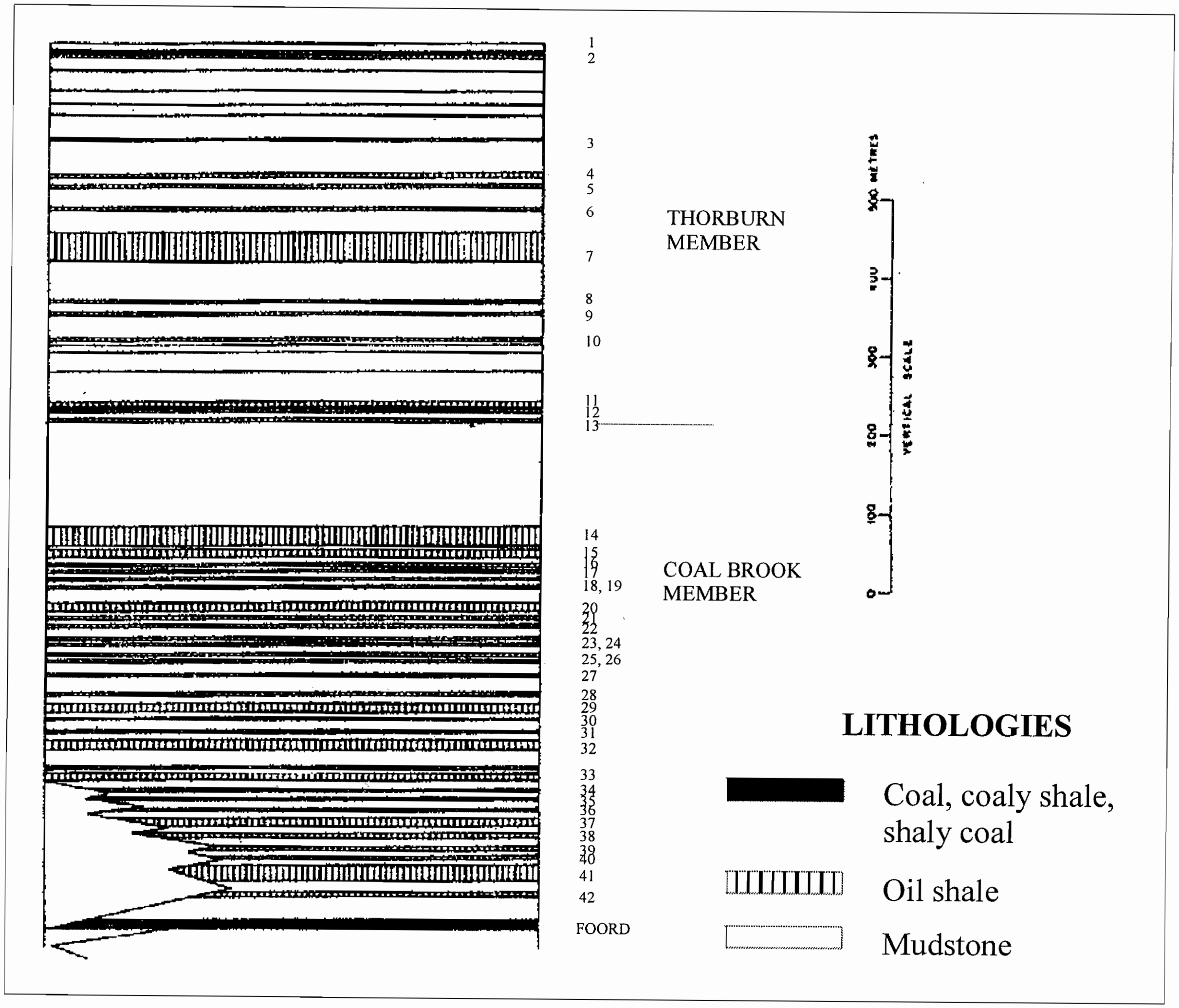


Figure 1-4. Stratigraphic column of studied members, Thorburn and Coal Brook Members, the Stellarton Formation (Naylor et al., 1989).

laminated mudrocks have been interpreted to be prodelta deposits and the fine-grained sandstones have been described as delta front and mouthbar deposits. The conglomerates are thought to represent braided fluvial deposits (Naylor et al., 1989).

1.2.4 The Thorburn Member

The Thorburn Member contains one of the intervals of the study. The Thorburn Member has an average thickness of 490 m (Naylor et al., 1989) and occurs in the eastern area of the basin. The lihologies present include oil shales that occasionally grade into coal seams and rhythmically layered mudstones which coarsen towards basin margin. Many of the lithologies are similar to those found in the Coal Brook Member and the Thorburn is inferred to have formed under similar conditions (Naylor et al., 1992).

1.2.5 Previous Work

The Stellarton Basin and Formation have been extensively studied over the past two centuries. The earliest studies by Dawson (1868) and Logan and Hartley (1869), as well as work by Poole (1904), Bell (1940), and Haites (1956), described the basic geology of the area. Since the earliest studies the strata of the Stellarton Basin have had several different nomenclatures including the Stellarton Series (Bell, 1926, 1940), the Stellarton Group (Bell, 1958), and most recently the Stellarton Formation, first used by Fralick and Schenk (1981). Bell (1940) subdivided the formation into six members on the basis of coal seam position (Fig. 1-3). The Stellarton Formation is classified as a part of the regional Cumberland Group (Ryan et al., 1991).

Although the coal and oil shale resources of the Stellarton Basin have always been of interest, more recent studies have centered on the structure of the area. Work to constrain the dextral movement of the two bounding faults, the Cobequid and Hollow, by several workers (Webb, 1969; Eisbacher, 1967, 1969; Benson, 1974; Donohoe and Wallace, 1978, 1985; White, 1983) has led to a number of suggested basin-forming mechanisms. Fralick (1980) and Fralick and Schenk (1981) suggested two possible mechanisms (Fig. 1-5): (1) a combination of the fault termination and the divergent fault models from the idea that the north bounding fault is a dextral splay of the Hollow Fault; and (2) a combination of the curved fault model and the side-stepping fault model from the suggestion that the basin formed at a bend in a braided wrench fault. More recent studies (Yeo, 1985; Yeo and Ruixiang, 1987) have concluded that the Stellarton Basin formed as an extensional pull-apart basin.

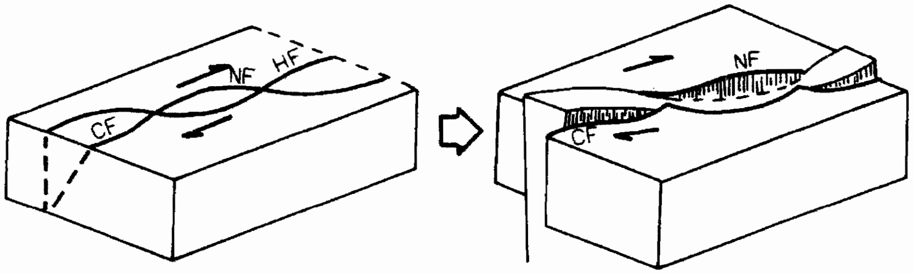
The depositional environment of the Stellarton Formation has been widely studied. Many workers (Naylor et al., 1989, 1992, Chandler et al., 1994) have suggested a lacustrine and fluvial environment. New evidence, however, presented in this study may influence the depositional interpretation of the Stellarton Basin.

1.2.6 Tidally-Influenced Deposits

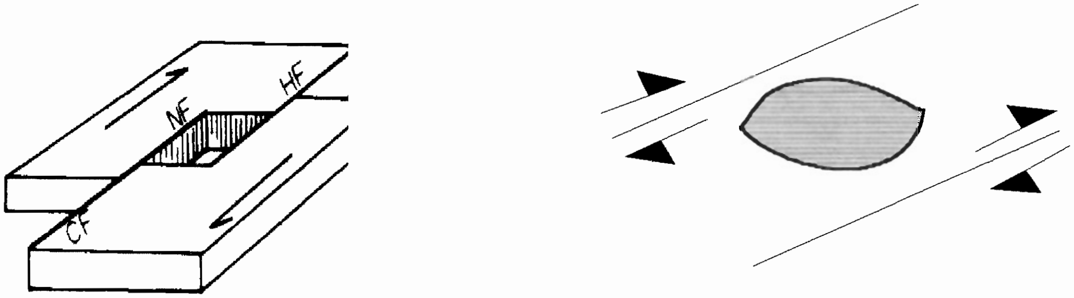
A distinct group of sedimentary structures reflect deposition in tidally-affected environments. The lithology and geometry of the deposits is controlled by variations in the direction and intensity of tidal currents. Flaser and lenticular bedding indicating predominantly sandy deposition with minor mud layers is common within tidal deposits. The distribution and configuration of the bedding is also characteristic of tidal deposits.

A. Fault termination model

B. Divergent fault model



C. Curved fault trace model



D. Side-stepping fault model

E. Pull-apart model

Figure 1-5. Possible basin forming mechanisms proposed for the Stellarton Basin (Fralick and Schenk, 1980).

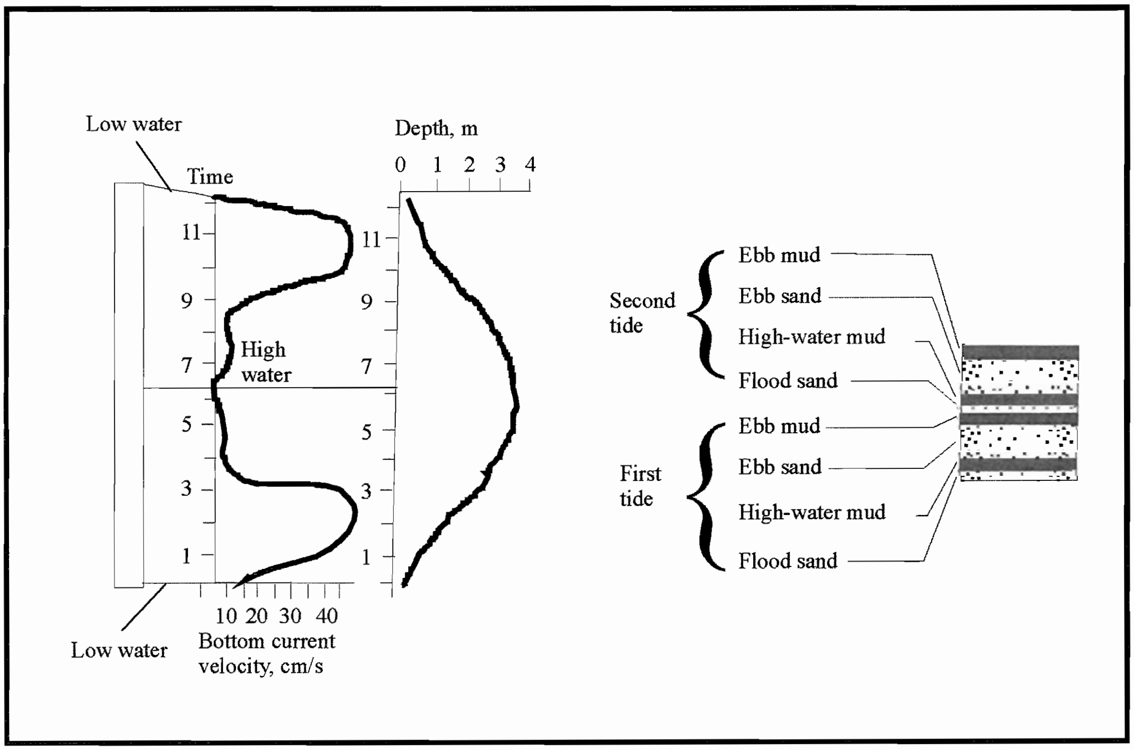


Figure 1-6. Formation process for tidal couplets (Reinech and Wunderlich, 1968; Visser, 1980; Smith, 1988).

The geometry of tidal deposits is characterized by both daily and monthly changes in tidal currents (Fig. 1-6). Daily changes are depicted with two tides (semi-diurnal), in this example, with a dominant ebb portion and a subordinate flood portion. Sand is deposited during both the flood and ebb tide. A thin layer of sand is deposited during the flood tide while a thick layer is deposited during the dominant ebb tide (Smith, 1988). Thin mud layers are deposited between the sand layers during slack tide periods. The difference in intensity between the dominant and subordinate tides causes mud couplets on either side of the thin sand layer to appear paired or coupled. The monthly periodicity of tidal currents also adds to the sedimentary signature of the deposits. As the intensity of tidal currents strengthen and weaken systematically throughout the month the thickness of tidal bundles also change systematically (Visser, 1980).

1.3 Methodology

This study examines the intervals between Oil Shales 7 and 8 and Oil Shales 21 and 22 of the Thorburn and Coal Brook Members, respectively, of the Stellarton Formation. This is accomplished through examination of drill core, outcrop, and thin sections. Seven drill holes were studied to provide a sedimentological and stratigraphic account of clastic facies within the intervals over an east-west distance of approximately 3.5 km. Available outcrop allowed for observation of the interval at a western point in the study area. Close examination of the sedimentological features of the facies was undertaken using thin sections. Constructed vertical columns, cross sections, and stratigraphic maps aided interpretation of the depositional environment of the interval. Mudstone drapes were examined in drillcore cut parallel to paleoflow direction and smoothed. By constructing tracings of the photographed core paired mud drapes were distinguished.

CHAPTER 2: LITHOFACIES DESCRIPTION

2.1 Introduction

The lithofacies observed as part of the study are found within two oil shale-bounded intervals in the Stellarton Formation. The Coal Brook Member contains the interval between oil shales 21 and 22 (Fig. 2-1), whih includes sandstones, mudstones, and oil shales (Table 2-1). The second interval, within the Thorburn Member (oil shales 7 to 8), includes oil shales, mudstones, and sandstones as well as coals and paleosols. The two studied intervals offer as spectrum of facies from fine- to coarse-grained.

2.2 Lithofacies Description

2.2.1 Oil Shale Facies

The oil shale facies forms the boundaries of both the Thorburn Member (Oil Shales 7 and 8) and Coal Brook Member (Oil Shale 21 and 22) studied intervals (Fig. 1-4). The oil shale units were studied in both drill core and outcrop (Fig 2-2). Each unit ranges from approximately 5 m to over 10 m thick and is comprised of black shale with occassional siderite (iron carbonate) bands. Two types of oil shale facies were observed: fissile oil shale (Fig. 2-3) and torbanite (Fig. 2-4). Rocks of the fissile oil shale lithofacies are dark grey to black with a brown streak. They show minor lamination and a specific gravity of 2.61 (Smith et al., 1991). Torbanite comprises a much smaller proportion of the oil shale units. It is a massive black rock with a dark brown streak and conchoidal fracture. It is less dense than fissile oil shale with a specific gravity of 2.36 (Smith et al., 1991). The oil shale facies locally contains plant fragments, ostracods, *Xenocanthus acinaces* and *Xenocanthus penetrans* (Calder, 1998) shark teeth, and locally abundant pelecypods (*Anthraconauta* sp. (Naylor et al., 1989)). A thin pelecypod-rich carbonate layer is located within Oil Shale 21.

Petrological examinations of the oil shales of the Stellarton Formation have been conducted by several authors (Kalkreuth and MacAuley, 1987; Smith and Naylor, 1990; Smith et al., 1991). Generally both fissile oil shale and torbanite are encountered in each

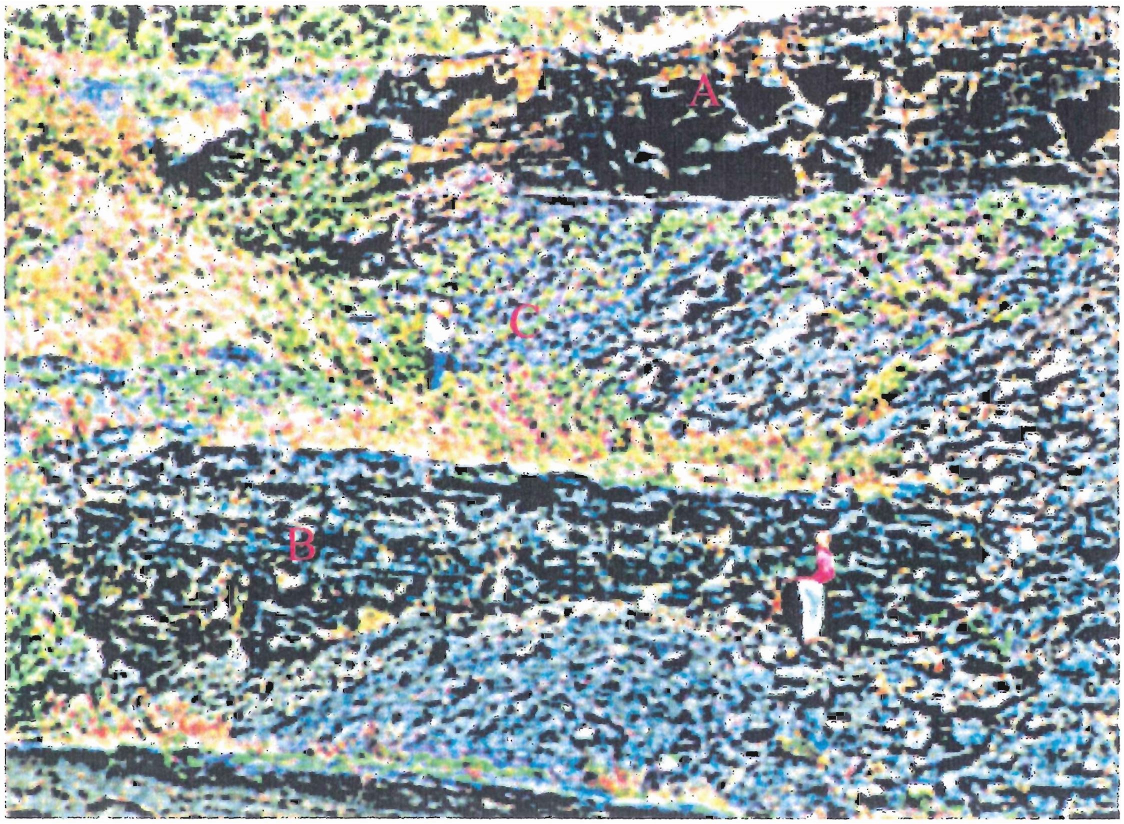


Figure 2-1. The Coal Brook Member studied interval, Shaw Clay Pit, Stellarton, N.S. Interval shows (A) Oil Shale 21; (B) Oil Shale 22; and (C) mudstone interval..

	Colour	Grain Size	Sedimentary Structures	Fossils	Compositional Modification	Inferred Depositional Environment
Oilshale (Torbanite and Fissile Oilshale)	greasy black with brown streak	clay	rare lamination in mainly fissile oilshale	transported plant fragments, ostracods, bivalves (locally abundant in fissile oilshale), shark teeth (in torbanite), abundant fine organic material	petroliferous, siderite bands (common in fissile oilshale)	low sediment supply (torbanite is strongly sediment starved), quiet, standing water conditions?
Mudstone (both massive and laminated)	medium to dark grey	clay to silt	lenticular (silty) beds have small-scale cross-bedding, mud drapes (some appearing paired), generally coarsening upward over approximately 10 to 50 cm, rare slump and dewatering structures	ostracods, bivalves, transported plant fragments, bioturbation (bivalve? escape burrows)	siderite bands (common to uncommon)	moderate sediment supply, current activity recorded in cross bedding
Interbedded Sandstone and Mudstone	pale to medium grey	clay to fine-grained sand	small-scale tabular cross-bedding, parallel bedding, mud drapes (some appear paired), generally coarsening upwards (cycles <1m)	bivalve? escape burrows, rare transported plant fragments	minor siderite bands	high sediment supply, current activity evident from cross-bedding, slack periods to allow fine sediment to fall out
Sandstone	pale grey	fine to medium grained sand	weakly stratified, parallel bedding, minor mud drapes, minor small-scale cross-bedding	rare transported plant fragments, bivalve? escape burrows	often calcite cemented, very minor siderite, orange tint possibly due to petroleum content in places	highest sediment, active current flow (asymmetrical ripples)
Coal	Black	Clay	N/A	Plant fragments	High vitrinite and inertinite maceral content	Mire formation
Paleosol	Pale to medium grey	Clay-silt	Distorted bedding	Root traces	Siderite nodules	Shallow to subaerial exposure

Table 2-1. Brief description of facies encountered in studied intervals.

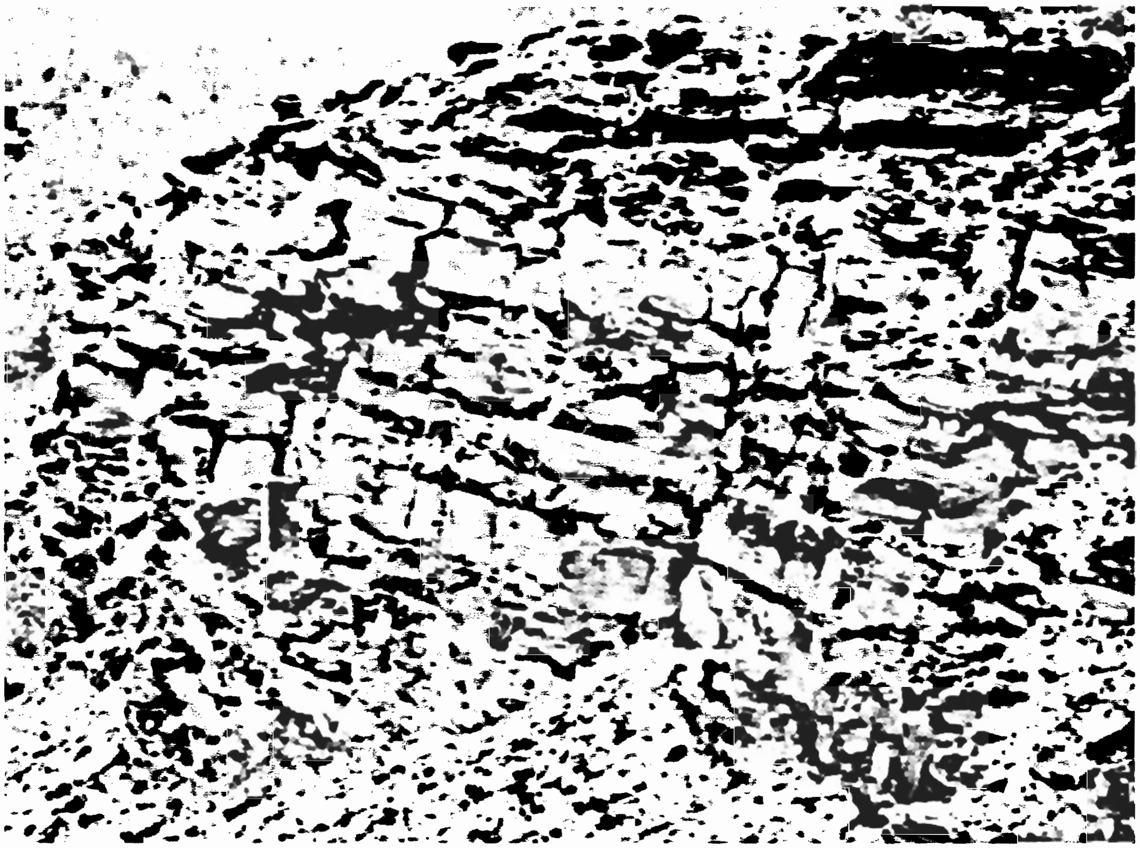


Figure 2-2. Oil Shale 21, Shaw Clay Pit, Stellarton, N.S.

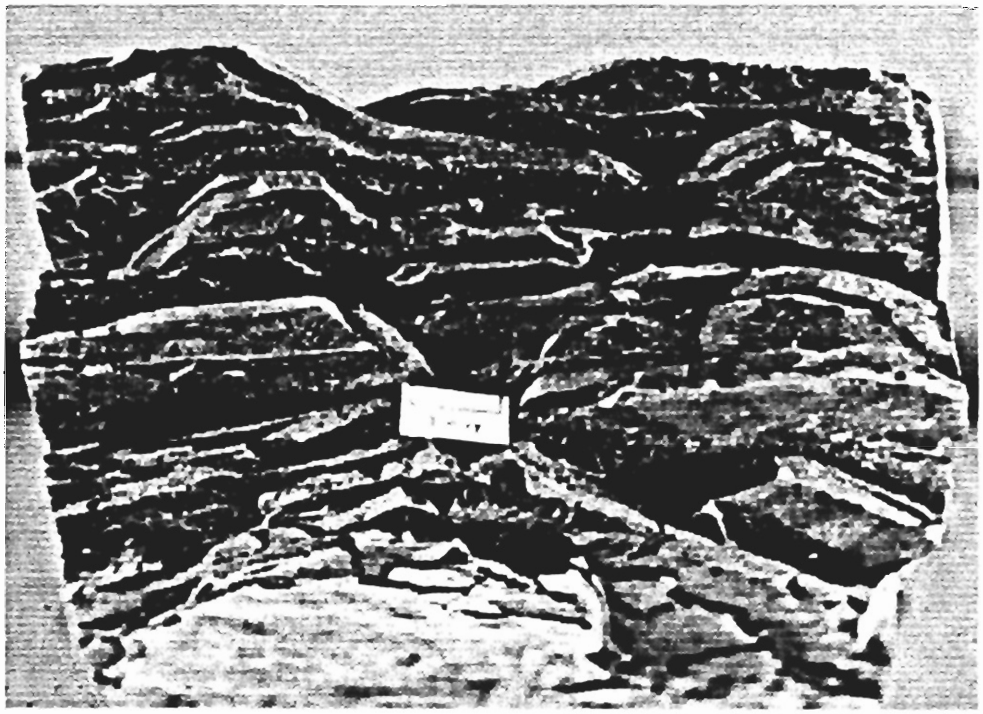


Figure 2-3. Fissile oil shale in hand specimen.

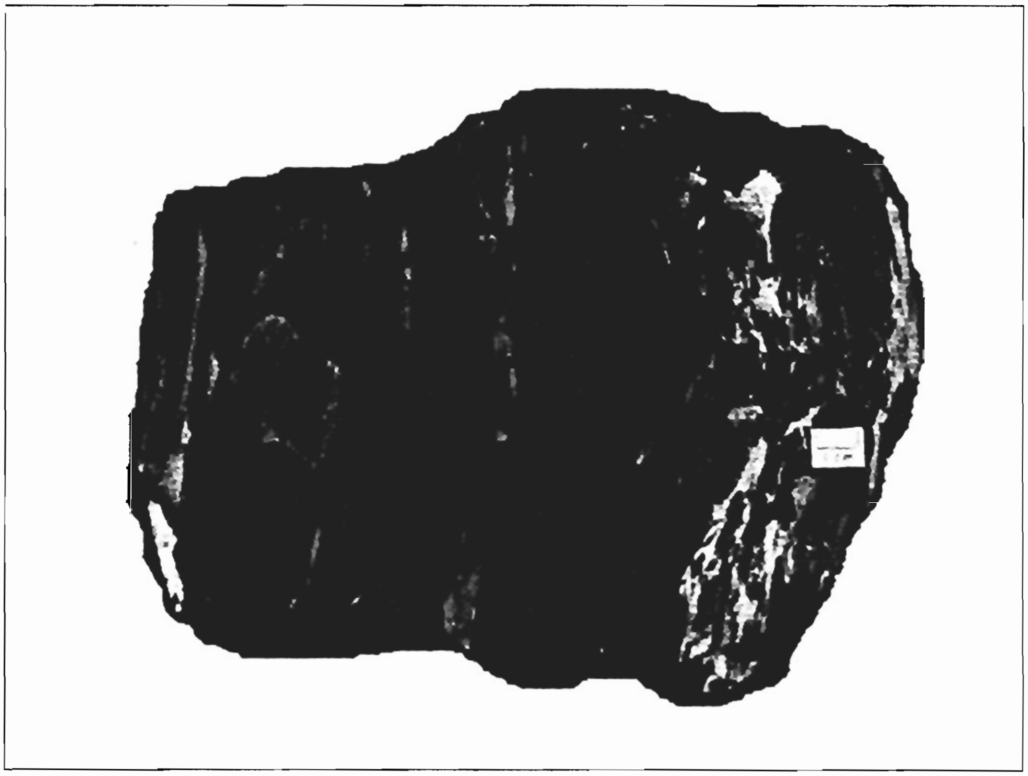


Figure 2-4. Torbanite oil shale in hand specimen.

oil shale unit. Oil shales in the Stellarton Formation are composed primarily of liptinite with varying amounts of vitrinite macerals (Hutton et al., 1980; Kalkreuth and MacAuley, 1987). Fissile oil shale makes up the majority of the oil shales encountered in the studied intervals. These oil shales generally have a relatively low total organic carbon (TOC) content (average 4.9 wt%)(Smith et al., 1991). They are composed of high amounts of liptinite macerals with lower proportions of vitrinite and inertinite macerals (Fig 2-5). The liptinite component is predominantly made up of lamalginite, which constitutes up to 73 vol % of the total organic material. The remaining liptinite macerals include telalginite (2-35 vol %) and sporinite (5-12 vol %) (Kalkreuth and MacAuley, 1987). In contrast, the torbanites have a higher TOC content averaging 9.0 wt % with some as high as 43.5 wt %. They display high amounts of vitrinite macerals (Kalkreuth and MacAuley, 1987) as well as liptinite macerals. The liptinite component of torbanite is commonly associated with telalginite originating as *Botryococcus braunii*, a green alga described in Figure 2-6 (Hutton et al., 1980). In the Stellarton Formation torbanites with high TOC contents contain higher amounts of vitrinite (Smith et al., 1991; Kalkreuth and MacAuley, 1987).

The oil shales of the Stellarton Formation have a silica-rich inorganic composition (Smith and Naylor, 1990; Smith et al., 1991). Clays such as illite, smectite, kaolinite, and chlorite dominate silica content. Quartz, minor carbonate, and trace sulfides are also found. Trace element analysis (Table 2-2) of oil shale 22 shows increased levels of As, B, Cs, Mo, Sb, and Se with respect to the crustal average (Smith et al., 1991).

Beginning in the mid-nineteenth century attempts were made to determine the potential for retorting the oil shales in the Stellarton Formation (Smith and Naylor, 1990.) Data on specific studied oil shales is shown in Table 2-3. The oil yield ranges from 2.9l/t to 152 l/t with higher yields in the older interval. The range of TOC content results from higher TOC values encountered in the torbanites (Hutton et al., 1980). The studied oil shales make up part of the approximately 60 oil shales of the Stellarton Formation. The oil shales of the Stellarton Formation are Nova Scotia's largest oil shale resource (Smith and Naylor, 1990).

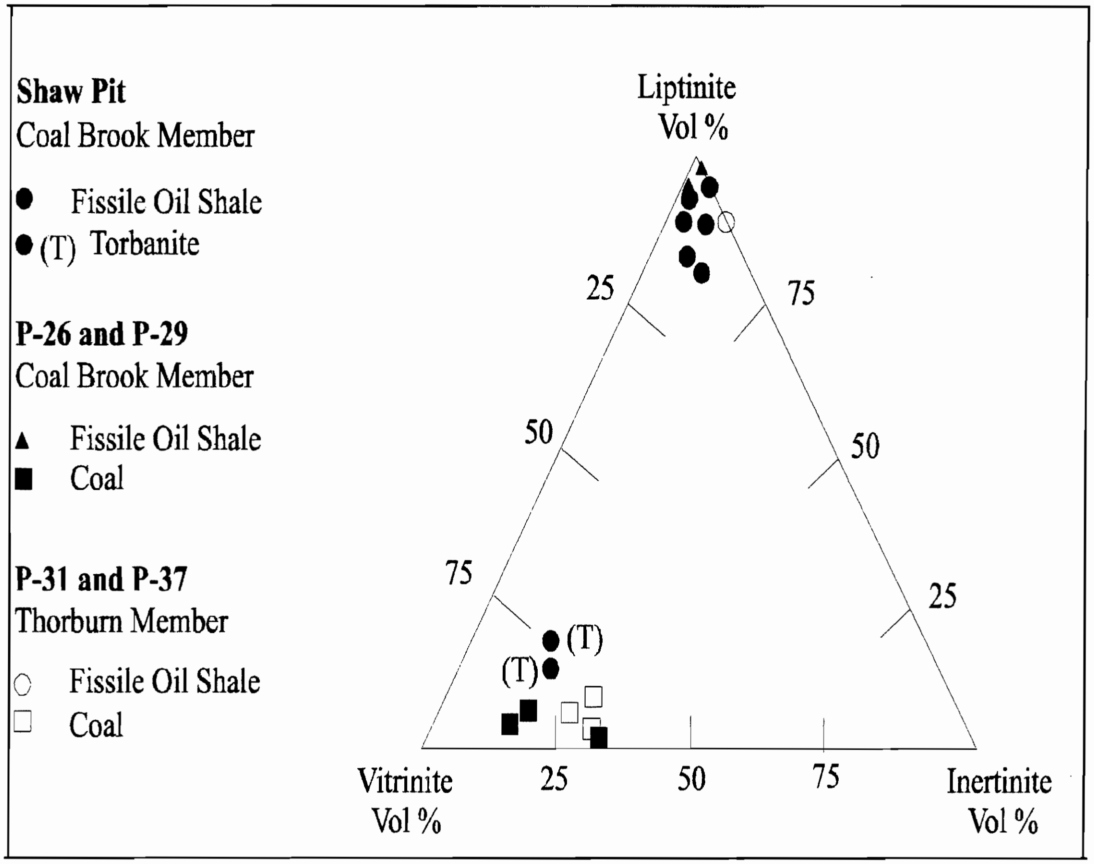


Figure 2-5. Maceral group composition for samples from Coal Brook and Thorburn Member oil shales and coals (modified from Kalkreuth and Smith, 1987).

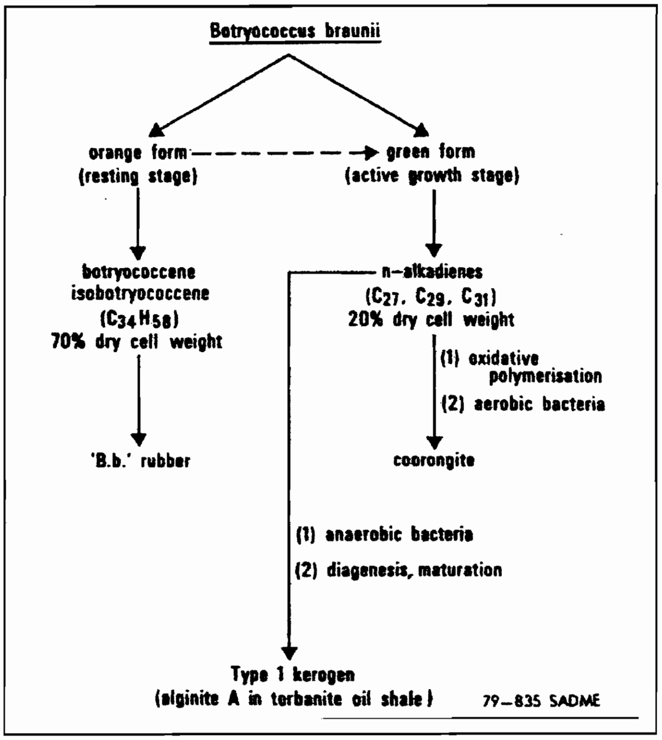


Figure 2-6. Genesis of lamalginite in oil shale facies from *Botryococcus braunii* (Hutton et al., 1980).

2.2.2 Mudstone Facies

A fine siliciclastic lithofacies in the form of laminated and massive mudstones (Fig. 2-7) makes up a large proportion of both studied intervals. The mudstones range from massive medium to dark grey clays and silts to rhythmically inter-layered medium grey silts and dark grey clay drapes. The author observed that the facies is generally found in higher proportion in more central basin positions (Fig. 2-8).

Mudstones found in the two studied intervals form units from less than 10 cm to over 3 m in thickness. These units are often fissile and easily weathered. They commonly contain siderite layers averaging 1-2 cm in thickness. Detrital carbonaceous material and calcite-filled microfaults are also common locally. The mudstones tend to show gradation in grain size, commonly coarsening upward. They can also mark possible flooding surfaces when sharply overlying coarser material. There is local soft sediment deformation in the form of distorted beds resulting from bioturbation and compaction. The biota of the lithofacies consists of generally rare burrow fills, transported plant fragments, bivalves, and ostracods with high local abundance. The macrofauna in the Stellarton Formation has traditionally been interpreted as strictly nonmarine although a marine influence has recently been inferred for much of the fauna in the Maritimes Basin (Calder, 1998).

The study indicates that the rhythmically interlayered silts and clays tend to show a gradation with the interlayeres sandstone and mudstone facies (Fig. 2-9) and the massive mudstones. The rhythmic layering is made apparent by clay drapes within predominantly parallel- bedded siltstone. The mud drapes occasionally show evidence of pairing. Localized silty lenses show small-scale tabular cross bedding and are generally cemented with siderite. These units also contain ostracods, bivalves, plant fragments, and burrow fills.

Sample no.	Oil Shale bed	As	B	Cs	Mo	Sb	Se
	Crust	1.80	10.00	3.00	1.50	0.20	0.05
NSP-84-72-19	Oil Shale 22	23.00	60.00	9.50	7.00	0.90	2.70
NSP-84-73-11	Oil Shale 22	17.00	80.00	13.60	7.00	1.30	2.70
NSP-84-73-26 to 28	Oil Shale 22	16.00	80.00	18.00	8.00	1.80	3.20
NSP-84-73-38	Oil Shale 22	11.00	90.00	17.10	6.00	1.40	0.60
NSP-84-72-13	Oil Shale 22	20.00	70.00	15.60	8.00	1.40	3.30
	Average black shale	N/A	50.00	N/A	10.00	N/A	N/A

Table 2-2. Selected trace element chemistry of Oil Shale 22, Coal Brook Member (modified from Smith et al., 1991).

2.2.3 Interlayered Sandstone and Mudstone Facies

A lithofacies composed of interlayered sandstone and mudstone represents a more proximal setting than the previous facies. Interlayered sand and mud is found in both studied intervals as primarily proximal deposits. It is composed of pale to medium grey clay, silt, and fine-grained sand. Deposits range from mud-rich parallel bedding to sand-rich flaser bedding. Minor siderite bands ranging from less than 1 cm to approximately 3 cm in thickness probably signal chemical precipitation associated with localized organic matter. The facies often shows a localized brown speckled appearance caused by fine-

Table 2-3 (following page). Petrographic examination of oil shales bounding studied intervals (modified from Smith and Naylor, 1990). TOC= Total Organic Content; Ro= Vitrinite Reflectance; n = number of analysis

Oil Shale Number					
Analysis		7	8	21	22
Oil Yield (l/t)	Range	2.9 to 63.9	16.0 to 65.9	9.8 to 139.7	tr to 152.2
	Average	24.5	31.2	38.5	31.4
	n	67	14	31	138
	Anomalies	73.9, 97.8	\	1	
T.O.C. (wt %)	Range	2.2 to 15.6	\	3.5 to 33.6	0.3 to 43.5
	n	3	\	10	116
	Anomalies	\	\	1	
Hydrogen Index (H.I.)	Range	136 to 347	\	225 to 445	182 to 496
	n	3	\	10	102
	Anomalies	\	\	91	5<100;9>640
Ro (Mean)	Range	0.7	\	0.43 to 0.59	0.41 to 0.71
	n	1	\	3	11
Petrography (Range; % m.m.f.)	Exinites	12 to 27	\	tr to 36	0 to 46
	Vitrinites	0 to 27	\	0 to 61	0 to 79
	Inertinites	4 to 14	\	tr to 9	tr to 15
Inorganic Geochem (%)	Fe	\	\	6.2	5.3 to 9.7
	Al	\	\	19.1	11.4 to 21.2
	Si	\	\	67.2	39.0 to 64.8
	Ca,Mg	\	\	2.8	1.9 to 3.7
	n	\	\	1	6
Mineralogy (Range and mean; in %)	Clays	\	\	32 to 47*	56 to 63
	Quartz/ Feldspar	\	\	48 to 66*	28 to 34
	Carbonates	\	\	1 to 5*	6 to 8
	Pyrite	\	\	0 to 2*	0 to 3
	Other min.	\	\	0 to 3(RH?,AP?)*	0
	n	\	\	8	3
Combustion Testing	Moisture %	\	\	1.1	0.067 to 1.9
	Volatiles %	\	\	28.4	16.5 to 30.07
	Ash %	\	\	51	47.3 to 75.4
	Carbon %	\	\	19.5	6.2 to 25.9
	Sulphur %	\	\	\	\
	BTU/LB	\	\	\	7843
Available Resources	Tonnes	46.35 X 10^6 t	10.5 X 10^6 t	30.6 X 10^6 t	15 X 10^6 t
	Shale Oil In Situ	7.9 X 10^6 bbls	2.3 X 10^6 bbls	8.25 X 10^6 bbls	5.1 X 10^6 bbls
Avg. Thickness		14.56 m	4.92 m	4.7 m	2.22 m

grained siderite within the sandy units. These units often show a coarsening-upward trend.

The author observed that this lithofacies is commonly characterized by mud drapes overlying structures within sandy sections. The sand can show parallel bedding but generally displays small-scale asymmetric cross bedding in which cosets are 1 to 5 cm thick. Clay drapes tend to overlie both the individual foresets and the entire coset. The clay drapes within this facies also commonly have a paired nature. Burrows, indicating oxygenated conditions, and plant fragments also occur locally and tend to be associated with cross-stratification.

2.2.4 Sandstone Facies

A predominantly sandstone facies represents the coarsest-grained lithofacies in both intervals. The sandstone is pale grey in colour and ranges from very fine- to medium-grained. It makes up approximately 40% of the lower Coal Brook Member interval at its eastern end while the proportion dwindles westward. Sandstone forms the upper section of coarsening-upwards cycles within the intervals. Sand deposition appears to also play a dominant role in the upper Thorburn Member interval.

The sandstone lithofacies shows weak stratification. It is predominantly parallel-bedded with localized flaser bedding showing small-scale asymmetrical cross-beds with average coset thickness of less than 5 cm. It was also observed that the cross-bed foresets and cosets are overlain by dark grey mud drapes. Bioturbation, in the form of burrowing,

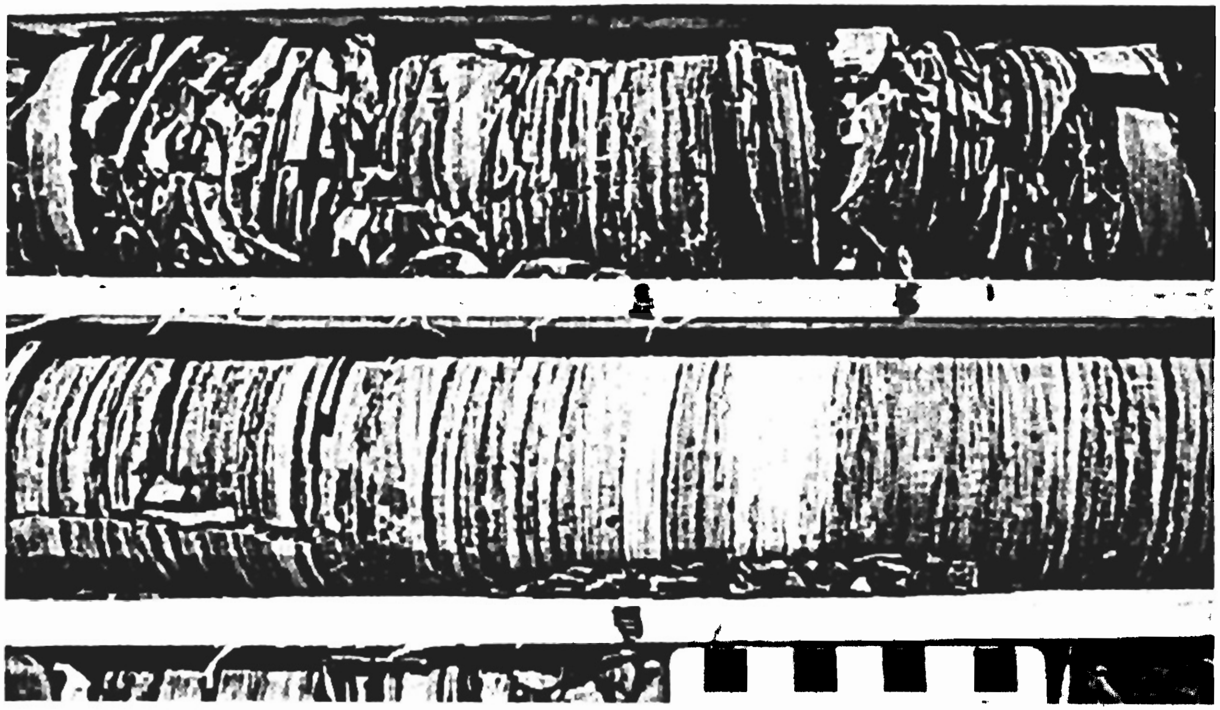


Figure 2-7. Mudstone lithofacies in drillcore, Coal Brook Member, drillhole P-59A.

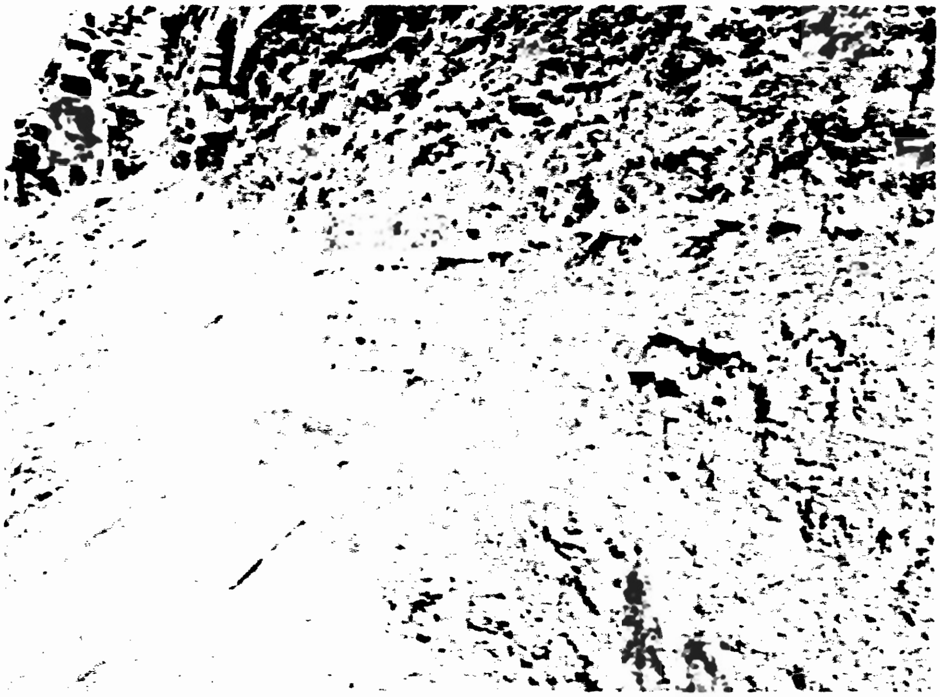


Figure 2-8. Laminated mudstone showing siderite banding, overlain by Oil Shale 21, Shaw Clay Pit, Stellarton, N.S.

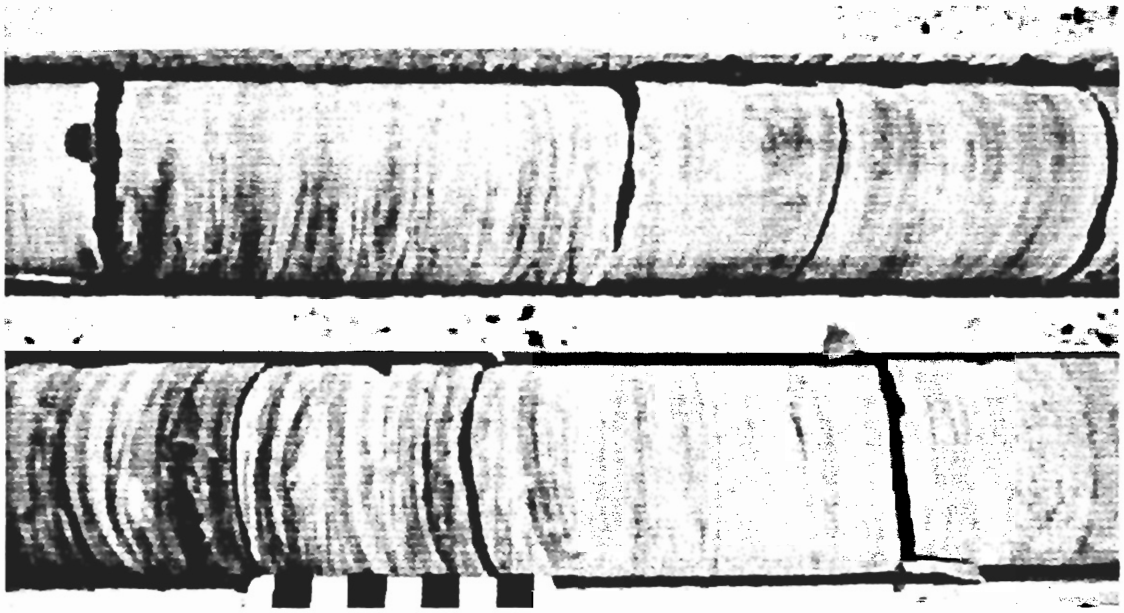


Figure 2-9. Interlayered sandstone and mudstone in drillcore, Coal Brook Member, drillhole P-59A.

is also found locally as are transported fragments of plant material. The sandstone is commonly cemented with calcite and locally with siderite. A patchy orange staining is apparent in the coarser-grained units, which may indicate petroliferous influence.

2.2.5 Coal Facies

Thin coals are encountered in the Thorburn Member interval. These together with bounding organic-rich shales range from approximately 10 to 50 cm in thickness. Plant fragments and imprints are abundant. The coals of the Stellarton Formation are often associated with oil shales. Coals within the area are predominantly composed of vitrinite and inertinite macerals (Kalkreuth and MacAuley, 1987). The Stellarton Formation coals are banded in nature and show predominantly low sulphur levels (< 2%) (Hacquebard and Donaldson, 1969).

2.2.6 Paleosol Facies

Paleosol development is observed mainly in the upper portion of the Thorburn Member interval. The paleosols are generally composed of pale to medium grey mudstones in the studied drillhole. Paleosol units appear to cap coarsening upward sequences. Plant fragments and other detrital organic matter are found within the paleosols. Siderite nodules nucleated around fossilized roots as well as visible root traces are common. Distortion and destruction of bedding becomes more obvious as evidence of rooting increases.

CHAPTER 3: Sedimentological and Stratigraphic Interpretation

3.1 Introduction

The two studied intervals show a similar spectrum of facies including oil shales, mudstones, and similarly laminated sandstones and mudstones. The Thorburn Member interval from Oil Shales 7 to 8 was observed in drillhole P-59. It shows an overall dominantly coarsening and then fining upward trend with several minor cycles, both coarsening and fining upward. There is also a definite increase in intensity of paleosol formation towards the top of the interval. Lateral variability in this interval could not be studied as a result of a lack of areal coverage in drill hole data. The interval between Oil shales 21 and 22 of the Coal Brook Member also shows an overall coarsening upward trend. This interval also shows systematic lateral variation in both unit thickness and grain size and can be studied over several drillholes (Fig. 3-1).

The facies found in both studied intervals are very similar and can be seen as end-members of one basic system. The Thorburn Member interval displays a series of facies indicative of a proximal basin to basin margin environment, with exposure resulting in paleosol development. The Coal Brook Member interval shows a predominantly basinal depositional setting. This is suggested by the predominantly fine-grain size of the sediments and lack of paleosol development.

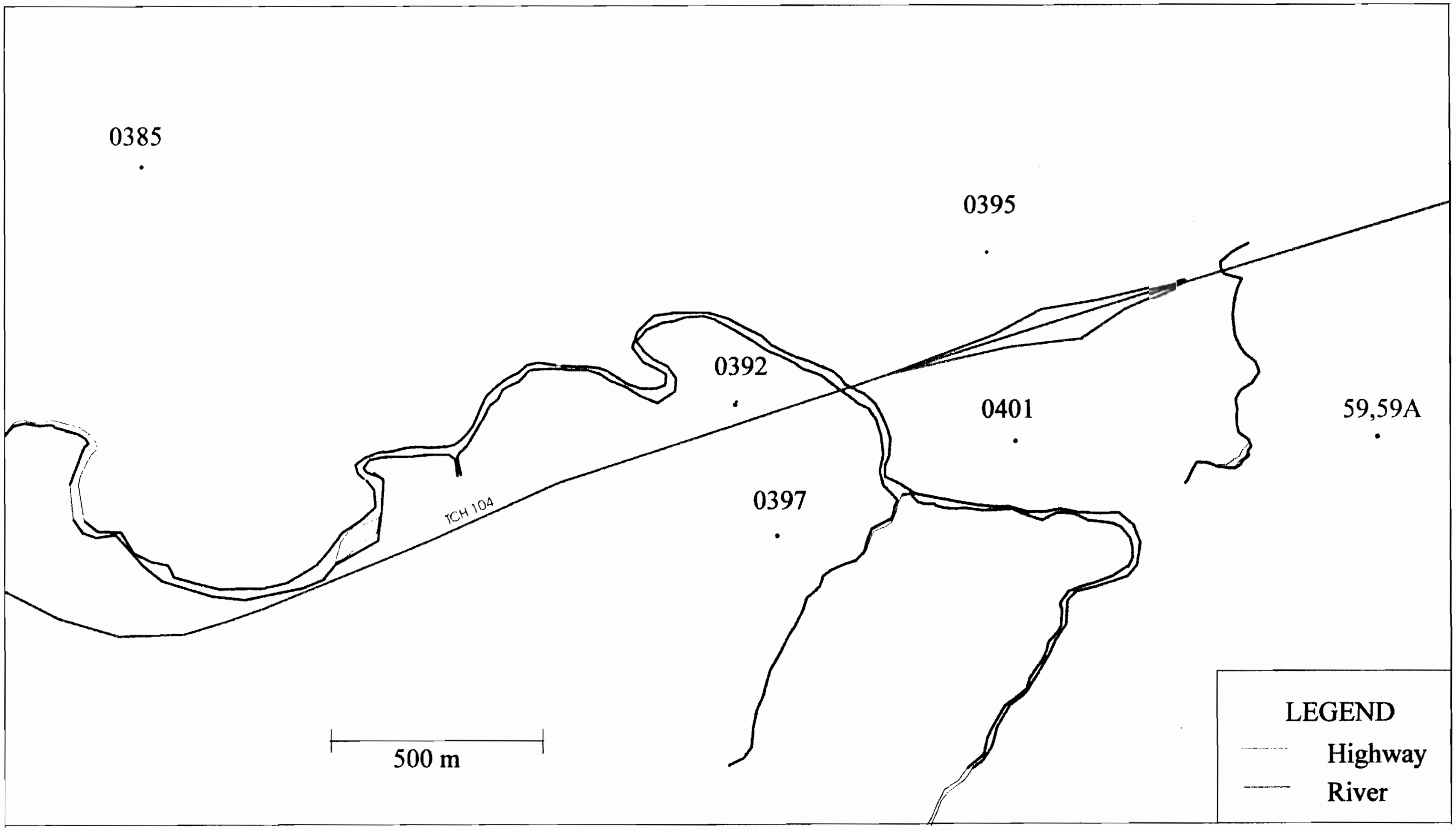


Figure 3-1. Drillhole placement map, oil shale bounded interval 21-22.

3.2 Oil shale interval 7 to 8

3.2.1 Cyclicity

Major changes occur vertically in the interval in both grain-size cyclicity and overall rock type in P-59. The interval goes through several cycles where grain size either coarsens or fines upwards with larger trends superimposed. Minor cycles showing gradation in grain-size are evident in Figure 3-2. These tend to range from less than 2 m to over 10 m in thickness. Bounding surfaces are commonly identified by an abrupt, obvious change in grain size such as shale overlying medium-grained sandstone. Facies within the cycles of this interval can range from fine mudstone and oil shales to medium grained sandstone. The interval shows a coarsening upward trend beginning with Oil Shale 8 below 210 m to sandstones at approximately 190 m. This is overlain by mudstone that signals a second coarsening upward cycle that extends to approximately 170 m. From 170 m depth to Oil Shale 7 at 155 m depth the drillcore exhibits several small packets of mudstone and sandstone in which many of the mudstones show paleosol development.

3.3 Oil shale bounded interval 21 to 22

3.3.1 Vertical cyclicity

The six drill holes used to study the interval bounded by oil shales 21 and 22 encompass a range of facies. The more drill holes in the eastern part of the study area show an overall coarsening upward trend beginning with Oil Shale 22 and ending with sandstone or interlayered sandstone and mudstone. This is overlain by a minor fining upwards in the upper one third of

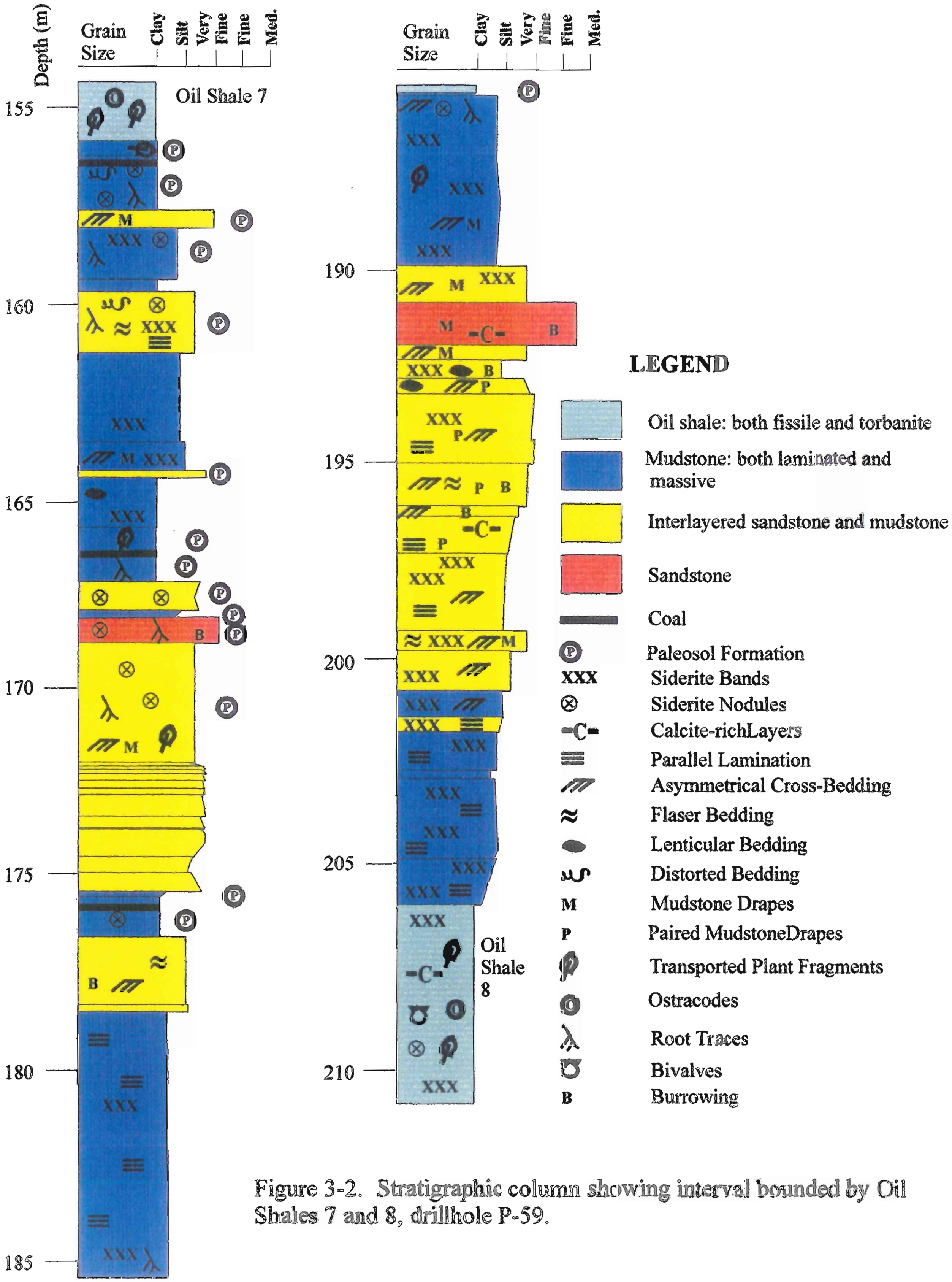


Figure 3-2. Stratigraphic column showing interval bounded by Oil Shales 7 and 8, drillhole P-59.

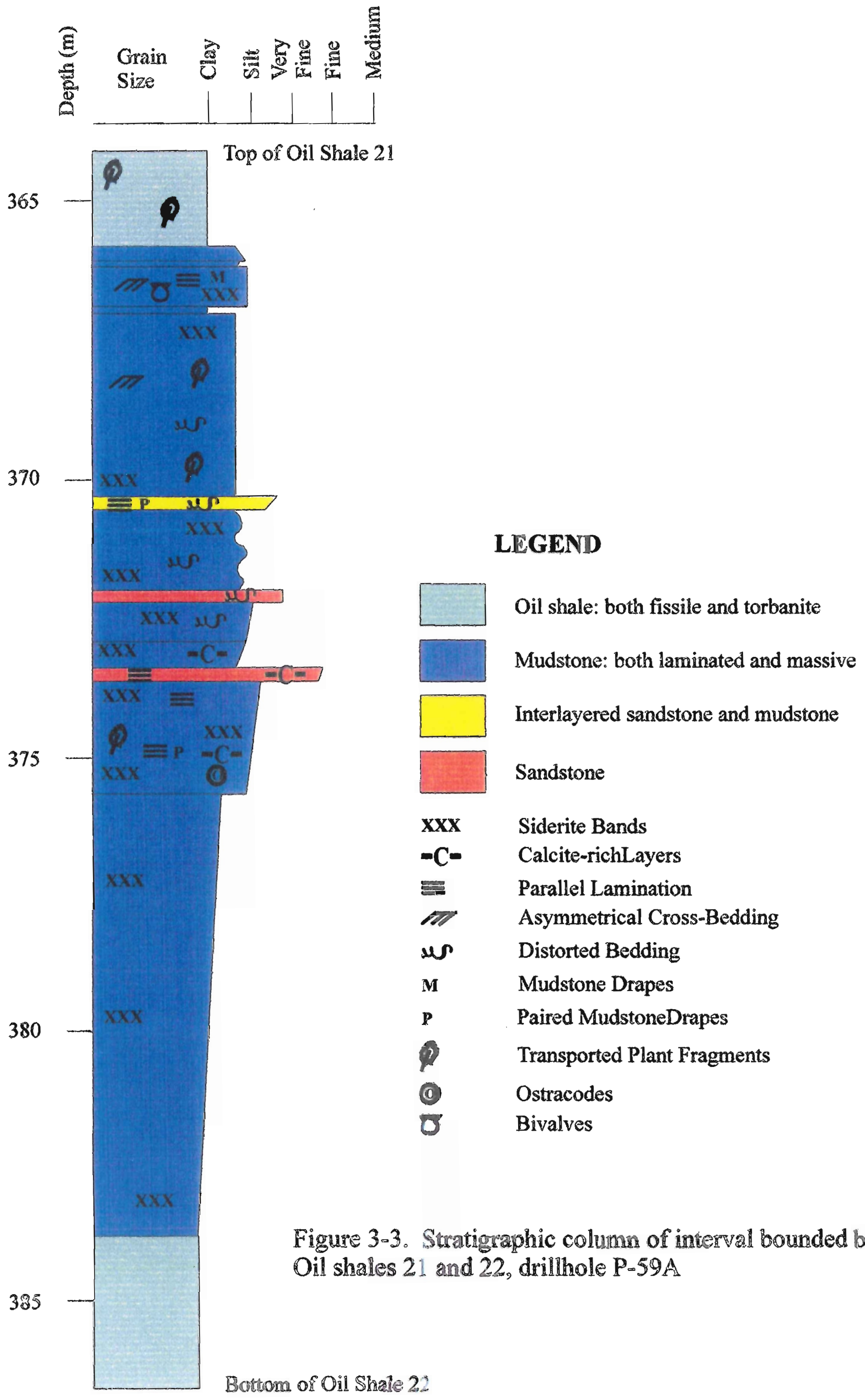


Figure 3-3. Stratigraphic column of interval bounded by Oil shales 21 and 22, drillhole P-59A

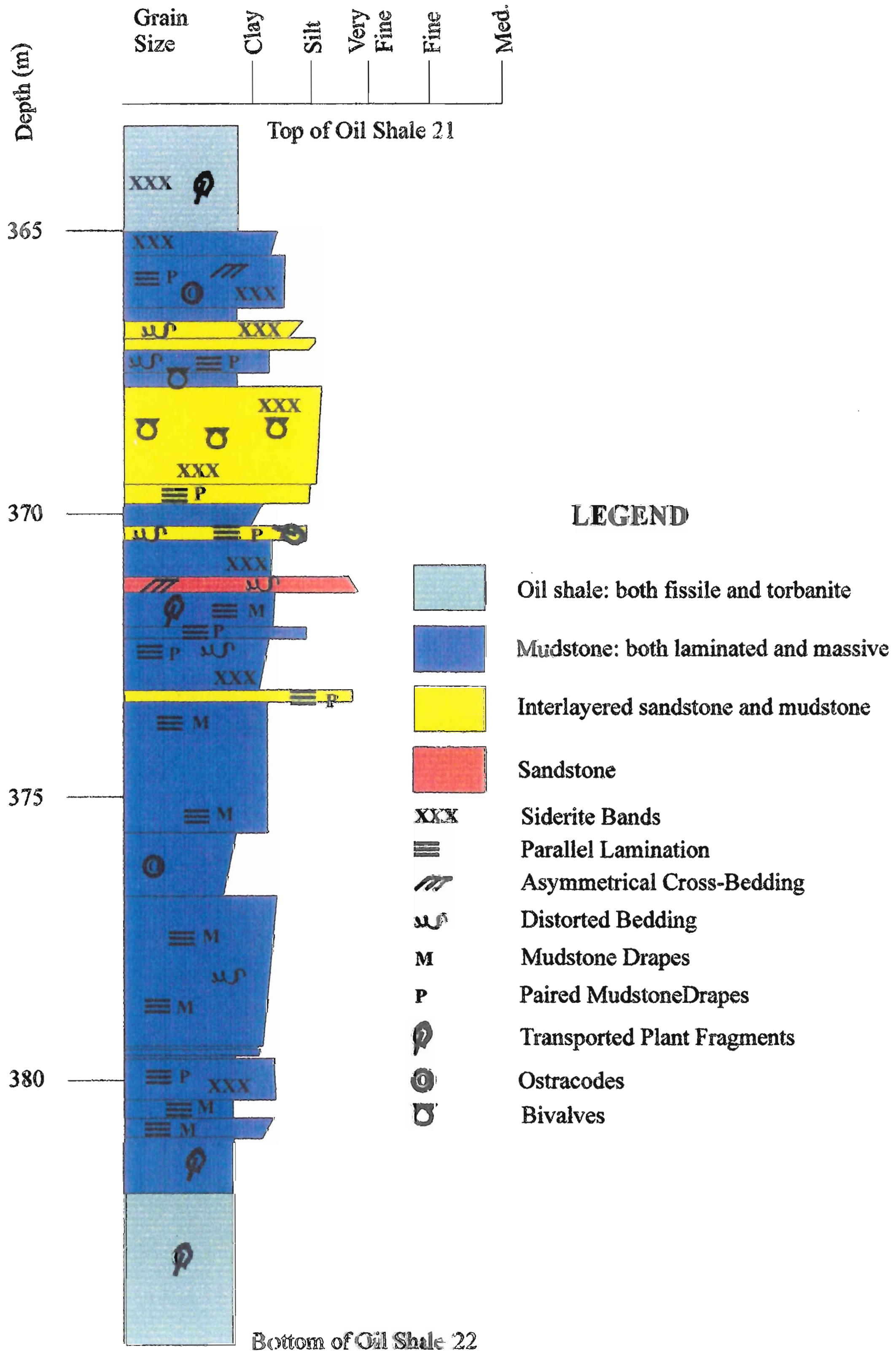


Figure 3-4. Stratigraphic column of Oil shales 21 and 22, drillhole AP-85-401.

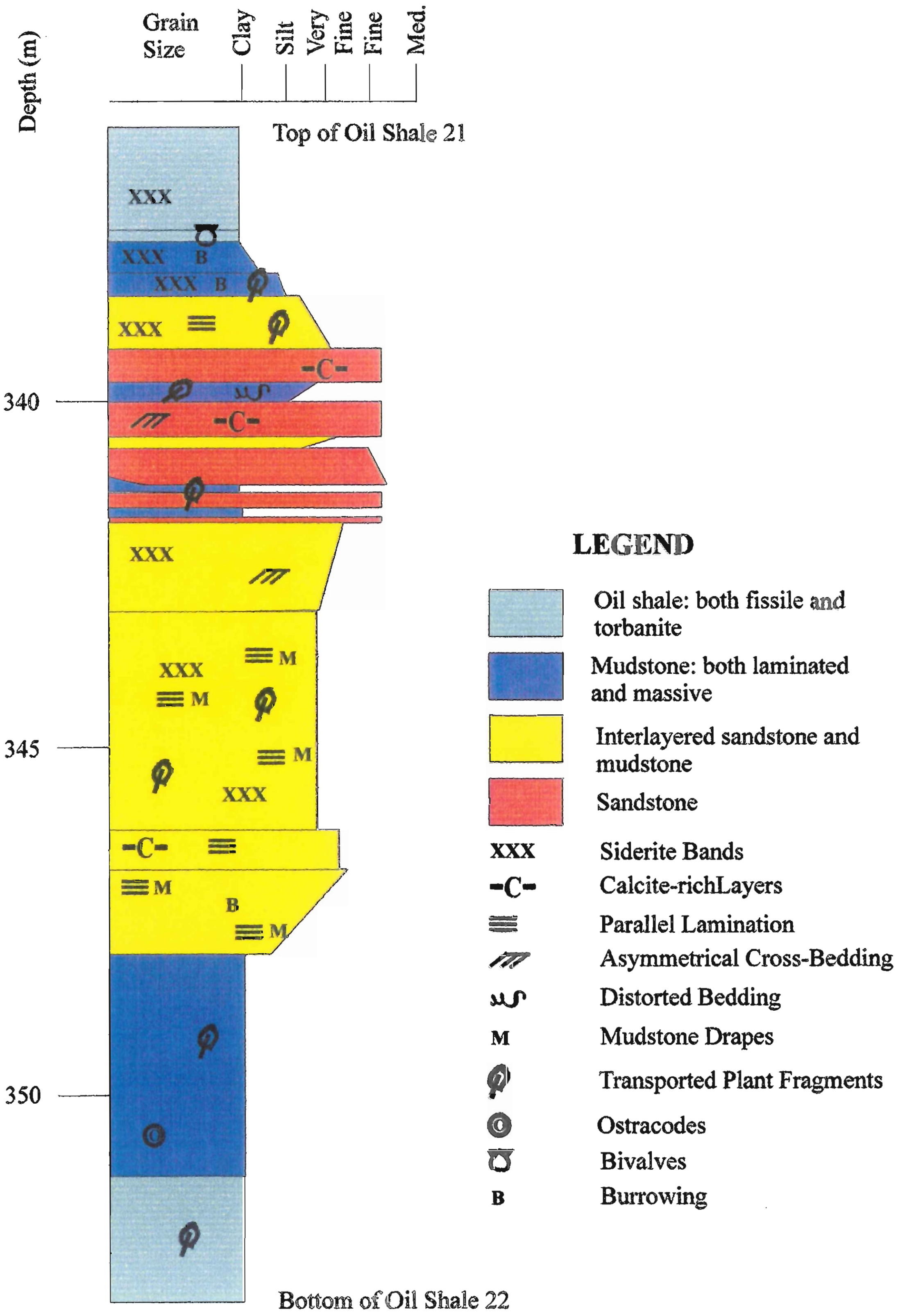


Figure 3-5. Stratigraphic column of interval bounded by Oil shales 21 and 22, drillhole AP-85-395.

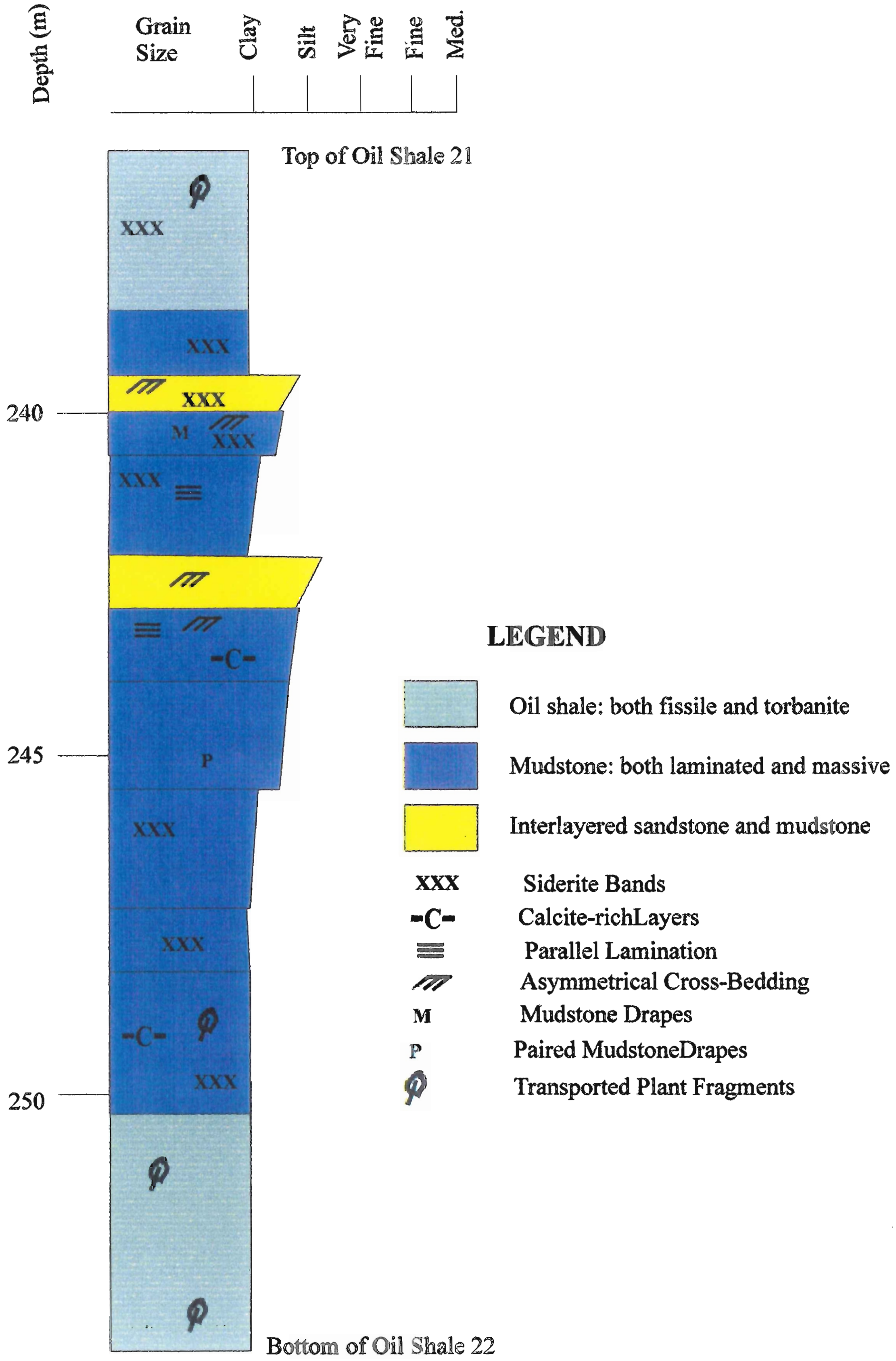


Figure 3-6. Stratigraphic columns of interval bounded by Oil shales 21 and 22, drillhole AP-85-397.

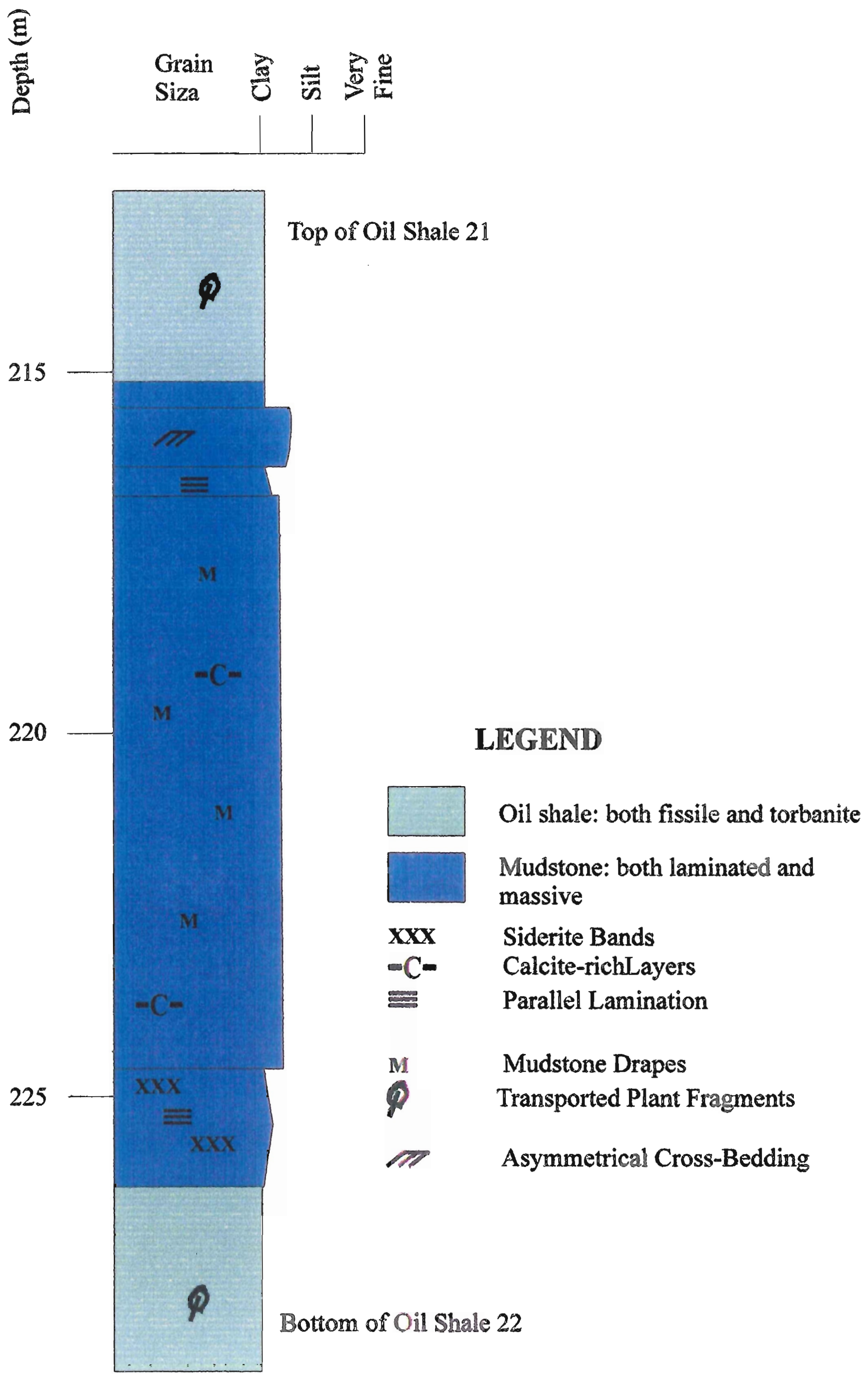


Figure 3-7. Stratigraphic column of interval bounded by Oil shales 21 and 22, drillhole AP-85-392.

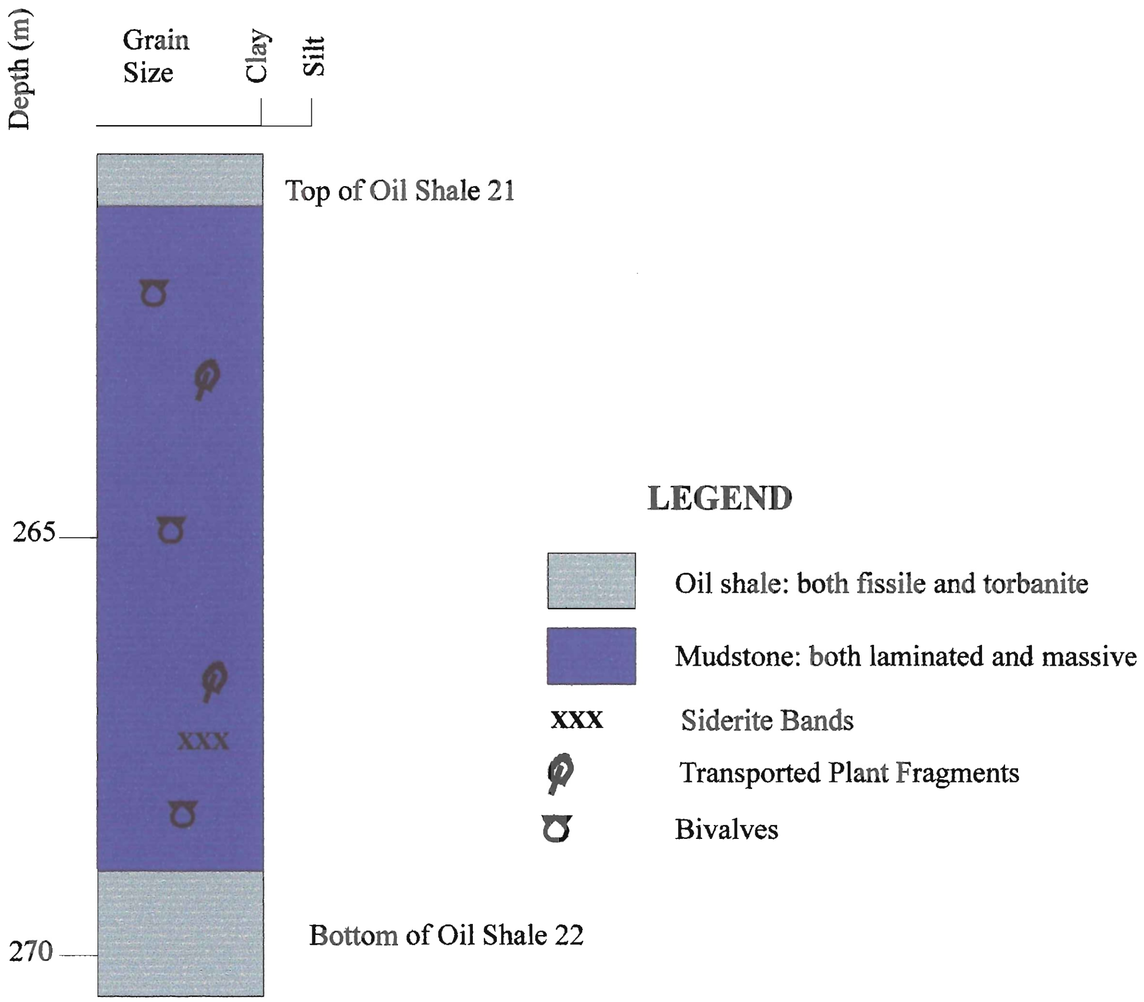


Figure 3-8. Stratigraphic column of interval bounded by Oil shales 21 and 22, drillhole AP-84-385.

the interval that ends with Oil Shale 21(Figures 3-3, 3-4, 3-5, 3-6, 3-7, 3-8). This trend is particularly obvious in the easternmost drill holes (with the exception of P-59A) where an increase in the proportion of coarser-grained sediment (i.e., sandstone) is evident. The drill holes in the western part of the study area consist predominantly of mudstone and show little to no upward variation in grain-size. There is no evidence of paleosol formation in the Coal Brook Member interval.

3.3.2 Lateral Thickness Variation

The thickness of the strata in the interval bounded by oil shales 21 and 22 changes laterally from east to west. This is evident from both the thicknesses of the complete interval and of individual units. Figure 3-9 depicts the thickness variation of the entire interval measured from the base of Oil Shale 22 to the top of Oil Shale 21. An overall trend from thicker to thinner occurs moving from southeast to northwest. The interval ranges from 23 m in thickness to 10 m. A small area to the south-west shows an abrupt increase in thickness from 18m to as much as 23 m over less than 100 m in distance. The rocks in this area have documented faulting (Naylor et al., 1986) which may account for the abrupt change in thickness although this is not shown on Fig. 3-9. This may affect the accuracy of thickness information and contouring in this area. The decrease in thickness from southeast to northwest suggests a progression from a proximal environment to a distal basin environment.

The thickness of individual units also changes laterally (Figure 3-10). The thickest

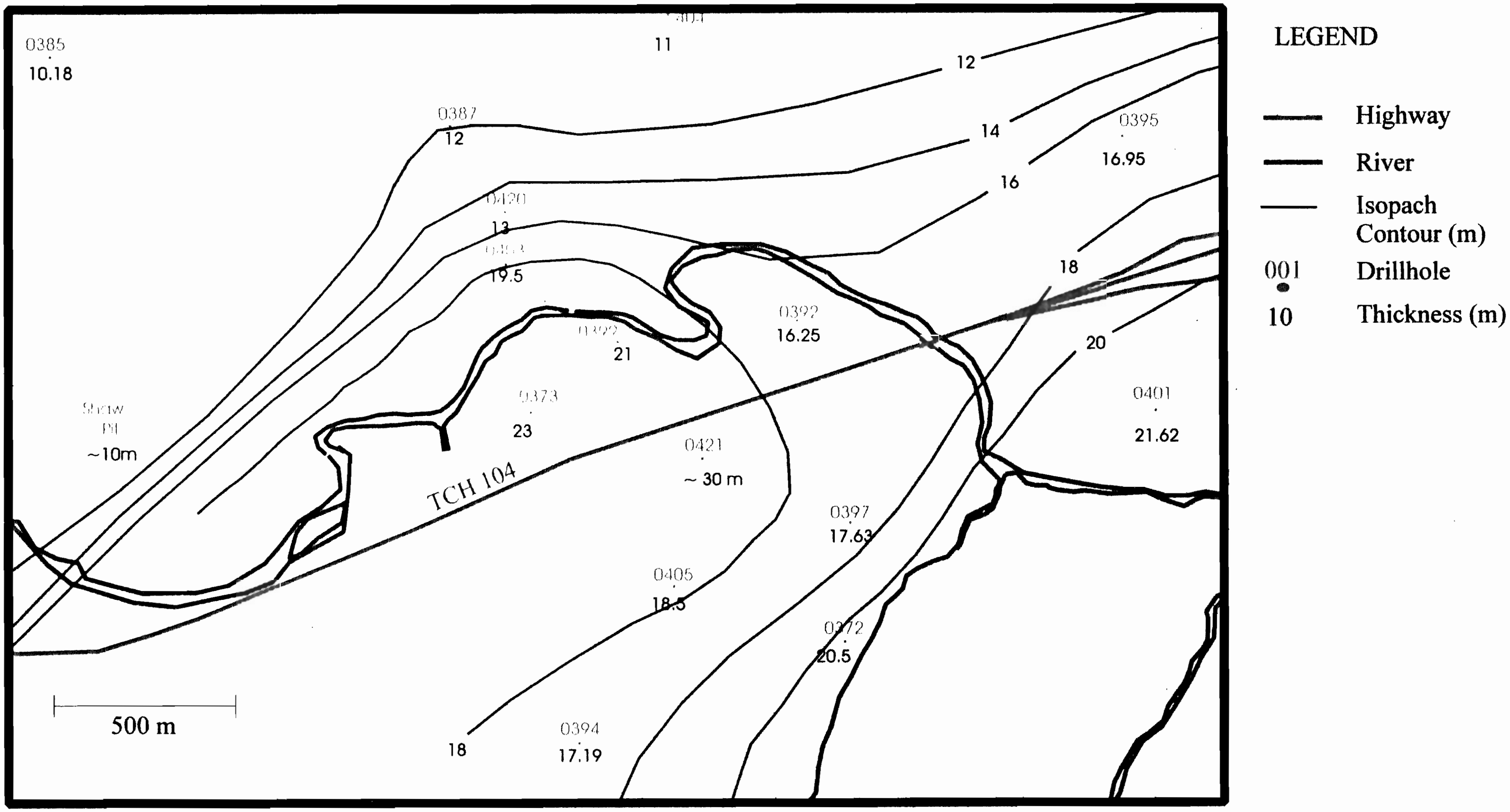


Figure 3-9. Isopach map of interval bounded by Oil shales 21 and 22 thicknesses.

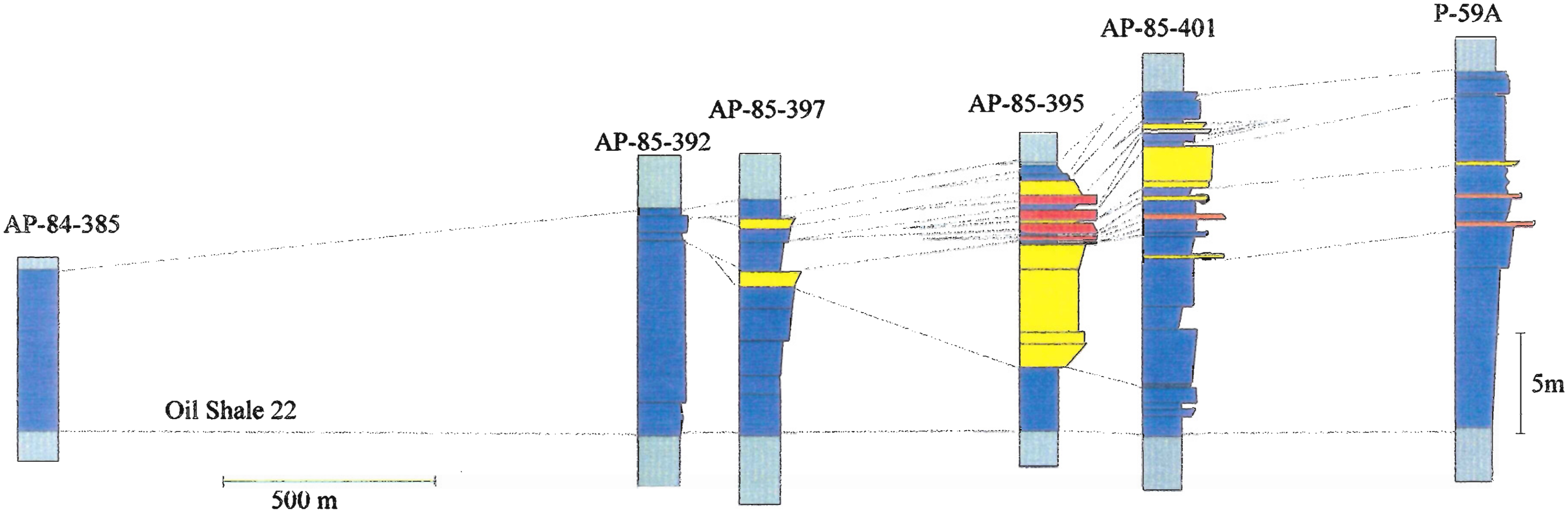


Figure 3-10. Cross-sectional view of thickness variation over the studied area, interval bounded by Oil shales 21 and 22. Cross-section follows a broadly SE-NW trend. See Fig. 3-1 for drillhole locations.

section of sandstone is found in drill holes AP-85-401 and AP-85-395. These drillholes show almost 15m and 10m aggregate thickness of sandstone, respectively. Although the entire interval thickens to the east the sandstone units appear to thin and pinch out over short distances making correlation between drill holes difficult. Minor mudstone units in AP-85-395 and AP-85-401 appear to thicken to the east from 1m and less to 3 m and over 5 m in drill hole P-59A. In the middle of the cross-section (drill hole AP-85-397) sandstone units thin to less than 1 m while mudstone units begin to thicken. Further west (drill hole AP-85-392) finer siltstone also thins very rapidly and eventually pinches out at the most distal location in the studied interval. The mudstone units reach their greatest thickness (approximately 8m) in AP-84-392 drill hole. The westward thinning of coarser grained units agrees with thinning of the entire interval. There is no systematic thinning or thickening of the oil shales throughout the studied area.

3.3.3 Lateral Lithofacies Variation

The proportion of various lithofacies varies with distance from the inferred sediment source in this studied interval. Figure 3-11 displays the proportions of sediments of particular facies (grain size) in each drill hole. The highest proportion of relatively coarse-grained sediments (sandstone and interbedded sandstone and mudstone) is found in the drillholes AP-85-401 and AP-85-395. Drill hole AP-85-401 contains approximately 17% of coarse-grained material while drill hole AP-85-395 contains an estimated 53% of coarse grained material. The proportion of coarse-grained material

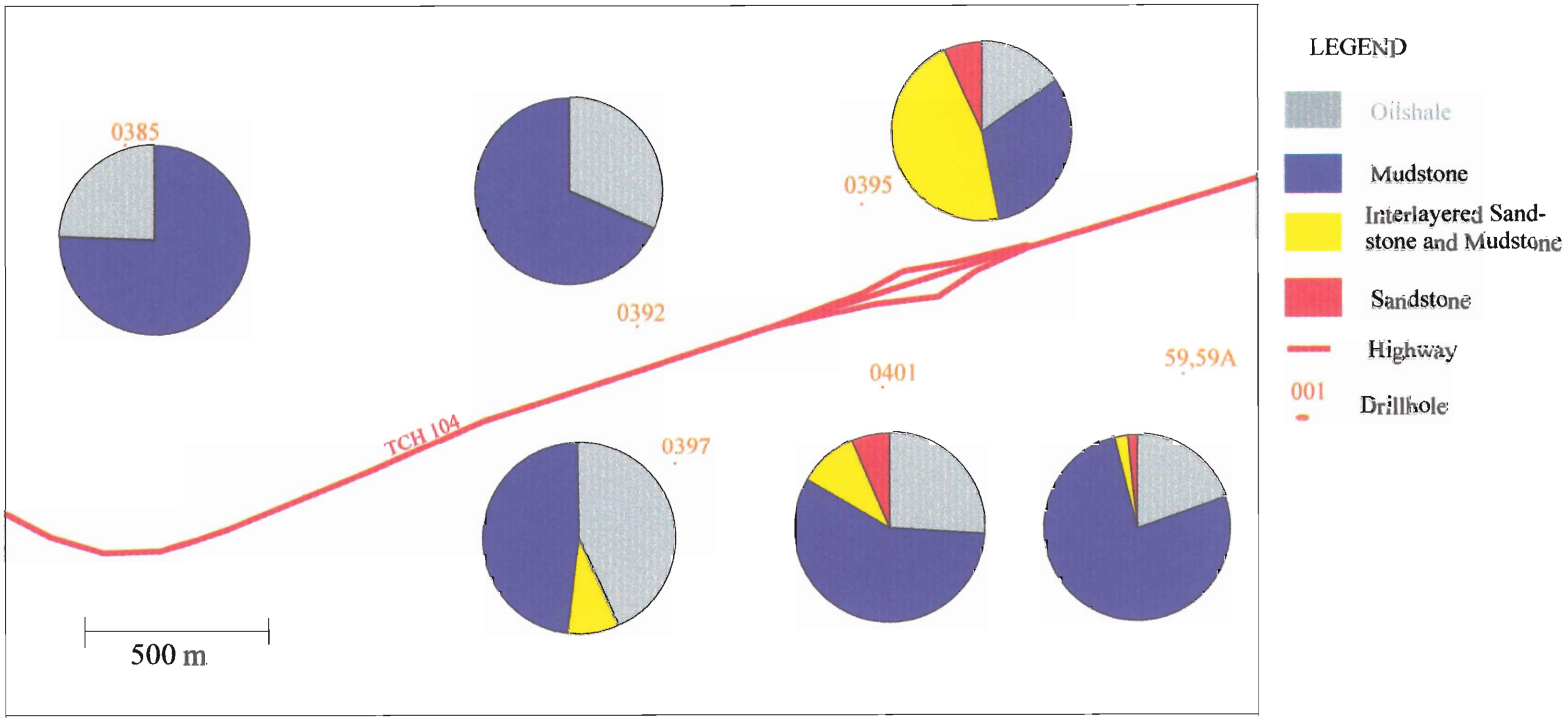


Figure 3-11. Distribution of Facies within studied interval bounded by Oil shales 21 and 22.

decreases to both the east and west. Drill hole P-59A to the immediate east contains approximately 2% of interbedded sandstone and mudstone and an estimated 2% of sandstone while to the immediate southwest AP-85-397 contains approximately 8% of interbedded sandstone and mudstone and no purely sandstone component. Further west the proportion of coarse-grained material becomes completely depleted. The proportion of fine-grained material follows the opposing trend. Mudstone percentage increases in both an eastern and western direction from the center of the studied area. Fine-grained sediments including laminated and massive mudstones and oil shales make up almost half of AP-85-395. To the east the percentage increases to near 85% in AP-85-401 and well over 90% in P-59A. Drillhole P-59A shows a decrease in coarse-grained facies that suggests less influence by prograding bodies. Westward an increase in the fine-grained component is also visible. AP-85-397 contains over 90% mudstones while the more westerly holes AP-85-392 and AP-85-385 are both completely composed of mudstone. Most drill holes from this interval are composed of predominantly fine-grained mudstones with an increasing sandstone component in the central part of the study area.

3.4 Depositional Setting Interpretation

The depositional setting of both intervals can be inferred through the many observations made in the course of the study. Both intervals show a similar spectrum of facies including oil shales, mudstones, and sandstones. The Coal Brook interval has a higher proportion of fine-grained facies and shows no evidence of possible subaerial exposure. The Thorburn interval contains similar clastic facies but has a higher proportion of coarse-grained component and shows evidence of paleosol formation. The described facies range from fine-grained mudstones to medium-grained sandstones.

A standing water basin dominated the Stellarton Basin during the deposition of both the Coal Brook and Thorburn intervals. This is indicated by the large amount of sediment-starved organic-rich oil shale deposited over a wide area within the intervals, which shows very little evidence for current action. The oil shales were deposited in anoxic conditions to allow for preservation of large amounts of organic matter. This lithofacies commonly grade upwards into organic-rich mudstones, of both clay and silt grain-size. The mudstones generally show few structures indicative of current action. This facies was deposited under slightly more sediment enriched but still quiet hydrodynamic environments, possibly suggesting deposition nearer the basin margin and possible prograding clastic wedges. This is supported by evidence of increased biological activity such as burrowing, which suggests a move to possibly shallower, more oxygenated bottom conditions.

The remainder of the observed facies indicates prograding sediment bodies moving into the basin. The coarsening upward characteristic of both intervals from mudstones to interbedded sandstone and mudstone to fine- to medium-grained sandstone and even paleosol formation signals the growth of relatively coarse-grained bodies out into the basin. Small-scale asymmetric cross bedding within coarse-grained facies indicates stronger unidirectional currents. Paleosol formation including rooting and distortion of bedding shows that prograding sedimentation resulted in periodic very shallow water depth and even possible subaerial exposure.

The features discussed are broadly applicable to a lake basin with deltas prograding from a river source as suggested by Naylor et al. (1989). Lateral grain-size variation and SE-NW overall thickness change signals some clastic sediment input and progradation from the southeast corner of the study area during deposition of the Coal Brook interval. Deposition of coarse-grained sediment at times outpaced subsidence of the basin to allow for paleosol development. Sediment would have been sourced both regionally and from the adjacent highlands along the bounding faults, predominantly the Hollow Fault in the Coal Brook interval, which accounts for the basin's rapid subsidence. This rapid subsidence probably accounts for the drowning which occurs as oil shale was once again deposited over the prograding body. A freshwater system is suggested for the Stellarton Basin based on fossils like ostracodes, bivalves, and xenocanthid sharks with an inferred nonmarine affinity. Although the features broadly fit a model consisting of a freshwater lake basin with prograding deltas, the possibility of tidal influence is further discussed in Chapter 4.

CHAPTER 4: Mudstone Lamination

4.1 Introduction

Mudstone laminae/drapes are found within two of the described lithofacies of the studied intervals: the mudstone (laminated) and the interbedded sandstone and mudstone. In the mudstone lithofacies the laminae occur as dark grey clay drapes within medium to dark grey siltstone. The occurrence of mudstone drapes is documented in oil shale bounded interval 7-8 in this study. Although mudstone drapes are evident in oil shale bounded interval 21-22, in predominantly the laminated sandstone and mudstone, they were not examined in detail. In the interlayered sandstone and mudstone of the Thorburn interval (bounded by Oil Shales 7 and 8) the mudstone drapes are evident within fine- to medium-grained sandstone. They are also found locally within the predominantly sandstone facies.

The rhythmic nature of the mudstone lamination in the Stellarton Basin has traditionally been ascribed to variation in hydrodynamic conditions ascribed to seasonal flooding (Naylor et al., 1989). It has been suggested that the coarser unit was deposited during periods of flooding and high sedimentation rate whereas the finer unit resulted from settling of suspended material during slack periods. These deposits have been termed 'varve-like' to describe their implied seasonal origin.

However, the mudstone laminae commonly have a paired nature. Paired drapes are generally considered characteristic of tidally influenced deposits and termed mud couplets (Visser, 1980). Mud couplets form part of a tidal bundle, which is defined by Boersma (1969) as repeating sandstone foreset cross-bedding units deposited by the dominant current of a subtidal system. The foreset unit is bounded at the top and bottom by a mudstone or carbonaceous drape. The subordinate subtidal current then deposits a thinner sandstone layer. The two drapes bounding the subordinate foreset take on a paired appearance as a result of its thinner character. The bounding drapes are deposited during the slack water period associated with tidal reversal at high and low tide (Terwindt, 1971).

4.2 Occurrence of the Sandstone and Mudstone Lamination

Sections ranging from less than 20 cm to more than 1 m thick were studied from drillhole P-59 in the interval bounded by Oil Shales 7 and 8 (Fig. 4-1, 4-2). The sections occur between 190 m and 200 m near the top of a minor coarsening-upward cycle. The sections consist of interbedded sandstone and mudstone with dark grey mudstone drapes and pale to medium grey, fine-grained sandstone. The proportion of sandstone to mudstone varies through the studied sections. The interlayered sandstone and mudstone facies is found near the top of an approximately 20 m thick coarsening-upward cycles. Mudstone dominated intervals with as much as an estimated 80% mudstone are generally 2 to 5 cm thick and occur locally. Generally the mudstone content in the sections ranges from approximately 15-30%.

The mudstone laminae are associated with intervals of repeating asymmetric sandstone bedforms with sub-planar set contacts. The distribution of set thicknesses (Fig. 4-3) shows a range from 1 cm to 6.8 cm with an average of approximately 3 cm. These thicknesses confirm that the structures occur as a result of migration of small-scale ripple bedforms (Ashley, 1990). Coset thicknesses range from a minimum of 5 cm to over 30

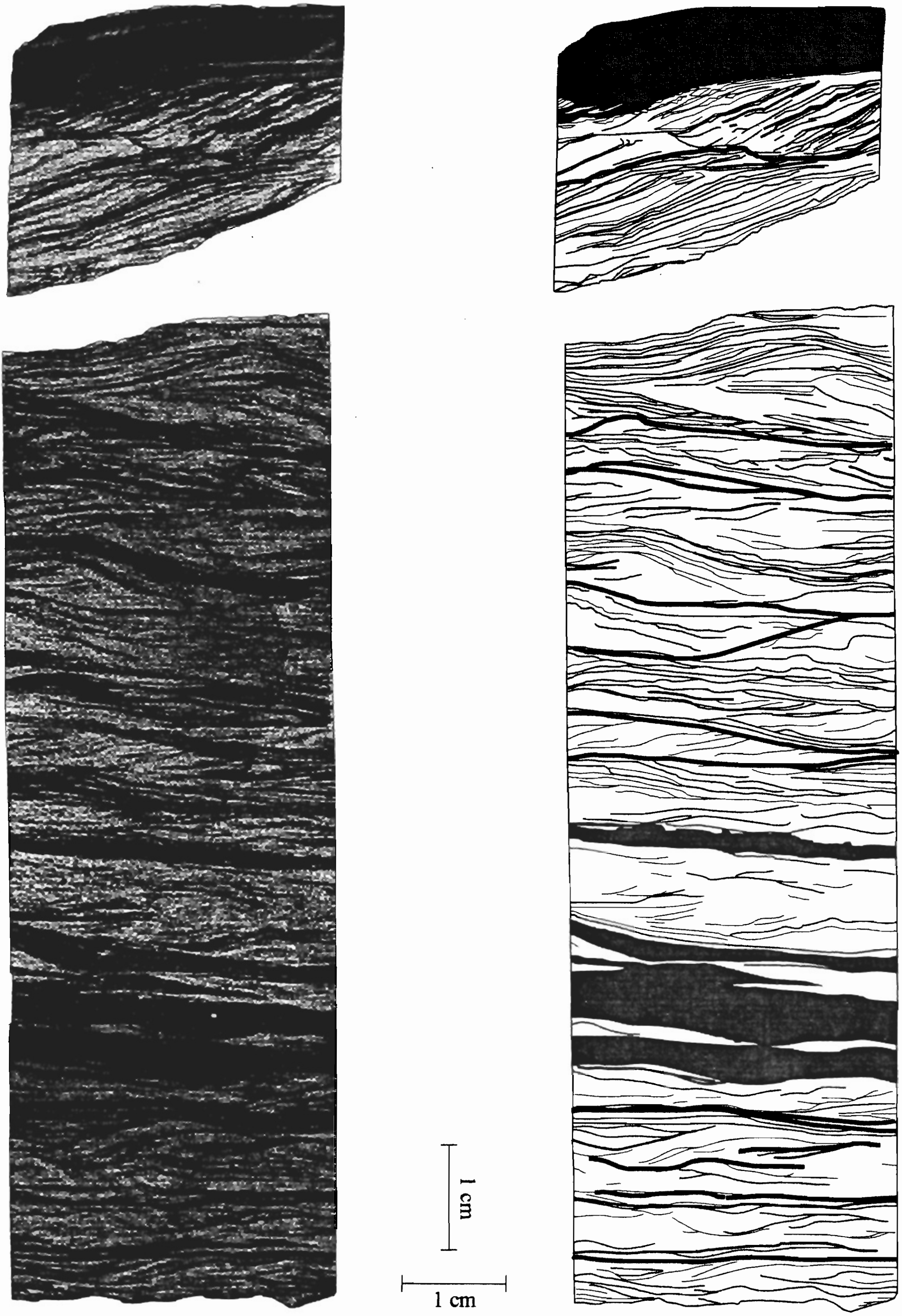


Figure 4-1. Studied section 1 from 200 m depth, drillhole P-59. Interbedded sandstone and mudstone lithofacies.

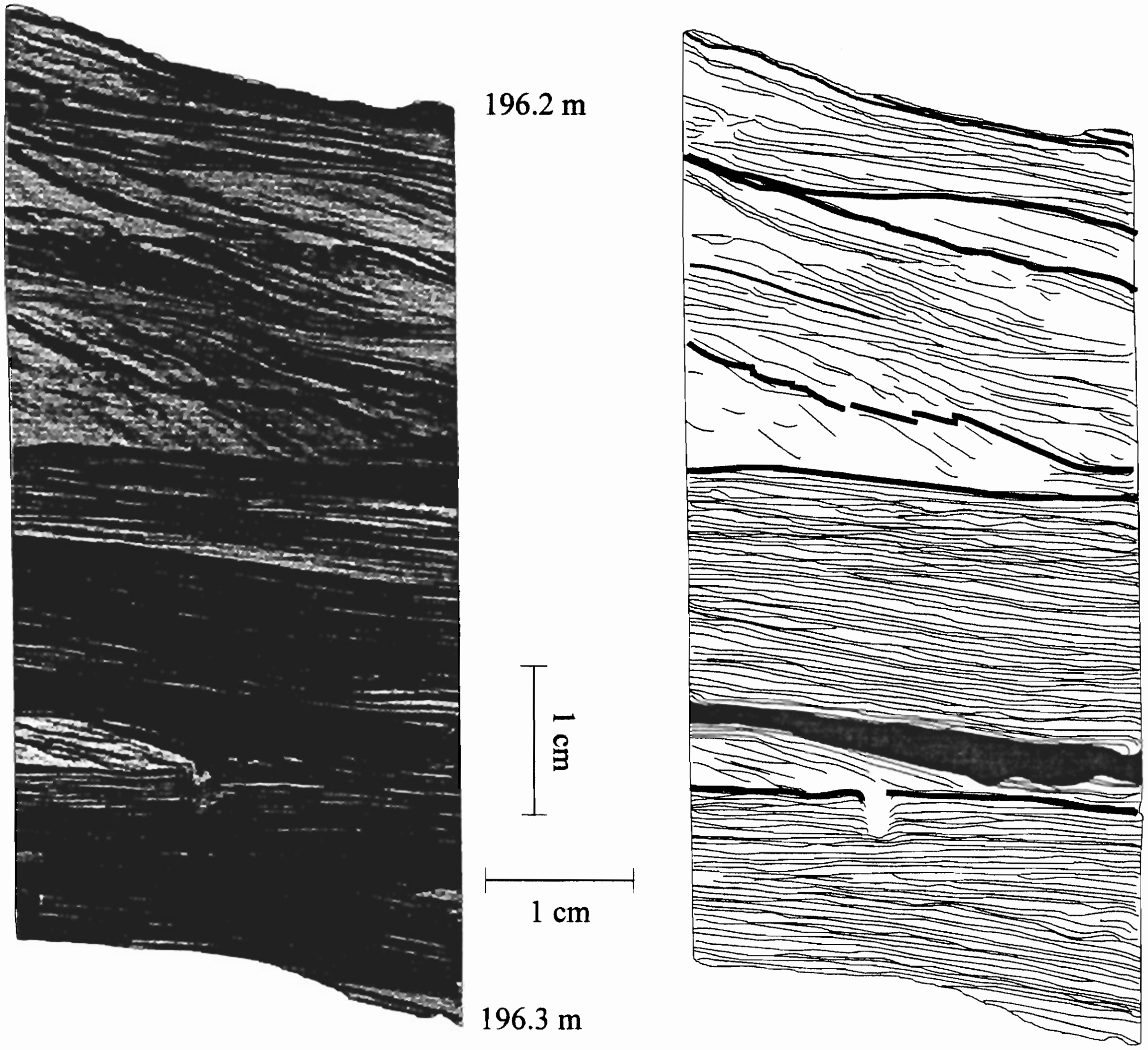


Figure 4-2A. Base of studied section 2, drillhole P-59. Interbedded sandstone and mudstone. Figure 4-2 displays a continuous vertical succession within drillhole P-59.

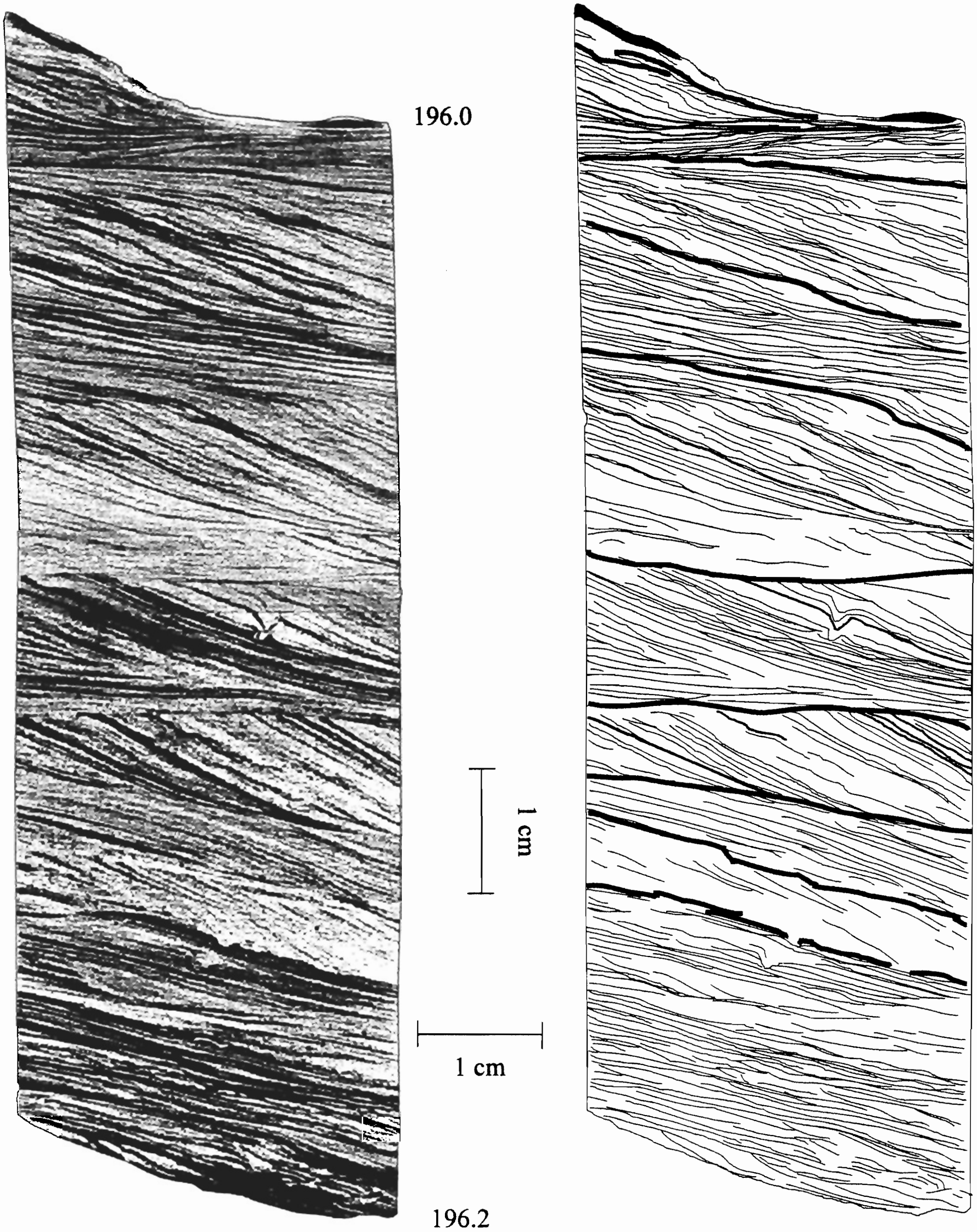


Figure 4-2B. Studied section 2, drillhole P-59.

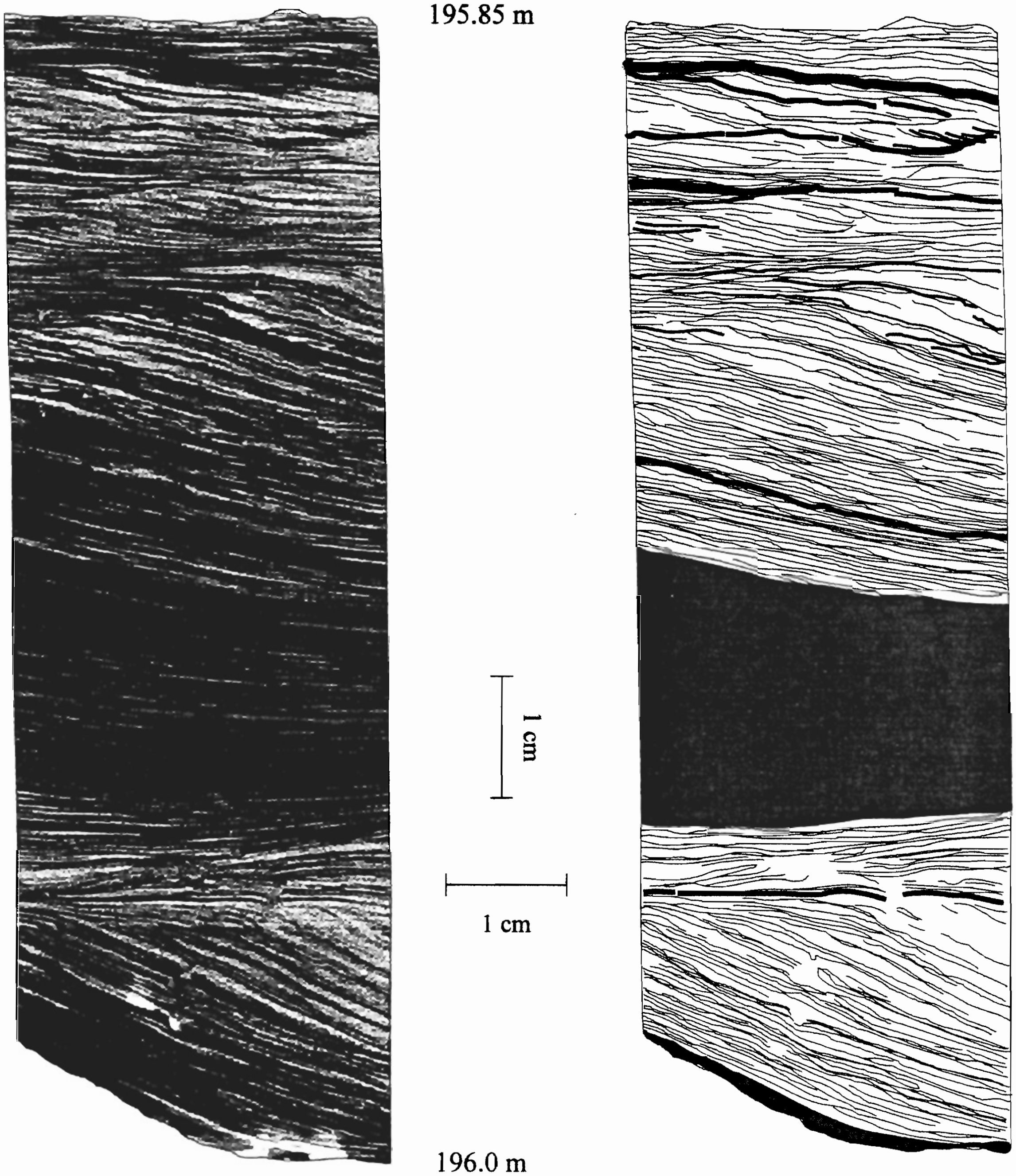
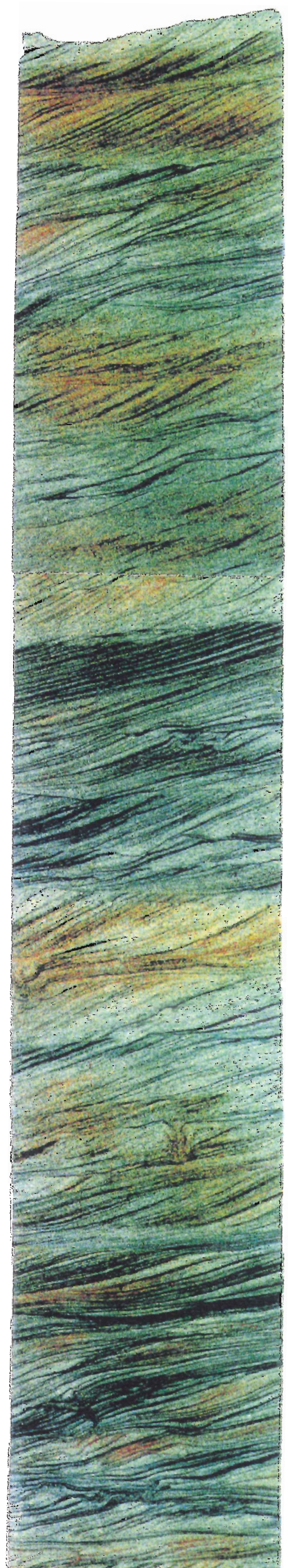
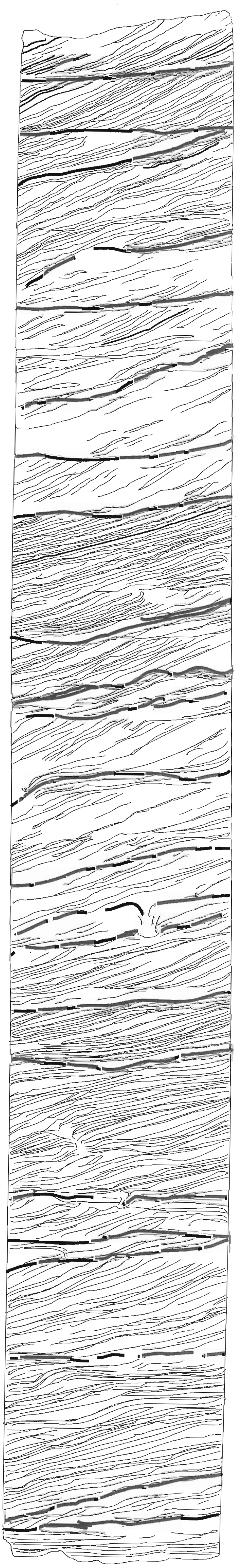


Figure 4-2C. Studied section 2, drillhole P-59.

Figure 4-2D (following page). Studie d interval 2, drillhole P-59.


195.4 m
195.85 m


1 cm
1 cm

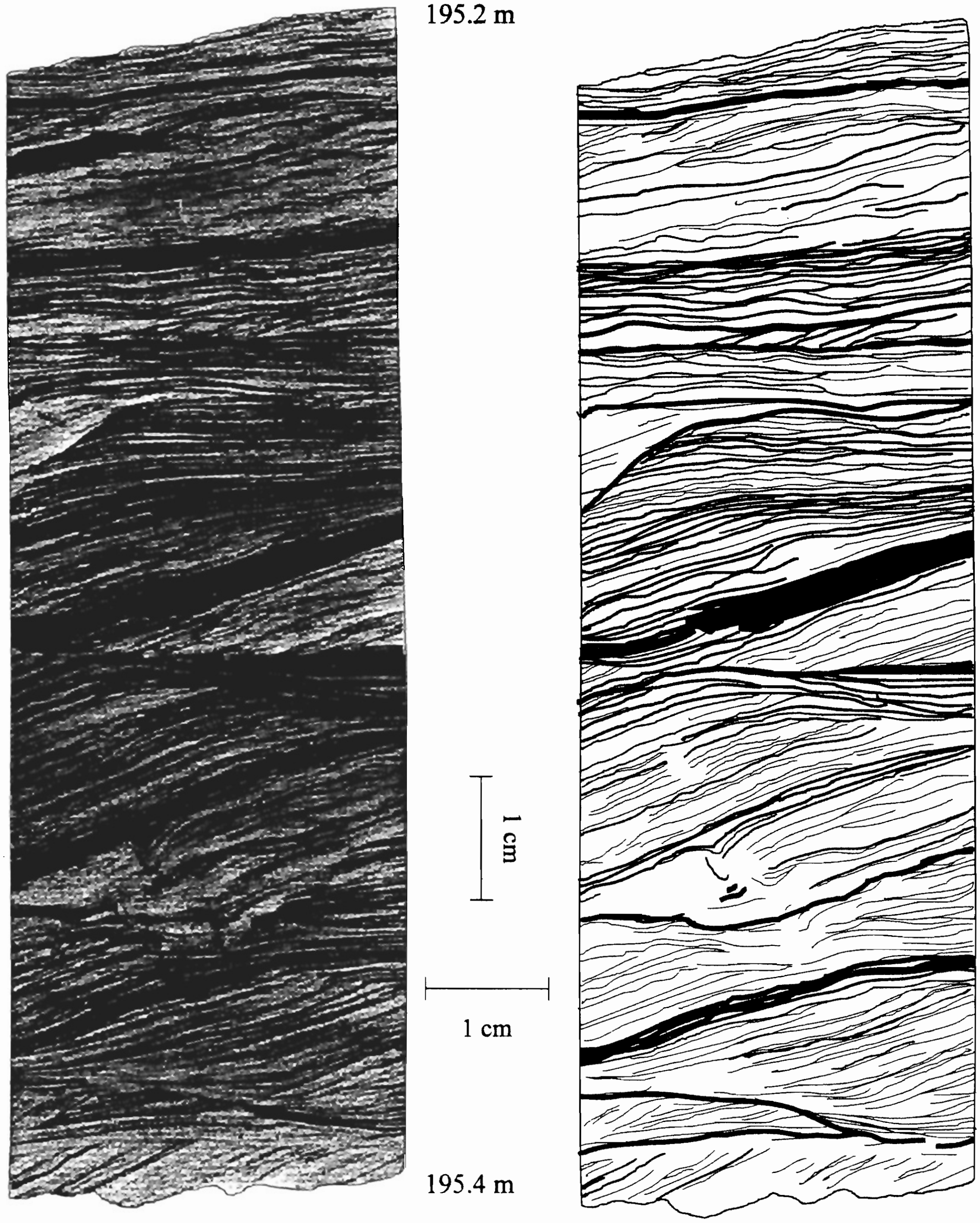


Figure 4-2E. Top of studied section 2, drillhole P-59.

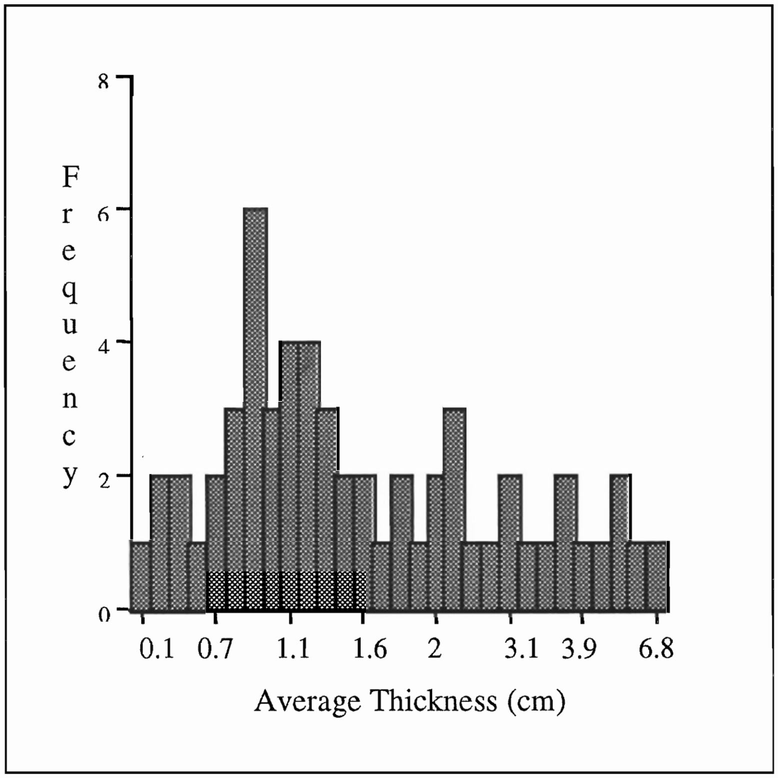


Figure 4-3. Frequency diagram showing average thickness of individual cross-sets

cm (Fig. 4-1, 4-2). The thickness of individual sand cross-layers is predominantly between 1 mm and 5 mm.

The sandstone cross-layers occur as planar foresets (Fig. 4-4) and sigmoidal climbing ripple cross-beds (Fig. 4-5). They originate from predominantly 2-D bedforms, as indicated by the relatively planar foresets across the width of the core and the scarcity of trough forms. Sandstone cross-beds are typically truncated below the base of the overlying cross-set (Fig. 4-6). Locally, individual bedforms occur as sigmoidal climbing ripples of Type 2 classification (Jopling and Walker, 1968). The direction of inclination of the foresets is relatively constant throughout the studied sections. Deviations from the dominant inclination direction occur locally between superimposed sets. Toeset sand layers(Fig. 4-7) (Visser, 1980) were observed in a few cross-sets and may signify the preservation of sediment deposited during a subordinate current, although they can also form as a result of flow separation over the bedform crest with reversed flow in the ripple trough under unidirectional flow conditions.

Well preserved, sigmoidal sandstone bedforms are capped by mudstone drapes. The mudstone drapes tend to extend over the entire bedform (topset to bottomset). Drapes are composed of mudstone with siderite/carbonaceous matter components ranging from <10% to almost 50%. Thicknesses of individual mudstone drapes are about 1 mm. The mudstone component of the facies ranges from less than 20% in relatively steeply inclined foresets to over 80% in intervals with relatively flat bedding. Some of the mud-rich intervals may reflect muddy ripple toesets with small proportions of sandstone, sectioned transverse to the paleoflow direction. Other intervals may represent sub-planar laminae.

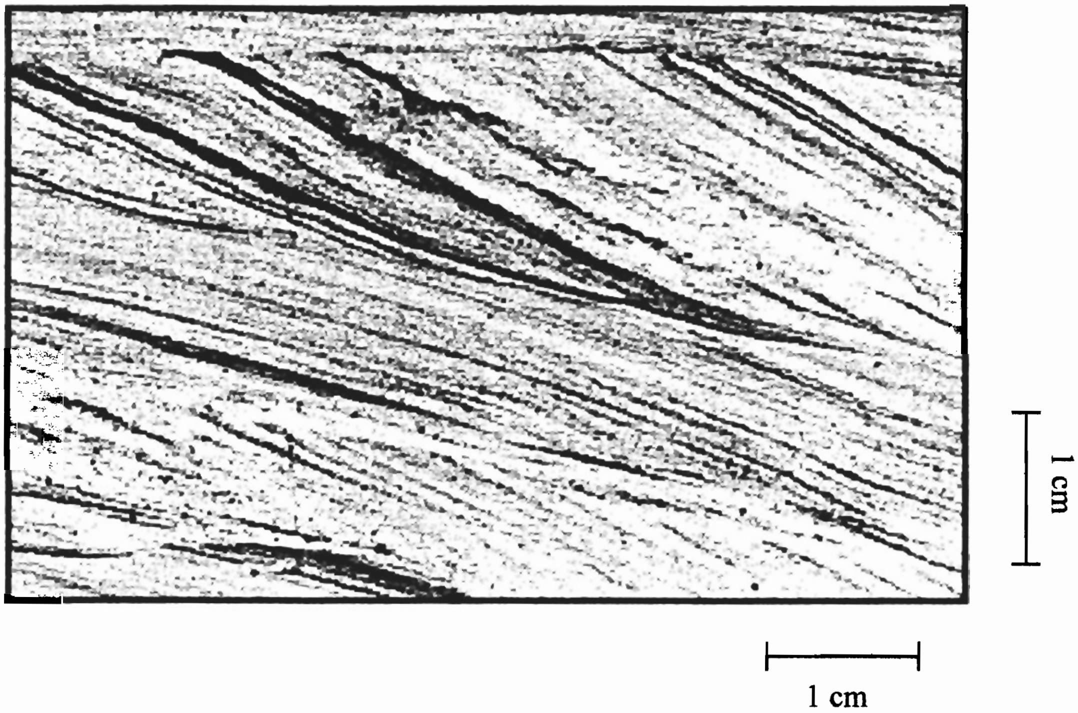


Figure 4-4. Small-scale truncated planar foreset cross-beds. Section 2, approximately 196.1 m, drillhole P-59.

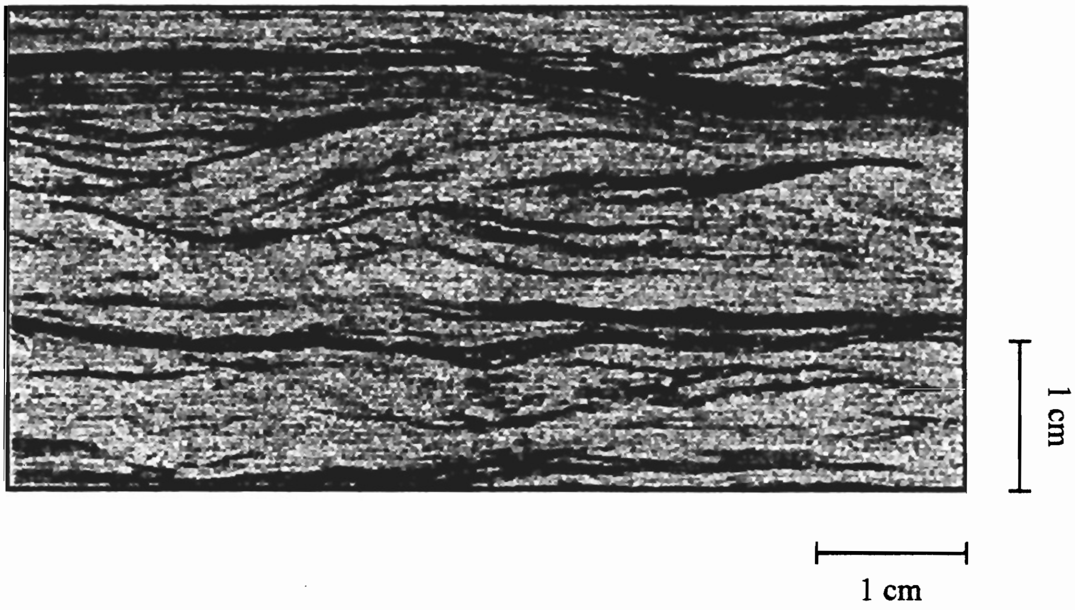


Figure 4-5. Climbing ripple cross-beds (both Type 1 and 2) in mudstone and carbonaceous drapes, approximately 199.9 m, drillhole P-59.

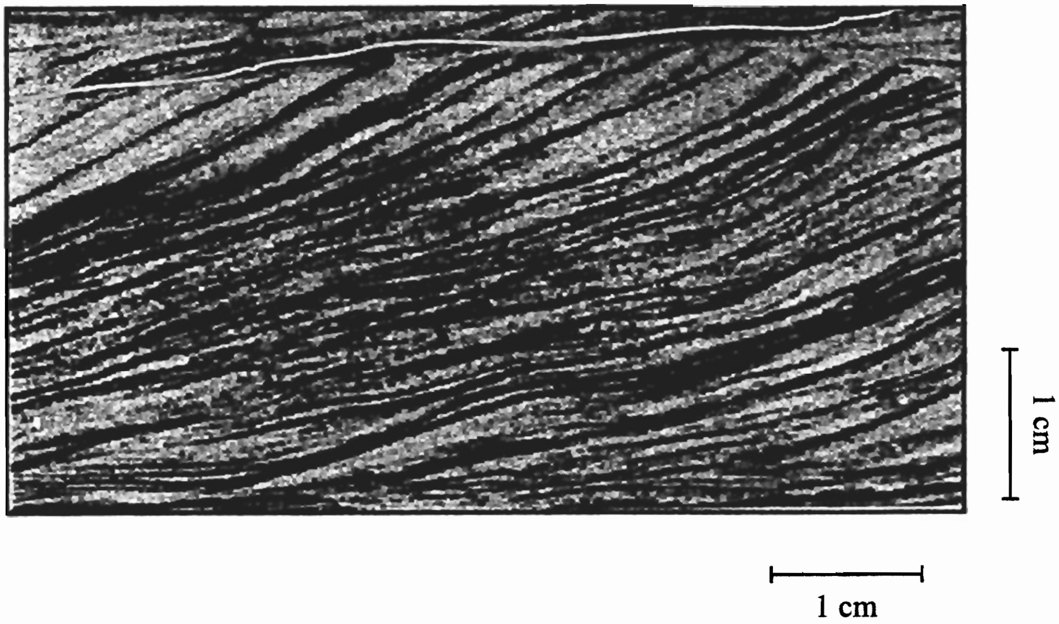


Figure 4-6. Small-scale foreset cross-beds truncated by set boundary (outlined in blue), and systematic thickness variation between sets of paired mudstone drapes within a set of cross-beds,approximately 195.6 m, drillhole P-59.

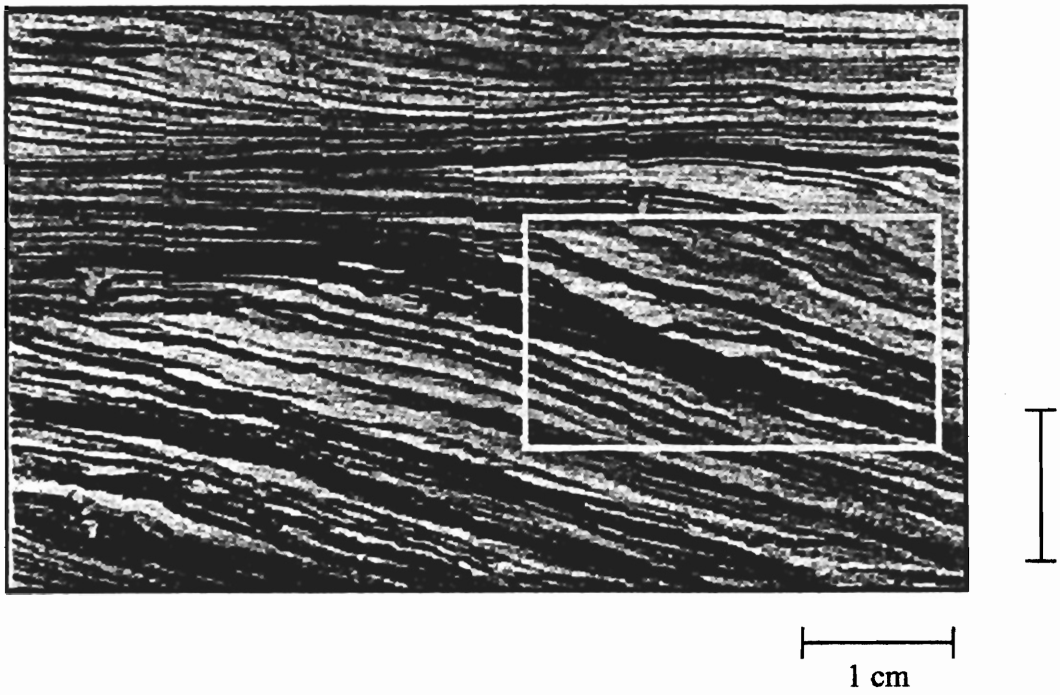


Figure 4-7. Toeset cross-beds indicating reversal in flow direction (shown in inset), approximtely 195.9 m, drill hole P-59.

Intervals that contain predominantly sandstone and lower proportions of mudstone also show localised disruption of the bedding. The distortion comes in the form of escape burrows and soft sediment compaction. Escape burrows are found throughout the sections and tend to cause distortion on the scale of a few mm (Fig. 4-8). Soft sediment compaction (Fig. 4-9) is generally caused as sand sinks into and disrupts the mudstone drape, also on the scale of a few mm.

4.3 Occurrence of Paired Mudstone Drapes

Within cosets of truncated and climbing ripples, the capping mudstone drapes are commonly paired. Paired mudstone drapes are found predominantly in intervals with less than approximately 25% mudstone content. Although not all mudstone drapes are paired, they are clearly evident in many cross-sets (Fig. 4-4). There is an apparent increase in proportion of paired mudstone drapes with increasing inclination of the foreset beds probably because mudstone couplets become more evident in cross-sections perpendicular to the dominant current direction. There is less of a paired nature in the mudstone drapes in intervals demonstrating transverse cross-sections and increased mud content.

The occurrence of paired mudstone drapes varies throughout the studied section. Within individual cross-bed sets the proportion of pairing of the mudstone drapes ranges from less than 10% to almost 50%. There is no systematic difference between individual mudstone drapes of a pair. As many as half of the mudstone couplets have approximately the same drape thickness while the remainder vary between thicker upper drape and thicker lower drape. Thin section analysis shows that where there is a difference in drape

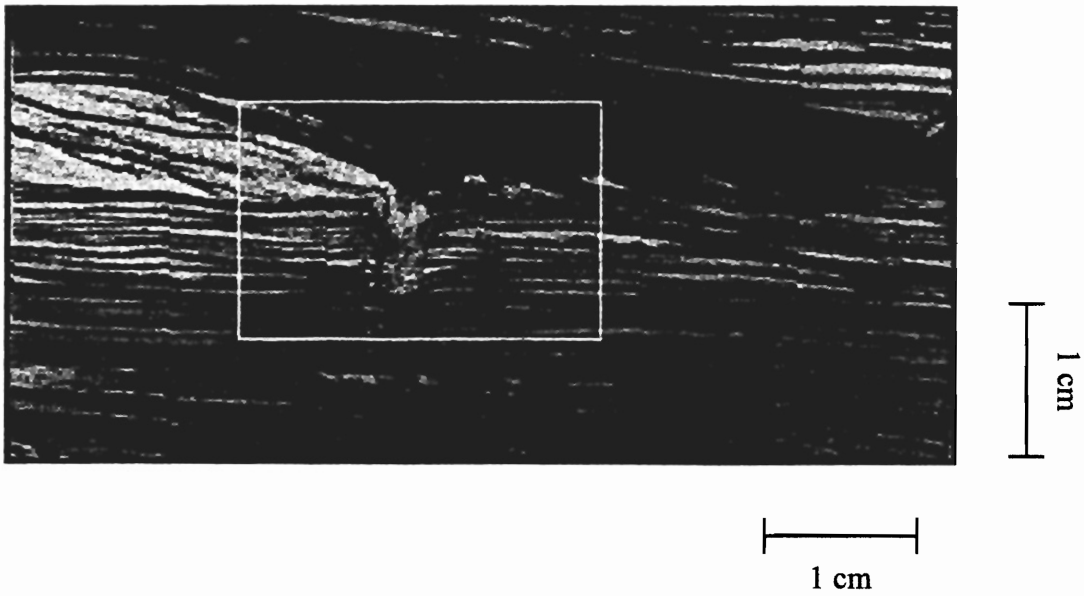


Figure 4-8. Bioturbation structure (escape burrow) shown in inset, approximately 196.3 m, drillhole P-59.

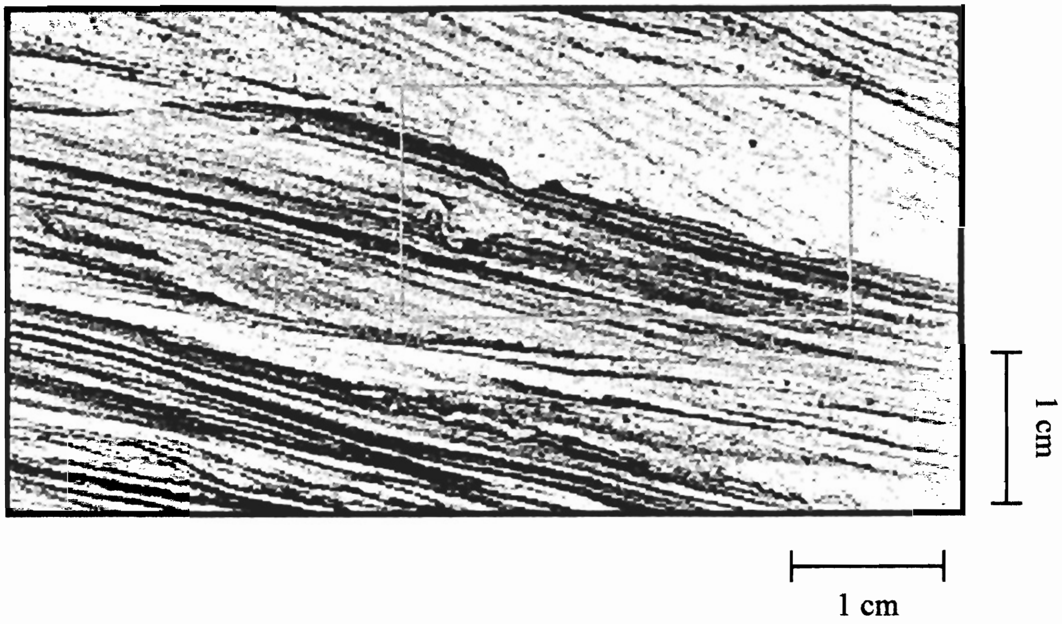


Figure 4-9. Soft sediment deformation (shown in inset) from approximately 196.15 m

thickness, coarser-grained mud and siderite/organic matter predominates in the thicker drape. The thicker sandy foresets reach approximately 2mm thickness near the top of the set and diminish downward in the set to <1mm. The grain-size within the thicker sandstone cross-layer appears to show a minor coarsening-upward trend. Any variation in upper and lower thickness between drapes within a pair implies unequal mud deposition during the two slack-water periods. Lack of erosion of mudstone drapes implies a low-energy environment allowing for near-complete preservation of cross-sets, with the exception of truncation of crests by the overlying cross-set.

4.4 Evidence of Tidal Influence

Sedimentary structures within the studied and evidence throughout the Upper Carboniferous of Nova Scotia support an inferred periodic tidal influence that was not accompanied by a salinity change. A general lack of marine fossils and the low-sulfur nature of the Stellarton coals suggest that salinity within the basin was low. Tidal influence can occur without an accompanying increase of salinity: tidal effects are recorded as far inland as 735 km from the mouth of the Amazon River (Officer, 1976). Occurrence of tidal deposits in estuarine environments with associated low-sulfur coals has been documented in the Westphalian C-D Brazil Formation, Indiana (Kvale and Archer, 1990). The tidal deposits of the Brazil Formation consist of tidal bundles within interlayered sandstones and mudstones that display neap-spring cyclicity. The authors infer that formation of tidal deposits and low-sulphur coals occurs as a result of transgressive (tidal) – regressive (peat-forming) cycles, with insufficient addition of marine-derived sulphate to produce elevated sulphur levels in the peat (coal).

The rhythmic nature of the cross-lamination indicates repeated periods of current flow depositing sandstone bedforms followed by slack water periods allowing settling of suspended material. Although some discrete interlayered sandy and muddy intervals could be associated with river flooding events, the pairing observed in many of the mudstone drapes is considered characteristic of tidal deposits and the author knows of no literature that interprets paired mud drapes as anything other than tidal in origin. The pairing indicates two directions of current flow: a dominant current and a subordinate current, each depositing different thicknesses of coarser-grained sediment. The existence of a subordinate current direction is supported by structures caused by flow reversals such as toeset laminae. These observations suggest that, during deposition of the interbedded sandstone and mudstone lithofacies, tidal currents often influenced the Stellarton Basin. This is the first documentation of marine influence in the Stellarton Formation and has considerable implications for paleoenvironment interpretation. If paired mudstone drapes are tidal, bedforms advanced approximately 1-2 mm during each tidal event.

Other evidence substantiating the likelihood of a tidal influence in the Stellarton Basin involves the documentation of marine influence in nearby coeval strata. Much of the Late Carboniferous strata of Nova Scotia has traditionally been interpreted as fluvial and lacustrine. However, the discovery of agglutinated foraminifera (fossil protozoans) (Wightman et al., 1993, 1994), which resemble modern estuarine and salt marsh species, in the Sydney Basin of Cape Breton indicates a regional marine influence during the Late

Carboniferous. Agglutinated foraminifera and trace fossils including *Cochlichnus*, *Kouphichnium*, and *Treptichnus*, found in the Westphalian A-B Joggins Formation (Archer et al., 1995) suggest fluvial deposition with a distant marine influence. Cyclothems within the Sydney Basin (Gibling and Bird, 1994) were interpreted to signal eustatic sea-level flux in the area. The discovery of paired mudstone drapes in the Late Carboniferous Port Hood Formation of Western Cape Breton (Allen, 1998) suggests tidal influence. Glaucony found in sandstone of Sydney Basin (Gibling et al., 1999) suggests a marine affinity. Increased salinity is possible in many Late Carboniferous coals with mean sulphur content of >5% (Gibling et al., 1989). The Westphalian C-D Malagash Formation to the immediate north of the Stellarton Basin is considered age equivalent to the Stellarton Formation. The Malagash Formation has been traditionally interpreted as fluvial in origin. However, over 10% of the formation is composed of interbedded sandstones and mudstones similar to those of the studied Thorburn interval. The heterolithic facies in the Malagash Formation includes thin mudstone laminae and agglutinated foraminifera suggesting estuarine and tidal influence (Naylor et al., 1998).

Conclusions

1) The intervals studied are found within the Upper Carboniferous Stellarton Formation. They were deposited within the rapidly subsiding Stellarton Basin. Dextral movement on the bounding Cobequid and Hollow Faults formed the pull-apart basin. The studied intervals are bounded by Oil Shales 7 and 8 and 21 and 22 of the Thorburn and Coal Brook Members, respectively. Both were deposited in a standing body of water with prograding bodies of coarser clastic material. Both fissile oil shales and torbanites comprise the end-member, distal oil shale lithofacies. These formed within the basin under anoxic, quiet hydrodynamic, and sediment-starved conditions. The mudstone facies comprises both massive and laminated shales and siltstones that show an increase in clastic sediment supply and current activity. The increase in biological activity, shown as burrowing, implies a move to oxygenated conditions. The interlayered sandstone and mudstone lithofacies forms a gradation towards the sandstone-bearing facies. The sandstone facies show an increased sediment supply and deposition under unidirectional currents. The proximal end-member comprises poorly developed paleosols with sideritic rhizo-concretions, root traces, and intensely distorted bedding. These units show deposition within shallow to subaerial conditions. An overall repeated coarsening-upward trend in the facies implies progradation of coarse-grained bodies into the standing water body.

2) The two studied intervals show lateral and vertical variations related to the depositional environment. The Thorburn Member interval bounded by Oil Shales 7 and 8 was studied in one core section, which shows an overall coarsening upward

trend from Oil Shale 8 below 210 m to approximately 170m. This is overlain by strata with a fining-upwards trend to Oil Shale 7 above 160 m. Smaller scale trends, both fining-upwards and coarsening-upwards, are superimposed on the larger-scale trends.

Both vertical and lateral differences are observed within the Coal Brook Member interval, bounded by Oil Shales 21 and 22 for which numerous core sections were available. An overall coarsening-upward trend is observed in locations inferred to be proximal to the sediment-input source. This trend is less apparent and eventually becomes insignificant with increased distance from the sediment-input. Interval thickness is at a high of over 20 m in the easternmost locations and decreases westward to approximately 10 m. Grain-size also varies laterally within the studied interval. Coarsest lithologies are encountered in drillholes AP-401 and AP-395 in the southeast and northeast study area, respectively. Grain-size decreases moving both eastward and westward from these locations. Changes in interval thickness and grain size suggest a local sediment source to the south-southeast of the study area.

3) Although the depositional environment has generally been ascribed to lacustrine deltas, evidence of a tidal influence has been uncovered. Mudstone drapes within the interbedded sandstone and mudstone lithofacies commonly show pairing which is considered characteristic of tidally influenced environments. These drapes cap small-scale sandstone cross-lamination, including climbing ripple bedforms. A thick sandstone layer was deposited during a dominant tidal current whereas a thinner sandstone layer was deposited during a subordinate tidal current. Toeset layers at the

base of foresets also suggest deposition during the subordinate current. This evidence supports a model where periodic tidal influence affected a standing body of water into which prograding sediment bodies built probably as a result of fluvial activity during the deposition of the studied intervals.

Further Work

Opportunities for further work include detailed study of clastics within the Stellarton Basin. Within these clastics, a study of the nature of the various styles of lamination in order to determine the extent of tidal influence within the Stellarton Basin could be completed. Examination of the areas showing tidal influence on a fine-scale to determine thickness variation associated with tidal cyclicity could constrain the periodicity of the tidal influence within the area. Further research into the macro- and micro-paleontology of the Stellarton Formation could discover indications of possible salinity changes accompanying the varying degree of restricted marine influence.

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APPENDIX A: DESCRIPTION OF LITHOLOGICAL UNITS, OIL SHALE-BOUNDED UNIT 21-22, DRILLHOLE P-59A

Unit	Thickness (m)	Lithology	Colour	G. Size	Sedimentary Structures, ets.	Fossils
1	1.615	oilshale	black	Cl	siderite layers	Pl-Tr (ab.), Os ®
2	0.367	silt	m. grey	St	grading (fining upwards), siderite layers	Pl-Tr ®
3	0.085	Silt/Shale	p/m grey	<St	cross-beds, silty drapes, burrowing, siderite layers	Bio ©, Pl-Tr (u)
4	0.677	Silt	m/d grey	vary	drapes (do not appear paired),coarsening-upward siderite layers	Biv (a)
5	0.117	Shale	black	Cl	siderite layers	N/A
6	3.25	Silt/Shale	m/. Grey	<St	cross-beds, convoluted, coarsening-upward overlain by flooding events?, siderite layers	Bio-possible, Pl-Tr ©
7	0.33	Silt/Sand	p/m grey	<Vf	drapes (some pairing possible), minor convoluted bedding, coarsening-upward, siderite layers	N/A
8	1.36	Silt/Shale	m. grey	St	grading (fining & coarsening cycles), convoluted bedding, siderite layers	N/A
9	0.21	Sand	p. grey	Vf	convoluted bedding, minor drapes - do not looked paired, siderite layers	Pl-Tr ®- chor, etc
10	0.754	Silt	m/d grey	St.	coarsening-upward, siderite layers	N/A
11	0.47	Sandysilt/shale	m. grey	>St	convoluted bedding, coarsening-upward, drapes (some pairing), siderite layers	N/A
12	0.175	Sand	p. grey	F	drapes, some look paired, calcite cement	N/A
13	1.98	Silt	m/d grey	St	grading (slight increase in sandier layers up section), siderite layers	Pl-Tr ©, Os (c)
14	7.76	Shale	d. grey	Cl	grading (slight coarsening up), siderite layers	N/A
15	2.67	Oilshale	black	Cl	N/A	N/A

Pl-Tr: plant fragment, Os: ostracodes, Bio: bioturbation, Biv: bivalve
Cl: clay, St: silt, Vf: very fine sand, F: fine sand

APPENDIX B: DESCRIPTION OF LITHOLOGICAL UNITS, OIL SHALE-BOUNDED UNIT 21-22, DRILLHOLE AP-85-401

Unit	Thickness (m)	Lithology	Colour	G. Size	Sedimentary Structures, etc.	Fossils
1	1.92	oilshale	black	Cl	siderite layers	Pl-Tr (r)
2	0.36	silt	m. grey	St	grading, siderite layers	N/A
3	0.09	silt/shale	m.d. grey	Vf/St	ripple cross-lamination, paired drapes, siderite layers	Pl-Tr (r)
4	0.32	silt/shale	d.m. grey	Vvf	ripple cross-lamination, grading, siderite layers	Os(a), Biv
5	0.54	silt/shale	m. grey	Vf/St	ripple cross-lamin, drapes (some paired), grading, siderite layers	Os, Biv, Pl-Tr, Bio
6	0.28	shale	black	Cl	siderite layers	Os(u)
7	0.26	v.v.f.g. sst	m. grey	Vvf	grading, convoluted bedding, siderite layers	Os(u), Biv(r)
8	0.28	v.f.g. sst	m. grey	Vf	grading, siderite layers	Pl-Tr (r)
9	0.2	silt/shale	d. grey	St	convoluted bedding, paired drapes, drapes	Bio
10	0.2	silt	d. grey	St	convoluted bedding, paired drapes, drapes	Biv(u), Bio
11	0.31	shale	black	Cl	N/A	Os(r), Biv(a)
12	1.67	silt/shale	unknown	F/Vf	grading, siderite layers	Os, Biv, Bio
13	0.33	silt/shale	l. grey	Vf	paired drapes, siderite layers	Pl-Tr (r)
14	0.44	silt	m.d. grey	St	grading, siderite layers	Pl-Tr (r)
15	0.21	silt/shale	d-l grey	F-St	convoluted bedding, paired drapes	Pl-Tr(r), Bio
16	0.65	silt	d.m. grey	St	siderite layers	Bio(r)
17	0.29	sandstone	l. grey	F	ripple cross-lamination, grading, contortions	Pl-Tr(u)
18	0.65	silt	d. grey	St	drapes, siderite layers	Pl-Tr(u)
19	0.22	silt	l.m.grey	F/Vf	ripple cross-laminination	Bio
20	0.58	silt/shale	d. grey	St	grading, paired drapes, siderite layers	N/A
21	0.32	ssilt/shale	m. grey	Vf/St	grading, convoluted bedding, microfaults, drapes, siderite layers	N/A
22	0.18	sandstone	l. grey	F	drapes (pairing)	N/A
23	2.36	silt	d. grey	St/Cl	drapes, siderite layers	Os(?)
24	1.14	shale	black	Cl	grading, siderite layers	Os, Biv, Pl-Tr
25	2.56	silt	d. grey	St	grading, drapes, convoluted bedding, siderite layers	Os(u)
26	0.12	shale	black	Cl/St	drapes	Os(c), Pl-Tr
27	0.11	silt/shale	m.d. grey	St/Cl	paired drapes, drapes, siderite layers	Os(c)
28	0.08	shale	black	Cl	drapes	unknown
29	0.66	silt	m. grey	St	drapes, paired drapes, siderite layers	possible Os
30	0.3	shale	d.grey/blk	Cl	drapes, siderite layers	N/A
31	0.35	silt	m. grey	St	grading, drapes, siderite layers	unknown
32	1.04	shale	d.grey/blk	Cl	siderite layers	Pl-Tr
33	2.62	oilshale	black	Cl	N/A	Pl-Tr (u)

Biv: bivalves, Cl: clay, St: silt, VF: very fine sand, F: fine sand

APPENDIX C: DESCRIPTION OF LITHOLOGICAL UNITS, OIL SHALE-BOUNDED UNIT 21-22, DRILLHOLE AP-85-395

Unit	Litho	Colour	G.S.	Thikness (m)	Sedimentary Structures, etc.	Fossils
1	Oilshale	black	cl	1.47	siderite layers	Pl-Tr
2	Limestone	d. grey	Cl	0.11	N/A	Biv
3	Shale	d. grey	cl	0.51	bioturbation near bottom, siderite	Bio
4	Silt	m/d grey	cl	0.32	rare siderite nodules	Bio, rooting
5	Sand/Mud	m. grey	st-vfg	0.76	siderite layers	Pl-Tr
6	Sand	l. grey	f.g.	0.5	siderite layers	carbonaceous material
7	Silt	m/d grey	st	0.34	convoluted bedding, siderite layers	Pl-Tr
8	Sand	l. grey	f.g.	0.42	siderite layers	carbonaceous material
9	Sand/Mud	m/d grey	>st	0.16	small scale cross-beds	Pl-Tr
10	Sand	l. grey	fg	0.47	N/A	carbonaceous material
11	Sand/Mud	l. grey	cl-fg	0.64	N/A	Pl-Tr
12	Sand/Mud	l/m grey	fg-st	1.3	cross-beds, siderite layers	Pl-Tr
13	Sand/Mud	m grey	st-fg	3.16	siderite layers	Pl-Tr
14	Sand/Mud	l-m grey	fg-st	0.54	convoluted bedding, siderite layers	carbonaceous material
15	Sand/Mud	m-d grey	st-fg	1.17	drapes, siderite layers	Bio
16	Shale	black	cl	3.3	siderite layers	Os, Pl-Tr
17	Oilshale	black	cl	1.78	N/A	Pl-Tr

Pl-Tr: plant fragment, Os: ostracodes, Bio: bioturbation, Biv: bivalves
cl: clay, st: silt, vf: very fine sand, f: fine sand

APPENDIX F: DESCRIPTION OF LITHOLOGICAL UNITS, OIL SHALE-BOUNDED UNIT 21-22, DRILLHOLE AP-84-385

Unit	Thickness (m)	Lithology	Colour	Grain Size.	Sedimentary Structures, etc.	Fossils
1	0.66	Oilshale	black	cl	N/A	N/A
2	8.02	Shale	black	cl	siderite layers	Biv, Pl-Tr
3	1.5	Oilshale	black	cl	N/A	N/A

Pl-Tr: plant fragments, Os: ostracodes, Bio: bioturbation, Biv: bivalves
cl: clay, st: silt