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SEDIMENTOLOGY OF THE LOWER PART OF THE
MORIEN GROUP IN THE SOUTHEAST PORTION OF
THE SYDNEY COAL BASIN, NOVA SCOTIA.

A Dissertation
Presented To The
School Of Graduate Studies
University Of Ottawa
Ottawa - Carleton Geoscience Center

In Partial Fulfillment
Of The Requirements For The Degree
Master Of Science
In Geology

By

Shawn James Dilles
September, 1983

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Dissertation Supervisor

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ABSTRACT

The Upper Carboniferous Morien Group in the Sydney Basin, N.S. was the first coal-bearing unit mined in North America, and is still an important producer. The basin is generally saucer shaped, and covers over 35,300 sq. km, 99% of which is offshore. The Morien Group (equivalent to the Pictou Group elsewhere in Maritime Canada) was divided into three megafacial zones by Bell (1923). This study deals with the older two zones in the eastern part of the Sydney Basin, between False Bay Head and Cape Perce.

Two facies associations are present in the study area. South of False Bay is the Sandstones Facies Association, containing less than 15% mudstone. The alternating Sandstone-Mudstone Facies Association makes up the remaining sections (see Fig. 1-1). Markov Chain Analysis of lithofacies transitions show a non-random preferred sequence of Se-St-Sh-Sr-F1-Fm for the Sandstone Facies Association (see CH. 4). The Alternating Facies Association has a somewhat similar non-random preferred sequence, and a higher tendency towards cyclicity.

The presence of well preserved fossil flora, coal seams over seatearths, upright trees, and fresh water mollusks and ostracods indicate deposition in a terrestrial environment. Marine fossils and thick coarsening-upward deltaic sequences are absent.

The Sandstone Facies Association is interpreted as a sandy distal braidplain deposit, similar to facies association S[ii] of Rust (1978). A modern analogue is the South Saskatchewan River model of Cant and Walker (1979), although the measured sections have fewer planar cross-stratified units. The presence of lateral accretion surfaces and low sandstone: mudstone ratio indicate that the Alternating Facies Association was deposited by a meandering fluvial system. Point bar, crevasse-splay, levee and floodplain deposits have been identified. Mudstone-filled channels resulted from chute cutoff, neck cutoff, or avulsion.

Paleocurrents from trough cross-beds show a consistent N-NE direction, indicating that drainage from the south and southwest was maintained throughout deposition of the Morien Group in this area. The basin is pictured as a gently downwarped area that gradually filled with continental deposits. Decrease in slope with time was accompanied by a change from a distal braided to meandering fluvial style. The change occurred later in the west than in the east. Coal development did not coincide with the start of meandering river deposition in the east, probably because of unfavorable climatic conditions.

A previously unrecognized feature is a north trending syncline seaward of the Cape Morien Headland. A reinterpretation of Morien Bay structure was proposed, suggesting the need for a re-evaluation of the coal resource potential of the area.

"On the whole, we can scarcely err in affirming that the habitat... was a peaty swamp, occasionally or periodically inundated, and in which growing trees and Calamite brakes were being gradually buried in sediment, while others were taking root at higher levels, just as now happens in the alluvial flats of large rivers."

John William Dawson (1820-1899)

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Special thanks are extended to my friend and colleague Irvine R. Annesley, and to all other graduate students at the Center with whom I have shared valuable discussions. Sincere appreciation is acknowledged to Ian McDougal for assistance with Markov Chain programming, and to Tony Hoesny for text editing.

The contribution of B.R. Rust is hard to overstate. He has been close at hand as thesis supervisor throughout the course of this project. His field mapping skills and acute editorial ability and patience are greatly appreciated.

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Chapter. I

INTRODUCTION

1.1 PURPOSE OF THE PRESENT STUDY

Coal has been mined from the Upper Pennsylvanian Morien Group in the Sydney Basin, Nova Scotia since 1720, and much study has been directed towards evaluation, analysis, and correlation of the coal seams. Until recently, however, little work has been directed towards the considerable thickness of clastic sediments between the seams. This study is part of a larger project which aims to establish lithostratigraphic subdivisions for the Morien Group across the basin and examine its sedimentology in detail (see Rust et al., 1982).

Work proceeded along four major lines:

1. Geologic mapping and description of sedimentary facies in coastal sections of the study area.
2. Logging of a 332 m (1089 ft.) borehole, and pertinent parts of two other nearby boreholes. These were correlated as closely as possible with measured outcrop section.
3. Petrographic and X-ray diffraction analysis of fine and coarse-grained clastics using 65 thin sections and 65 powdered samples.

4. Markov Chain Analysis to determine

- 1) if an ordered sequence of facies is present, and
- 2) if there are significant vertical and/or lateral facies changes in the study area.

In addition, samples were collected for spore analysis to aid in chronostratigraphic control. These were submitted to M.S. Barss of the Geological Survey of Canada at the Atlantic Geoscience Center.

Fieldwork was carried out between May and September of 1982. Work was supported by the Nova Scotia Dept. of Mines and Energy (N.S.D.M.E.) and the Geological Survey of Canada through the Canada-Nova Scotia Cooperative Mineral program; and by the Dept. of Geology at the University of Ottawa. The Cape Breton Development Corporation (Devco) provided access to the cores that were logged.

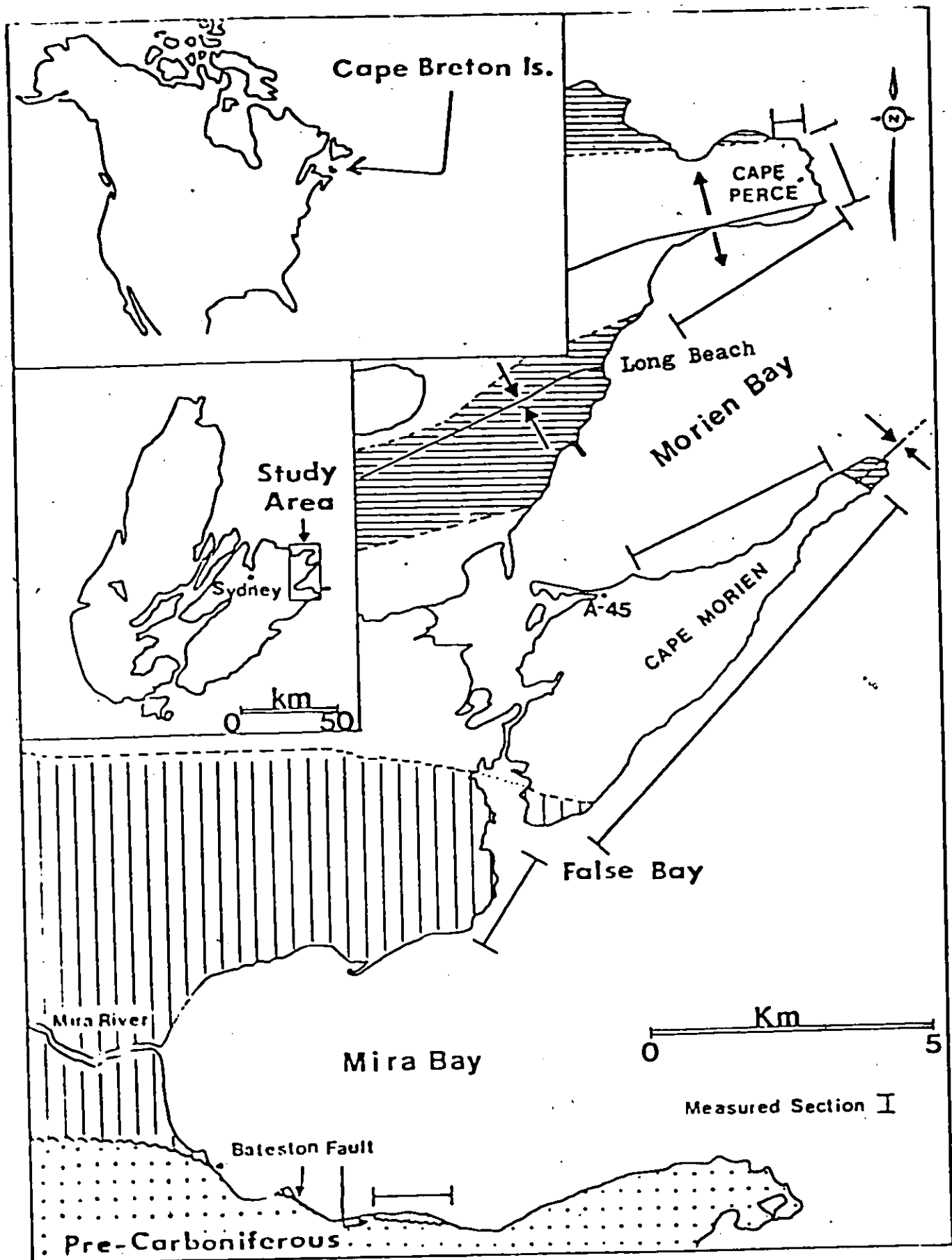
1.2 STUDY AREA LOCATION AND ACCESS

The Carboniferous Sydney Basin occupies the northwest corner of Cape Breton Island, Nova Scotia, and extends offshore almost to Newfoundland (Hacquebard, 1983). This study was limited to the area between Cape Percé and False Bay Head (Figure 1-1). This area is underlain by rocks of the Lonchopteris and Linopteris obliqua megafloral zones

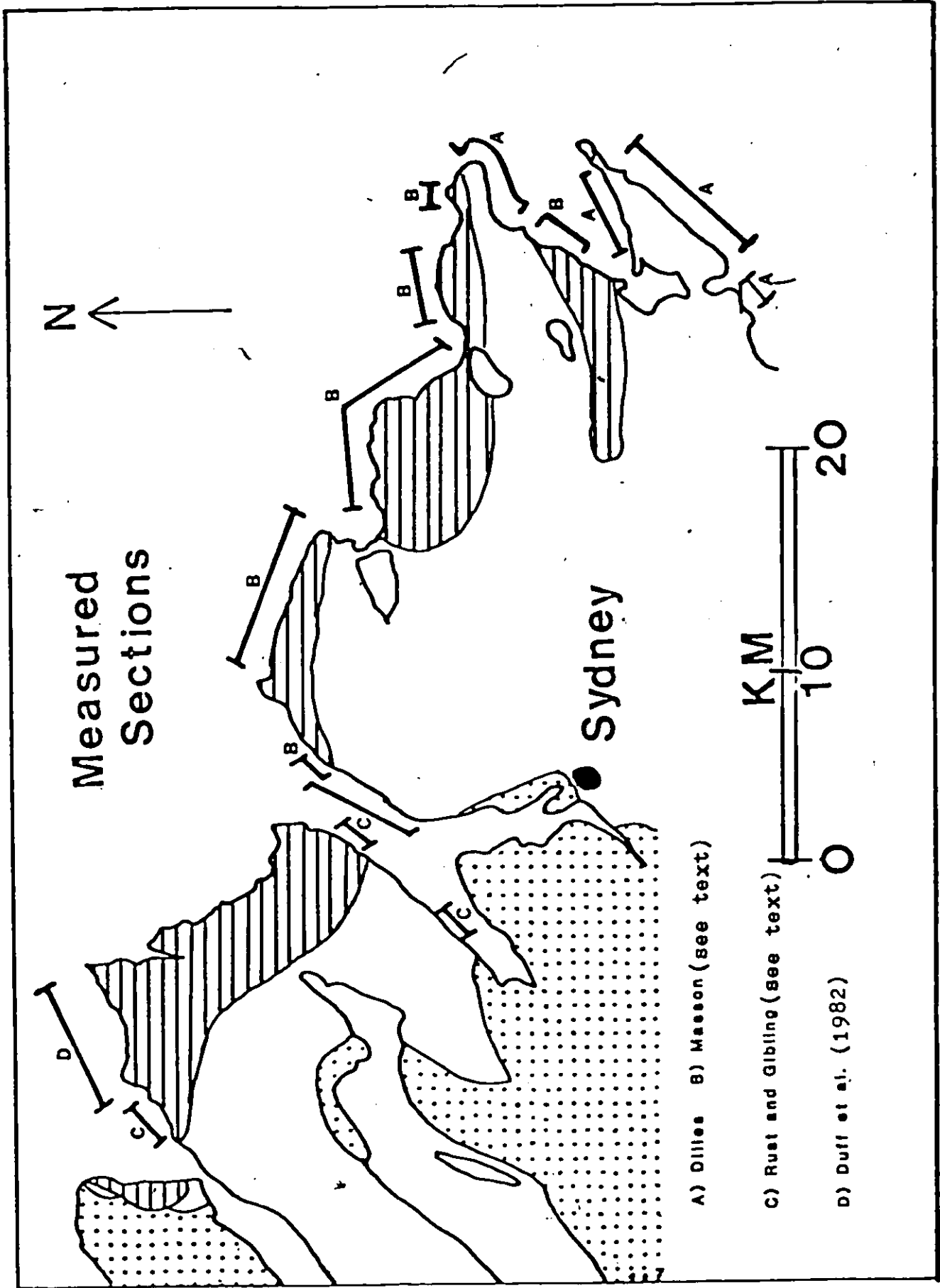
(Bell, 1938). The Lonchopteris zone at Bateston was described by Rust and Gibling (Rust et al., 1982; Dilles and Rust, 1983), and is similar to the section at False Bay Head. The Ptychocarpus unicus zone around the study area was described by Guy Masson (Rust and Masson, 1981). Figure 1-2 shows the coastal areas recently mapped. The N.S.D.M.E. has undertaken the mapping of the entire inland portion of the basin, as part of the Carboniferous Basin Mapping Project. Work began in the 1982 field season and is expected to conclude in the 1983 season (Giles, 1983, Personal Comm.).

All of the sections were measured along the shore. Outcrops in the study area ranged from isolated exposures at beach level to continuous cliffs 40 m (132 ft.) high and several kilometres long. Most outcrops occur as near-vertical cliffs between 15 and 25 m (49 and 82 ft.) high. In many cases the sections could only be reached by foot at low tide, and about 10% of the area was inaccessible even then. A 4.9 m (16 ft.) aluminum boat with a twenty horsepower Johnson engine was used whenever conditions permitted. The boat decreased travel time and increased both access and safety. Where the cliffs were low enough (under 15 m or 49 ft.) and gently sloping (under 45 degrees), ropes were used instead of attempting a beach landing.

Figure 1-1



Location of study area and measured sections. Horiz. ruling: *Ptychocarpus unitus* megafloreal zone; vert. ruling: *Lonchopteris* zone; blank: *Linopteris obliqua* zone (of Hayes et al., 1938).



A) Dillies B) Masson (see text)

C) Rust and Gibling (see text)

D) Duff et al. (1982)

Figure 1-2. N.E. Cape Breton Island, showing recently measured sections of Upper Carboniferous rocks. Hor. ruling, Ptychocarpus unitus zone. Blank, Linopteris obliqua and Lonchopteris. Dots, other.

In order to provide a comprehensive picture of the exposed sections a 35 mm black and white photographic survey was conducted by boat before mapping got under way. The photos served as a base for further work, and were especially useful for planning rope and boat access sites. The geological map # 362-A (Glance Bay Sheet) was used extensively (Hayes, Bell, Goranson, 1938). Stereoscopic air photos from the Maritime Resource Management Service were useful for planning overland routes, and also aided structural interpretation, particularly in shallow marine areas.

1.3 PREVIOUS WORK

The Sydney Basin has been the major producer of coal in Atlantic Canada and has attracted a great deal of study. The amount of published material on exploration and development that has built up over the years is quite large. For the purpose of review five phases of research have been recognized. These are: a) Early Investigations, b) Systematic Surveys, c) Early Work related to mining (to 1960), d) Recent Work (1960-1980), and e) Current Work (to 1983).

1.3.1 Early Investigations

This phase includes all work conducted before the first systematic geological survey. Today this material is considered to be largely of historical interest. A good summary is given by Hayes and Bell (1923).

Coal was first noted in the Sydney Basin by Nicholas Denys in the "Description Geographique et Historique des Cotes de l' Amerique Septentrionale", published in Paris in 1672 (see Hayes and Bell, 1923). The first mine in the Basin was opened by the French in 1720, providing coal for the nearby Fortress of Louisbourg.

Richard C. Brown published "The Coal Fields and Coal Trade of the Island of Cape Breton". Included was a detailed stratigraphic section measured along Sydney Harbour, and a classification of Carboniferous stratigraphy based on the European system.

Two famous workers made contributions in 1843. In his book "Travels in North America in the years 1841-2" Sir Charles Lyell classified many of the fossil plants that he found in the basin. In the same year Sir Richard Dawson published the first edition of "Acadian Geology". In later editions of this book he challenged the system of Carboniferous nomenclature proposed by Brown.

Other workers also made contributions in this period. Lesley (1863, Hayes and Bell, 1923) for example, made detailed measurements of coastal sections near Lingan and Glace Bay.

1.3.2 Systematic Geologic Surveys

The first organized effort to map the land portion of the Sydney Basin was carried out for the Geological Survey of Canada by Charles Robb between 1872 and 1875 (see G.S.C. Report of Activities for those years). His work was updated by Fletcher between 1895 and 1897 (see G.S.C. Summary Reports). In 1901 Fletcher published a "Descriptive Note of the Sydney Coalfield" summarizing previous work. An impressive amount of work was done in this period. For example in 1873-4, Robb made over 4000 measurements and 7,444 m (24,000 ft.) of strata were described. Two maps were prepared from the data, with vertical sections to show the position of the coal seams on a scale of 2 cm to 96 m (1 inch to 400 ft.). This was the most thorough investigation to date and it remained the standard reference for over twenty years.

The second G.S.C. survey was begun by Hayes during the field seasons of 1917-19 and was completed by Bell in 1921. Their report appeared in 1923 as G.S.C. Memoir 133. Coastal sections were remeasured in the area east of

Sydney, and new boreholes were logged. Bell assigned strata to zones based on their megafloreal content for the first time.

The Hayes-Bell report contains verbal descriptions of sections in the study area, but like the first survey its focus is primarily on the stratigraphic position of the coal seams. One example from the log of a section currently under study demonstrates this:

"Strata---254 ft. 0 in.

Coal --- 0 ft. 10 in."

One of the most useful part of this report is the correlation of coal seams between Cape Perce and Cape Morien (also known as Northern Head and South Head) and other parts of the basin.

1.3.3 Other work related to mining (to 1960)

Most of the Sydney Basin lies below the Atlantic Ocean (King and Maclean, 1976). The early coal mines soon led to the shore, and continued under the ocean bottom.

Gray (1934) discussed the submerged portion of the Sydney Coalfield, a topic updated by Gray and Gray (1941), and revised by Haites (1952). According to Haites, coal seams are thicker in the axes of most synclines than over the anticlines, implying that the folds developed during sedimentation.

The importance of geology to the economic development of the basin was outlined by MacNeil (1948) and by Haites (1951).

1.3.4 Recent work (1965-1980)

Knowledge of the Sydney Basin grew primarily along two fronts during this period. First, a detailed chronostratigraphy was established for the Morien Group and time equivalent units of the Pictou Group based on palynology. Secondly, offshore mining necessitated a better understanding of the size and shape of the basin, and of the seaward continuity of its coal seams.

Hacquebard, Barss and Donaldson (1960) first noted the potential usefulness of fossil spores in correlating Upper Carboniferous deposits in eastern Canada. Barss and Hacquebard (1967) divided the Pictou Group into five spore zones, which correspond with Bell's (1938) megafloral zones. Cape Morien was used as the type area for the lower three zones. Hacquebard and Donaldson (1969) contrasted the fluvial deposits of the Sydney Basin with limnic deposits of the Pictou coalfield. Palynology played a major role in determining the local environment of deposition of the coal seams. Since then Hacquebard has made several resource appraisals of the Sydney Basin (Hacquebard, 1976b, 1979, 1983).

As mining progressed offshore and a new undersea mine was planned for the Cape Perce area, more detailed information on seam thickness and continuity was sought. A deep seismic survey of the Scotian Shelf indicated that the 510 sq. km (200 sq. mi) land exposure was just a small fraction of the entire basin. King and Maclean (1976) found the offshore extension to cover almost 35,300 sq. km (13,800 sq. mi) and reach almost to Newfoundland. A shallow seismic survey in Morien Bay detected a disturbance which was attributed to a zone of dislocation (Howells, 1977). As a result of that survey and later work, the Port Morien area was ruled out as a possible site for a new undersea mine (Hacquebard, 1983).

An unsuccessful search for oil and natural gas was initiated in the mid 1940's and reached its climax in 1968 with the drilling of a test hole near Cape Perce (McPhee, 1966; McLean, 1968). The hole was drilled on the axis of the Cape Perce anticline, and provided a continuous section through most of the Lower Morien Group.

1.3.5 Current Work (1980-1983)

In recent years the importance of sedimentology to coal mining has become established (Horne et al., 1980). Knowledge of the environments of deposition of not only

the coal but of nearby strata has become useful in mine operations and planning (Foregeron, 1980; Moebs and Ellenberger, 1981). Because of this, new studies have been based on sedimentological analysis of the entire Sydney basin, (Rust and Masson, 1981; Dilles and Rust, 1983; Rust et al., 1982). Land exposures along the coast west of Point Aconi have been described by Duff et al. (1982) (Figure 1-2).

A final aspect of current research in the basin is the program of coal seam evaluation being carried out by the N.S.D.M.E. Boreholes are being drilled to determine seam continuity and quality for the purpose of strip mining (Gilles, 1979). Concurrently the Dept. of Mines is also remapping the entire land portion of the basin (Giles, 1983 Personal Comm.).

Chapter II
STRATIGRAPHY AND STRUCTURE

2.1 INTRODUCTION

Lower Morien Group¹ strata form an integral part of the Sydney Basin. This basin is just one structural element in a depositional system in Atlantic Canada that extended from the end of the Devonian into the Permian (Fig 2-1). In the first part of this chapter the regional depositional framework will be reviewed. Attention will then focus on the structure and stratigraphy of the Sydney Basin, and the areal and stratigraphic position of the study area within the basin.

2.2 REGIONAL SETTING

Kelley (1967) estimated that Carboniferous and Permian deposits underlie approximately 166,400 sq. km (65,000 sq. mi) of Atlantic Canada, with about 60% currently submerged. Subsequent to that study, the offshore portion of the Sydney Basin was found to be over 34,600 sq. km (13,500 sq. mi) larger than previously recorded (King and Maclean, 1976; Hacquebard, 1983), bringing the total area to at least 201,000 sq. km (78,500 sq. mi). Figure 2-1 shows the

¹An informal term used here to designate rocks in the Lonchopteris and Linopteris obliqua zones.

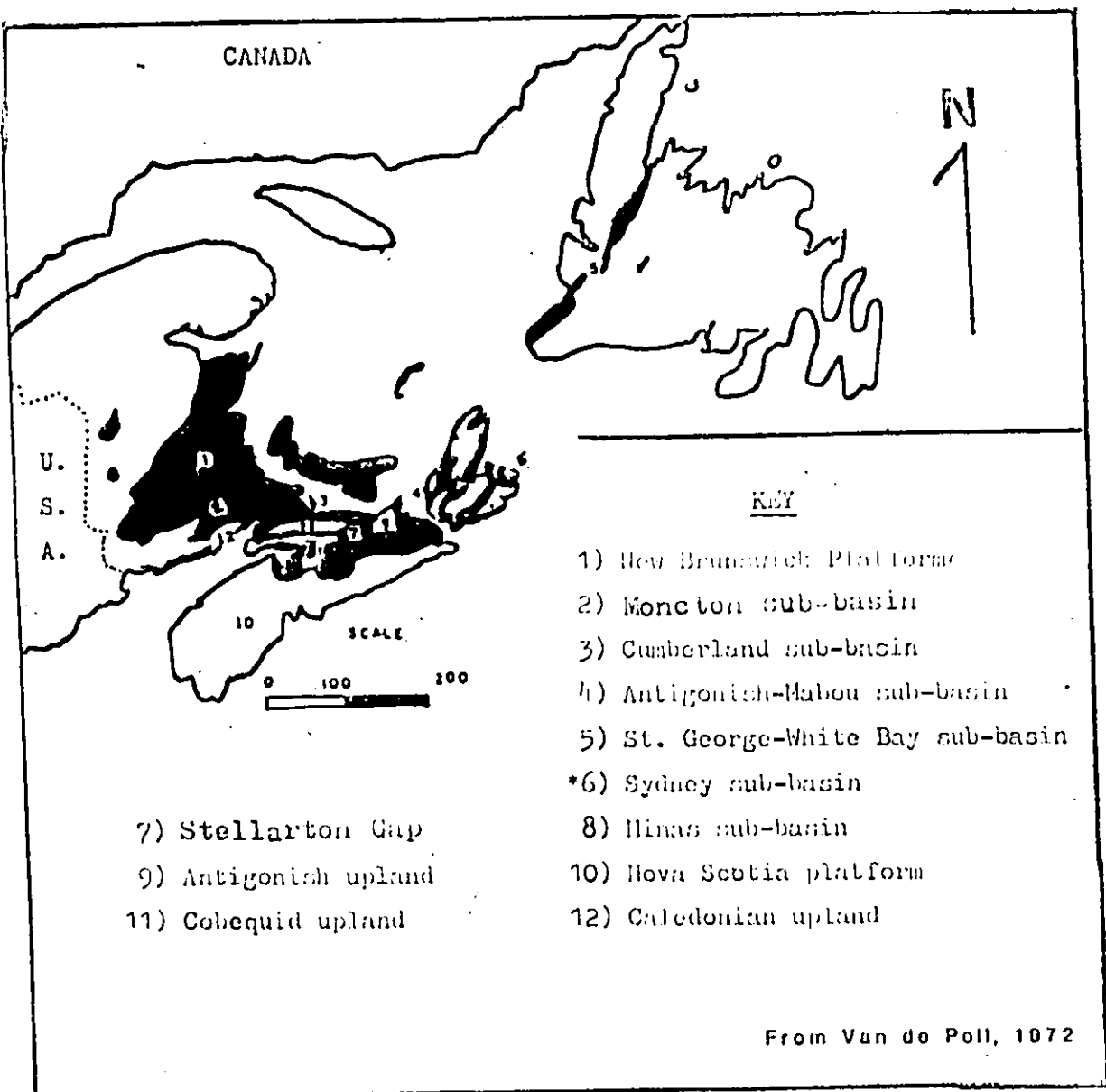
distribution of Permo-Carboniferous sedimentary rocks in the region. ~~This~~ area was undoubtedly much larger before erosion removed some of the original strata. For example, Van de Poll (1970) estimated that up to several thousand feet of Permo-Pennsylvanian strata were removed from southwest New Brunswick by post-depositional uplift and erosion.

Deposition occurred in a broad, northeast trending area extending from southern New Brunswick to Newfoundland, and from northeast Gaspé to eastern Cape Breton Island. Within this area there are several distinct depocenters separated by upland areas^(Fig 2-1). During the latest part of the Devonian period the area of deposition was relatively small. It grew progressively throughout the Carboniferous and Permian as younger deposits overstepped older ones (Van de Poll, 1972).

This area was called the Fundy Basin by Bell (1944) because the thickest deposits and most intense tectonism occurred around the present Bay of Fundy. Bell pictured a wide, generally downwarping trough with local areas of uplift separating complementary basins. In Cape Breton the Antigonish-Mabou sub-basin was separated from the Sydney sub-basin by the Cape Breton Highlands. The uplifted areas provided material for the young basins. As these primary basins filled and subsidence continued, sediments overlapped over the original upland areas and joined separate depocenters. Bell's general view was shared by most subsequent workers (Poole, 1967; Kelley, 1967). Van de Poll

(1972) questioned the internal tectonism proposed by Bell and pictured "mild but widespread epeirogenic uplift together with local subsidence and expansion of the basin" (p.15).

Figure 2-1



Distribution of Permian-Carboniferous rocks in Atlantic Canada (in black).

Two distinct structural zones are recognizable within this region. The area between southeast New Brunswick and northern Nova Scotia is characterized by thick sedimentary deposits and a relatively high degree of tectonism. Belt (1964, 1969) restricted the term "Fundy Basin" to this center of deposition. On the flanks of this basin are foreland areas with a thin sedimentary cover and little tectonism. Examples of this region are the New Brunswick Platform and outlying areas of Nova Scotia (including the Sydney Basin).

The terminology for the tectonic setting of the Fundy Basin has not been standardized. Belt (1969) interpreted the basin as a complex fault-bounded rift valley. Howie and Barss (1974) and Kelley (1970) considered the basin to be either an epieugeosyncline or a taphrogeosyncline. Poole (1976) interpreted it as a successor basin filled with molasse of the Horton Group (upper Devonian to Visean age). Keppie (1977) described the Fundy Basin as a "long, secular, linear downwarp whose development was arrested at an early stage of rifting". Using the terminology of Shatski (1961), he termed the Fundy Basin the Fundy Aulocogene.

The structural picture is complicated by movements inferred to have occurred parallel to the Bay of Fundy between late-mid Devonian and early Carboniferous time, and by east-west movement on the "Minas Geofracture" (Keppie, 1982). Figure 2-2 shows a palinspastic map of the area for the Permian (after Keppie, 1982).

All tectonism in the Permo-Carboniferous is attributed to the Maritime or Alleghenian Disturbance (Poole, 1967; Keppie, 1982), to distinguish it from the Acadian Orogeny of Mid to Late Devonian age.

2.3 PERMO-CARBONIFEROUS STRATIGRAPHY

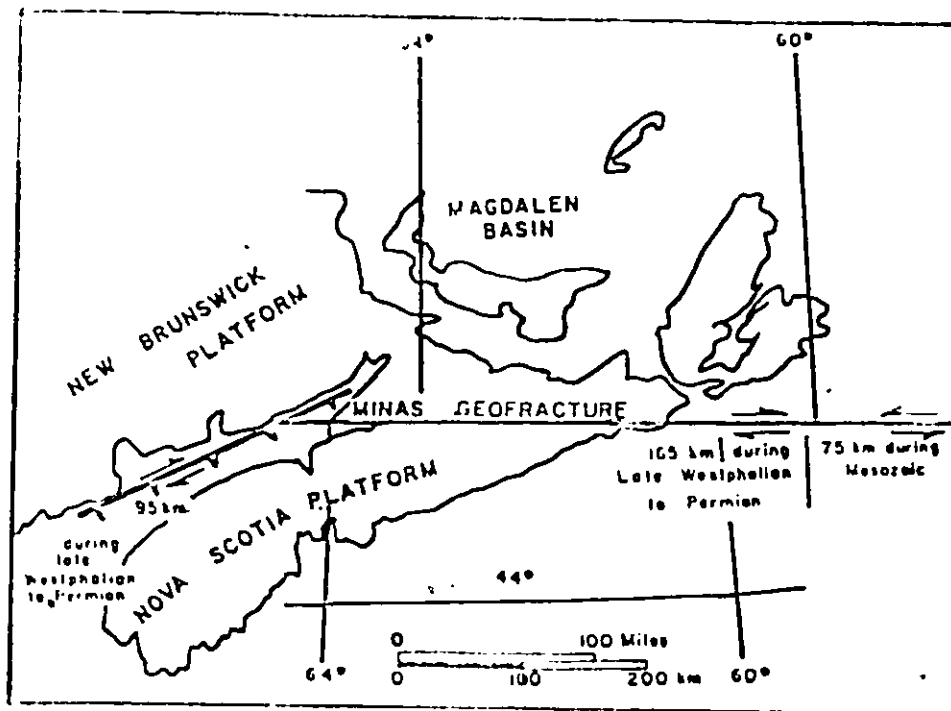
Descriptions of Permo-Carboniferous stratigraphy have been given by Bell (1944), Barss et al. (1963), Hacquebard (1960; 1971), Belt, 1964, and Kelley (1967). Table 2-1 (modified from Van de Poll, 1972) summarizes Carboniferous nomenclature for New Brunswick and Nova Scotia.

Bell (1944) divided the Carboniferous into six "Groups", originally on the basis of fossil content. Bell believed that these groups had time-parallel boundaries. From oldest to youngest these are the Horton, Windsor, Canso, Riversdale, Cumberland, and Pictou Groups.

Subsequent workers extended this classification system across the Maritime Provinces, frequently without the aid of fossils for correlation. As a result, strata in new areas were named on the basis of unconformities and lithologic similarities to the type areas. It was soon found that the boundaries of Bell's original "Groups" were diachronous from place to place. It was realized that localized uplift produced unconformities in some areas, while leaving deposition a few kilometres away completely undisturbed. As a result, the original time boundaries of Bell's units have been revised (Belt, 1964; Kelley, 1967).

Figure 2-2

Permian palaeogeographic map modified from Keppie, (1982).



The Horton Group consists of red and greenish-grey siltstone, shale, sandstone, conglomerate and coal. In some areas volcanics are interbedded with the clastics. The group was originally believed to be of late Mississippian (Tournaisian) age, but Kelley (1967) recorded a Late Devonian to early Visean range for the unit. In all places the group rests unconformably on older rocks. The unconformity is probably the result of uplift and erosion resulting from the Acadian Orogeny (Keppie, 1982). The sediments of the Horton Group have been interpreted as primarily of fluvial and lacustrine origin.

The Windsor Group rests either conformably, disconformably or unconformably on the Horton Group. It contains marine carbonates and evaporites interbedded with non-marine sandstones, siltstones and shales (Keppie, 1982). The Windsor was divided into five subzones, A-E, by Bell (1929). Schenk (1967) considered these to represent depositional environments ranging from shallow marine through supratidal to subaerial. On the basis of megafaunal evidence the group was originally believed to be of Visean age. However, Mamet (1970) used microfauna to correlate it with the late Visean to early Namurian.

The Canso Group consists of all non-marine units of Namurian age below the Riversdale Group. In New Brunswick it is referred to as the Hopewell Group. It rests either conformably or disconformably on the Windsor Group and is

separated disconformably or conformably from the overlying Riversdale Group. Lithologically the group consists of non-marine red and grey siltstone, and non-marine limestone. In the area near Sydney, Nova Scotia, the Point Edward Formation was deposited at this time.

The Riversdale Group consists of red and grey siltstone with grey sandstones and, locally, a conglomerate base. The Group was first thought to have been deposited during Westphalian A time, but has since been shown to extend into the latest Namurian (Kelley, 1967, Table 2-1). The Point Hood Formation of the Riversdale group was interpreted as fluvial in origin by Gersib and McCabe (1981).

The Cumberland Group overlies the Riversdale Group conformably, disconformably, or unconformably. Its upper boundary with the Pictou Group is usually unconformable or disconformable, but may be conformable in western Nova Scotia (Van de Poll, 1972). The Cumberland Group is the thickest Carboniferous sequence in Atlantic Canada, and includes the classic section at Joggins, N.S.

The Pictou Group is the most widespread unit in the Permo-Carboniferous of the region. The Group commonly oversteps older Carboniferous and pre-Carboniferous rocks. It consists of grey and red clastics with minor coal and rare non-marine limestones. Deposition is considered to be continental (Hacquebard and Donaldson, 1969; Legun and Rust, 1982). The Group was originally believed to extend from

Westphalian C to D, but few fossils have been found at the type locality. Rocks later assigned to the Group were found to contain fossils ranging in age up to the Permian. The main areas of deposition are the Cumberland, Sydney, Minas, and Moncton sub-basins, the New Brunswick Platform, and Prince Edward Island (Figure 2-1). The Morien Group of the Sydney Basin is time equivalent to the Pictou Group.

In summary, the Permo-Carboniferous of Atlantic Canada was marked by continental deposition, except during the Windsor marine transgression. Deposition became more widespread as irregularities of the basin were filled by early deposits, allowing later units to cover a wider area.

Against this general background of predominantly continental sedimentation, the stratigraphy and structure of the Sydney Basin will be reviewed.

2.4 SYDNEY BASIN STRATIGRAPHY

Stratigraphic nomenclature for the Sydney Basin is summarized in Table 2-2. Dawson (1868) and Brown (1871) based their classifications on general lithologic characteristics such as the presence and quality of coal, and the amount of sandstone in the section. These early workers attempted to correlate between Carboniferous strata in North America and Great Britain, and so distinguished between Productive Coal Measures and the barren (unproductive) Millstone Grit. Brown and Dawson placed the

upper boundary of the Millstone Grit at different stratigraphic positions. This is due to a facies change in this interval from east to west across the basin, and will be discussed in detail later.

Bell (1944) used the megaflora to define three zones in the Morien Group. From oldest to youngest these are the Lonchopteris zone, Linopteris obliqua zone, and Ptychocarpus unitus zone. The lower two units were dated as Westphalian C, and the upper as Westphalian D. Barss and Hacquebard (1967) found that these megafloral zones correspond to miospore zones. From oldest to youngest these zones are designated A, B and C (Table 2-2). These workers also dated strata at the top of Bell's P. unitus zone as Stephanian. This was confirmed by recent megafloral studies (Zodrow and Gastaldo, 1982). Offshore, strata may extend into the Permian (Hacquebard, 1983).

This study deals with the Lonchopteris and Linopteris obliqua zones (or spore zones A and B) of the Morien Group in the southern corner of the Sydney Basin. These units will informally be referred to as the Lower Morien Group. Along Mira Bay (Fig 1-1) the measured section dates from the top of zone A to the middle of zone B. On the west side of Cape Morien and around Cape Percé the measured sections extend from the top to the middle of zone B.

Table 2-2

Stratigraphic nomenclature of the Morien Group.

| | AGE | Robb 1875 | Hayes, Bell and Goranson 1938 | Barss and Hacquebard 1967 |
|---|---------|--------------|-------------------------------------|---------------------------------|
| P | | | | |
| E | West- | Productive | Ptychocarpus | Thymospora |
| N | phalian | coal | unitus | zone |
| N | D. | Measures | zone | C |
| S | | | | |
| Y | West | Millstone | Linopteris | Torispora |
| L | phalian | Grit | obliqua | zone B |
| V | C | | zone | |
| A | | | | |
| N | | | Lonchopteris | Vestispora |
| I | | | zone | zone A |
| A | | | | |
| N | | | | |

The rocks of the Lonchopteris zone consist of coarse to medium sandstone grading locally into a sequence of alternating sandstone and mudstone. Coals are thin and not laterally continuous across the basin. The base of the zone is not exposed in the study area. Hayes et al., (1938) believed that the zone lay disconformably or unconformably over Mississippian Canso or older strata. However, an oil exploration well drilled just west of Cape Percé suggests otherwise. Murphy Oil's Sand Lake well penetrated 1337 m (4400 ft.) of strata, and reached the Cambro-Ordovician (McLean, 1968). Strata between 0-842 m (0-2770 ft.) were interpreted as belonging to the Morien Group. Spores from this interval were dated as Westphalian C and D (Barss, 1968). Strata from 842 to 1037 m (2770-3400 ft.) were described as a "dark grey, maroon, purple to varicoloured shale" (McLean, 1968, p. 4) and interpreted as the Point Edward Formation. This view is in agreement with the sequence of rocks measured in outcrop (Hayes et al., 1938). Spore samples from this unit between 851 and 878 m (2800 and 2890 ft.), however, contain an assemblage of spores characteristic of the Cumberland Group, of uppermost Westphalian B age (Barss, 1968) and not of the late Visean to Westphalian A Canso Group.

Two explanations for the presence of these rocks are : 1) that they represent sediments of the Cumberland Group that lie unconformably above the Point Edward Formation and

either conformably or unconformably below the Morien Group, or 2) that they represent the base of the Morien Group in this area. In either case no Westphalian B strata have been mapped on the surface in the Basin to date. It is suggested that spore samples be obtained and analyzed from the top of the 'Canso' Point Edward Formation. Other Westphalian B spores may possibly be found in this unit.

Excluding the section north of False Bay, strata of the Lonchopteris zone are coarse. They range from coarse to medium sandstone with some thin pebble conglomerate units and very rare mudstone and coal (Rust et al., 1982). North of False Bay the zone consists mainly of medium and fine-grained sandstone and mudstone. This lithostratigraphic boundary is not parallel to the biostratigraphic boundary between the Lonchopteris and Linopteris obliqua zones.

The lower boundary of the Linopteris obliqua zone was placed arbitrarily at 6.1 m (20 ft.) above the Tracy coal seam by Hayes et al. (1938). In the study area, rocks in this zone consist mainly of alternating medium and fine sandstone and mudstone, with minor amounts of coal. No significant lithologic difference was noted between Linopteris obliqua and Lonchopteris strata north of False Bay. However, west of Glace Bay the entire Linopteris obliqua zone is lithologically similar to Lonchopteris strata south of False Bay: coarse to medium sandstones with rare mudstones. In contrast, rocks of the Ptychocarpus unitus zone are more uniform across the basin.

The lithologic change across the basin within the Lonchopteris and Linopteris obliqua zones explains why Brown and Dawson disagreed about the upper boundary of the Millstone Grit. Dawson's classification applies to the western side of the basin while Brown's coincides with the eastern half. Even the term "Millstone Grit" of Brown (1871) and Robb (1875) and Fletcher is not strictly a lithostratigraphic unit as used locally, because north of False Bay the "Millstone Grit" is lithologically similar to adjacent strata. Because the Tracy coal seam was the lowest productive coal seam, all strata below it were grouped together as the Millstone Grit even if the lithology differed locally from the type area in northern England.

Hayes et al. (1938) estimated the greatest thickness of the Lonchopteris zone to be 911 m (3000 ft.), but the base is not exposed in the study area. 48 m (158 ft.) of strata were measured from this zone north of False Bay and 148 m (487 ft.) south of it, with about 100 m (329 ft.) concealed between.

Robb (1875) and Fletcher and Hayes and Bell (1923) gave the thickness of the L. obliqua zone as 699 m (2300 ft.) in the study area. Sections measured along Cape Morien are in general agreement with their measurements. The Cape Percé section repeats the top 240 m (814 ft.) of the zone. South of Cape Percé the cliff section is parallel to the fold axis, producing a strike section. Therefore, no part of the section exposed north of the axis is repeated.

2.5 STRUCTURE OF THE SYDNEY BASIN

2.5.1 General Structure

Hayes, Bell and Goranson (1938) and Bell and Goranson (1938 a,b,c) mapped the structure of the land portion of the Sydney Basin as a series of simple folds, with major faults along the south and west borders of the basin. The fold axes trend northeast in the western part of the basin (e.g. Boulardarie Syncline and Boisdale Anticline), and swing progressively towards the east in the southeast part of the basin (Cape Percé Anticline and Port Morien Syncline). The latter two folds are notably asymmetric, with their northern limbs dipping over 45 degrees, whereas their southern limbs dip between 5 and 10 degrees.

Only minor thrust faulting has been documented within the basin (Haite, 1951). The trend of most of these faults is NW-SE with thrusting toward the south, approximately perpendicular to the trend of the major fold axes. Although several of the faults show only a few metres or less displacement Haite believed the throw increased with depth. Hacquebard (1983) extended a minor thrust from Glace Bay into Morien Bay to account for an apparent displacement of 850 ft. (253 m) in that area (Section 2.5.2, Fig 2-4).

King and McLean (1976) conducted an offshore seismic survey and extended the boundary of the basin almost to Newfoundland. They described the structural style of the basin as 'saucer shaped, and except for local folding all

beds dip towards the center'. Except for the projected size of the basin, their structural interpretation is similar to one reached by Gray and Gray (1941).

Folding in the land portion of the basin is a minor overall feature which dies out within a short distance offshore. Some of the folds are known to have a basement core, such as the Boisdale Anticline (over the pre-Carboniferous Boisdale Hills), and the Bridgeport Anticline (over the Coxheath Hills). Haites (1951) suggested that coal seams are generally thicker in synclinal areas than over anticlines, implying that folding was initiated during deposition. Hacquebard (1983) supported this idea, but coal seam thickness data (Figure 5-7 of Hacquebard, 1983) show more of an eastward thickening than evidence of structural control by folding. He attributed the folding and minor faulting to "variable subsidence due to sediment load enhanced by differential compaction of the coal measure strata". Gray and Gray (1941) believed the folding was produced by a compressive force, probably from the northwest. The asymmetric folds, southeast thrusting and rotation of the fold axes parallel to the resistant basement are cited to support their view.

2.5.2 Structure of the Morien Bay area

Air photos of the Cape Morien peninsula (South Head) show a marked deflection in the strike of strata on either side of the cape. This indicates the presence of an easterly plunging syncline with its axis approximately along the line of the headland (Figure 2-3). This necessitates the presence of an anticline in Morien Bay between Cape Morien and the Morien syncline of Hayes et al. (1938). It is proposed that the newly recognized syncline be called the South Head syncline, and the inferred anticline the South Head anticline.

The structure of the offshore portion of the study area is poorly understood. Offshore seismic surveys were conducted off Cape Percé (Golder Assoc., 1980) and in the Morien Bay area (Howells, 1977). The latter survey was made during poor weather conditions. The author reports that "high winds, rough seas and subsequently high survey boat speeds degraded the records sufficiently that, for the most part, only prominent reflectors could be seen". Although neither of the two newly reported folds (the South Head syncline and anticline) were detected, the Morien syncline was traced offshore for 7 km. Near the entrance to Morien Bay north of Cape Morien, the axis of the Morien syncline "...takes an abrupt swing to an approximately E-W trend for at least 3 km offshore." Howells (1977) speculated that the axis shift "suggests the possibility of a zone of structural disturbance", possibly a N-S fracture zone.



Air-photo showing deflection of strike around
Cape Morien. North is at top.

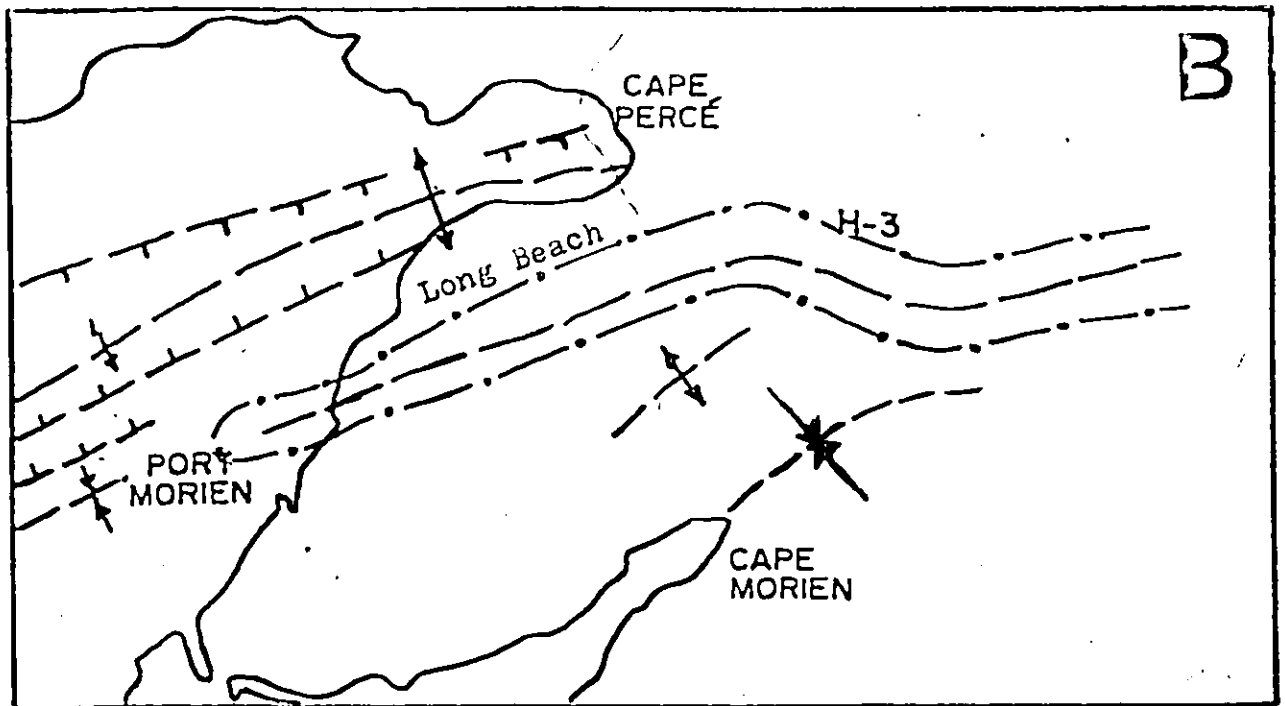
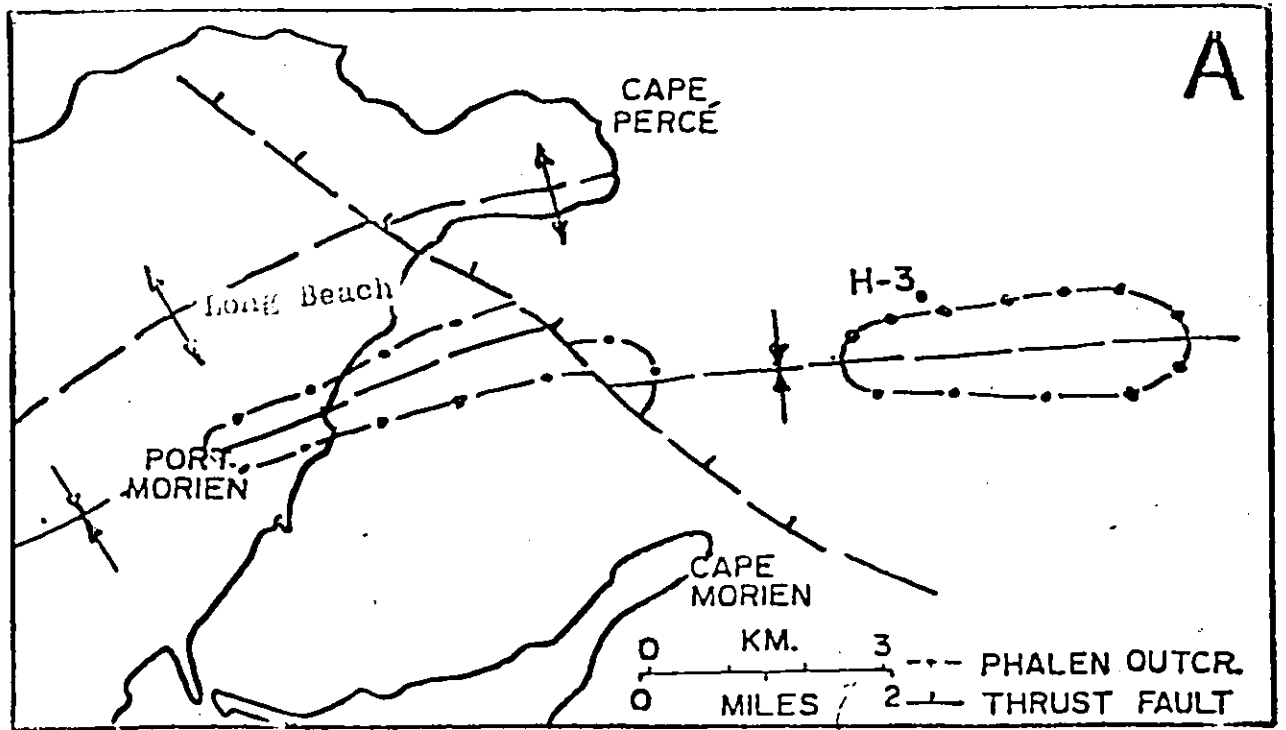


Figure 2-4. Structure of the Morien Bay area interpreted by Hacquebard (1983) (2-4A) and by the present author (2-4B).

Subsequently, Borehole H-3, drilled in Morien Bay (Hacquebard, 1983), showed an unexpected stratigraphic sequence. The Phalen coal seam was predicted at a depth of 451 m (1480 ft.) but a seam interpreted as the Phalen on the basis of palynology was encountered at a depth of 198 m (650 ft.). Hacquebard (1983) believed that the 253 m discrepancy could be accounted for by a thrust fault. Haites (1951) reported a small thrust with a few metres vertical displacement at Glace Bay. Hacquebard extended this fault to meet a small thrust north of Long Beach, and then out into Morien Bay to connect with the "disturbed zone" north of Cape Morien (see Figure 2-4-A).

A reassessment of the structure is necessary in light of new and previously ignored old evidence. Two seismic surveys made on land between Glace Bay and Port Morien show thrust faults on Cape Percé, but they trend NNE, not ESE (Golder Assoc., 1980; N.S.D.M.E., 1968). The more recent survey is supported by borehole and outcrop data, and indicates that the 253 m vertical displacement of the Phalen seam cannot be explained in terms of a thrust from Glace Bay to Morien Bay. In the cliff section north of Long Beach Hacquebard (1983) noted a fault (Figure 2-4A). Although the throw of the fault was not reported in that report, the present author found it to be 2.5 m. This is the same order of magnitude as the small thrust faults reported by Haites (1951) and not nearly large enough to account for the borehole data. The

trend of the reported thrust faults is subparallel to the trend of the oversteepened limb of the Cape Percé anticline, and the two features may be related.

The "disturbed zone" discussed by Hacquebard (1983) was recorded by the seismic survey of Howells (1977) as an "abrupt swing" in the trend of the Morien syncline axis. This zone must be considered in relation to the newly recognized South Head Syncline, and its assumed anticline complement. On this basis, the 253 m vertical discrepancy in the position of the Phalen Seam can be accounted for. Howells (1977) estimated the dips of both limbs of the Morien Syncline to be about 9 degrees in Morien Bay. Using this estimate, a southward shift of the syncline axis of about 1.6 km (1 mile) would account for the discrepancy, and seems a more likely explanation for the vertical discrepancy in Borehole H-3. (Figure 2-4B). The calculation is as follows:

Dip of syncline limbs: 9°

Discrepancy in borehole data: 253 m

Horizontal shift in axis to account for borehole data: X

$$\text{SIN } 9^{\circ} = 253 \text{ m}/X \text{ or } X = 253 \text{ m}/\text{SIN } 9^{\circ}$$

$$\text{SIN } 9^{\circ} = .156, \text{ so } X = 253/.156 = 1.6 \text{ km} \quad \&$$

2.5.3 Minor Faults in the Study Area

None of the measured sections in the study area was significantly displaced, but several minor faults were noted in addition to the ones near Cape Percé.

On Cape Morien a fault with a vertical displacement of a few metres was mapped by Hayes et al. (1938). Although it is clearly visible in the cliff section, no suitable access was afforded for detailed measurement. Just below Wadden Cove slickenslides were found at the base of a channel sandstone, indicating minor movement relative to the underlying mudstone. South of False Bay a minor fault was noted below the Shoemaker seam. Although the exposure is poor it appears that the northern side of the fault moved down relative to the southern side.

Chapter III

PETROGRAPHY

INTRODUCTION

Work on the fieldwork was carried out with four main objectives:

1. To describe the lithotypes in detail. The conglomerate classification of Pettijohn (1975) and sandstone classification of Dott (1964) and mudrock classification of Potter et al. (1980, p. 15) were used.
2. To determine as much as possible about the source area of the constituents
3. To describe briefly the major diagenetic features of the rocks, and
4. To show the relationship between the lithotypes and the lithofacies of Miall (1978). This will be carried out in Chapter 4.

3.2 METHODS

Petrographic study included both field and lab examination of the basin lithologies. Field observation emphasized characteristics not readily apparent in hand samples or thin sections (i.e. uniformity of color in outcrop; extent and nature of weathering). In the lab over 150 hand samples were described. Thirty sandstone hand samples were cut and treated with sodium cobaltnitrate and rhodizonate to stain potassium feldspar and plagioclase. A total of 65 thin sections (15 stained) were made of typical specimens from each lithotype. Samples were collected from outcrops and from DEVCO core A-45. The mineralogy of the fine-grained rocks and mudstones was determined using X-ray diffraction analysis (section 3.6).

3.3 PREVIOUS WORK

No previous work of any detail on the petrography of the study area is known to the author. Bell and Goranson (1938 a,b,c) describe the rocks of the Lonchopteris zone as "arkosic grit". This presumably connotes a coarse, angular sandstone with abundant feldspar (Pettijohn et al., 1973, pp. 162,166), but the amount of feldspar was not specified. More detail is given about the rocks of this zone in the western part of the basin, where the "... basal conglomerates of the Morien Series carry abundant fragments of feldspar derived from the igneous rocks of the Saint Anne

Complex." (Hayes et al., 1938). These "basal conglomerates" are a local feature (Rust et al., 1982), and the source of feldspar in rocks of Lonchopteris age from the eastern part of the basin is not as easily traced.

The most detailed study to date (known to the author) on Sydney Basin petrography is by Rust and Masson (1981). Ten lithotypes were proposed:

1. Conglomerate to very coarse lithic and sublithic sandstone
2. Coarse to medium lithic and sublithic sandstone
3. Medium to fine sublithic sandstone
4. Fine to very fine sublithic sandstone
5. Sandstone to siltstone interlaminated with mudstone or shale
6. Silty shale and/or mudstone
7. Purple-green shale and/or mudstone
8. Various calcareous and limestone beds
9. Nodules
10. Coal

The authors briefly described the first seven lithotypes. Subsequently, algal-laminated limestones (part of type 8) were also described (Masson and Rust, 1983).

3.4 LITHOTYPE CONSTITUENTS AND CLASSIFICATION

The two criteria used to classify the wide variety of clastic rocks from the study area are grain size and composition. Grain size varies from under 2 microns for the claystones and clayshales to 15 cm for a quartz clast, and over 5 m for some carbonized tree trunks, a range of 10^4 . Composition of the constituent clasts also shows great diversity. Fragments of igneous and metamorphic rocks are common, as are extrabasinal and intrabasinal sedimentary rock fragments. Almost all of the constituents are present throughout the stratigraphic sequence, but there are significant changes in their relative proportions for each lithotype.

Table 3-1 summarizes the major constituents. Several points of explanation accompany the table: When polycrystalline quartz (Qpx1) grains are stretched they are grouped as metamorphic rock fragments (MRF's). Otherwise they are grouped together with chert and monocrystalline quartz (Qm). The following types of extinction were noted for quartz under crossed polarized light: single grain straight, slightly undulose and undulose; composite grain straight to undulose. Feldspars were distinguished in hand samples by staining (section 3.2), and in thin section by their twinning, cleavage, and alteration (It is anticipated that the amount of feldspar estimated in unstained thin

sections is slightly low because of the difficulty in recognizing untwinned, unaltered grains). Granitic rock fragments were differentiated from arkosic sandstone fragments by the nature of the intergrain contacts. Slate was distinguished from phyllite and shale at the outcrop and in hand samples. Some sedimentary rock fragments could not be distinguished as either intrabasinal or extrabasinal, but most were readily identified on the basis of composition and color. Finally, plant fragments are considered to be rock fragments, following the definition of 'rock' by Bates and Jackson, (1980, p. 542). They are grouped as sedimentary and intrabasinal.

The wide variety and changing proportions of the primary constituents have produced a correspondingly wide range of lithotypes. The coarse-clastic classification selected to distinguish and define these types should best reflect the properties of the rocks under study, and should be widely accepted. Of the more than 50 'triangle' sandstone classifications that have come into use since 1948 (Okada, 1971), the one proposed by Dott (1964) is used here because it meets these two criteria. It is especially useful because, unlike most other classifications, it takes into account the mud-size matrix in the sandstones. The appearance of this system in several widely used texts (Pettijohn, 1975, p. 211; Pettijohn, Potter, and Siever, 1973, p. 158; Greensmith, 1979, p. 67; and Scholle, 1979, p. 96) attests to its general acceptance.

Table 3-1

Major Sandstone Constituents

- (1) Major detrital mineral constituents
- (a) Quartz - monocrystalline, polycrystalline and quartzite²
 - (b) Feldspar²- Kspar >> Plagioclase; Microcline > Orthoclase
 - (c) Opaques - less than 1 % of any sample
 - (d) Muscovite
- (2) Precipitated minerals
- (a) Silica²
 - (b) Calcite
 - (c) Hematite
 - (d) Siderite²
 - (e) Pyrite
- (3) Igneous (plutonic) rock fragments²
- (a) Granitoid (Feldspar and Quartz) clasts
 - (b) Granophyric Granite (showing intergrowth of Qtz and Kspar)
- (4) Metamorphic rock fragments²
- (a) Phyllite, Slate (with abundant Chlorite?)
 - (b) Stretched polycrystalline quartz

² Indicates that an example of the constituent is shown in Figure 3-2,3.

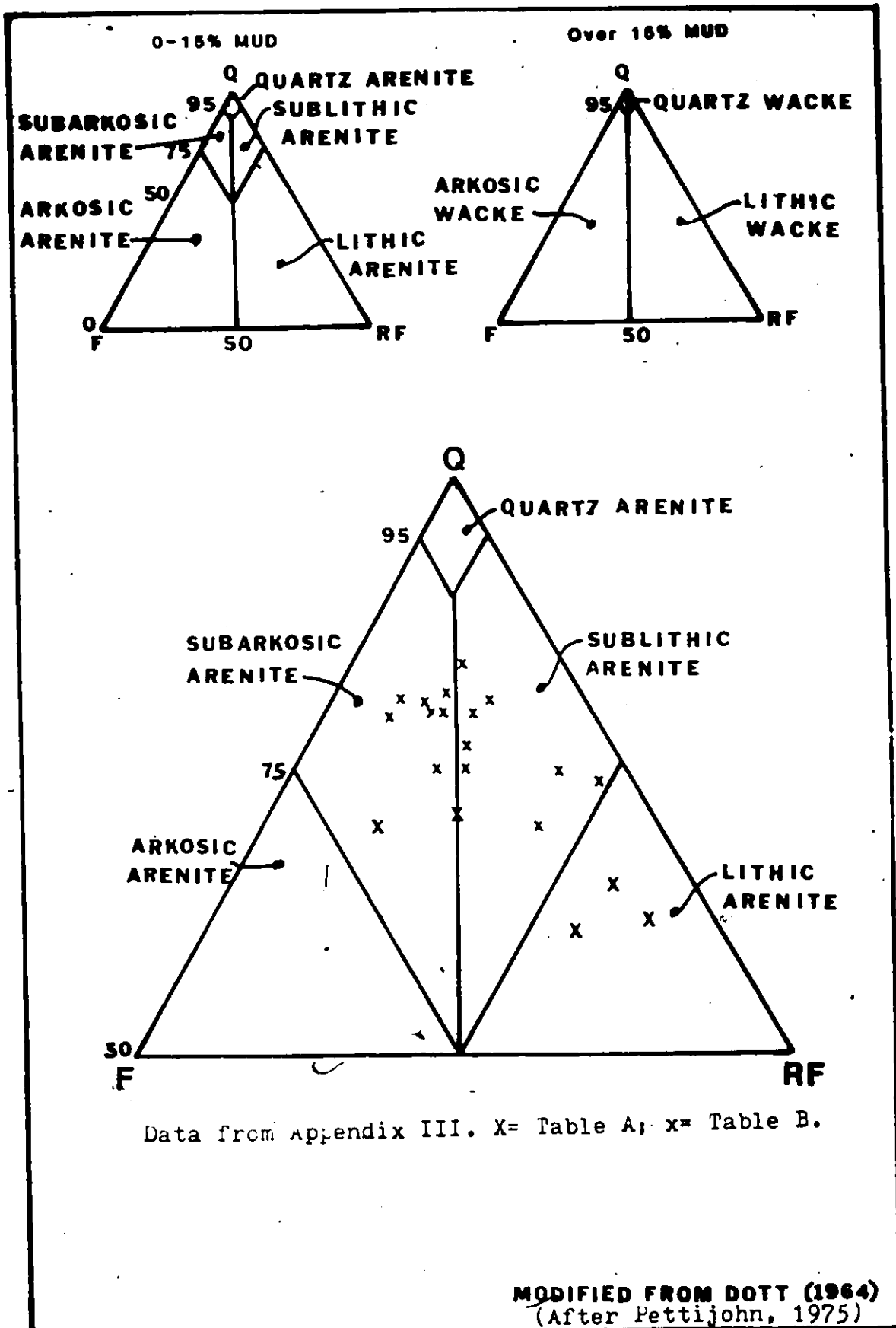
Table 3-1 cont.

- (c) Schistose rock fragments
- (5) Extrabasinal sedimentary rock fragments
 - (a) Mudrocks - shale, mudstone etc.
 - (b) Siltstone to medium grained sandstone (commonly red).
 - (c) Chert
- (6) Intrabasinal sedimentary rock fragments
 - (a) Mudstone - Claystone: black, grey, green, some red: (forms matrix)
 - (b) Siltstone to Fine-grained sandstone
 - (c) Siderite nodules?
 - (d) Plant Fragments - ranging in size from microscopic spores to carbonized trees several metres long.
- (7) Other
 - (a) Minerals produced by weathering of primary constituents: limonite (from hematite, siderite), various products of pyrite oxidation.

The only modification to Dott's (1964) classification deals with feldspar content. In the original system only separate grains of feldspar were grouped under the "F" pole of the triangle. Because of the intimate association between feldspar grains and granitic rock fragments in sandstones from the study area, the feldspar-rich rocks are grouped under the "F" pole. There is precedent for this in the classification systems of Folk (1974, p. 129) and others.

Figure 3-1 shows the range of constituents in the major coarse clastic rocks present in the study area. The major types are: Subarkosic Arenite and Wacke, Sublithic Arenite and Wacke, and Lithic Arenite and Wacke. The general characteristics of these types will be described below. Mudrocks will be described in section 3.6.

Figure 3-1



Composition of sandstones from the study area. Lower triangle is an enlargement of the top half of triangle at top left.

3.5 SANDSTONE LITHOTYPES

3.5.1 Subarkosic Arenite and Wacke*

To be classified as a subarkose under Dott's (1964) system a sandstone must have between 5 % and 25 % feldspar and more feldspar than rock fragments. If there is less than 15 % mud matrix the subarkose is considered an arenite, but if matrix content exceeds 15 % the rock is grouped as a wacke.

There are no grain size considerations (other than to define "matrix" as mud-sized) in the system. As there are significant petrographic differences between rocks within the same class, the subarkosic group has been subdivided as follows:

1. Conglomeratic subarkose
2. Coarse-grained to granule-bearing subarkose
3. Medium-grained to coarse-grained subarkose
4. Fine-grained to medium-grained subarkose, and
5. Very fine-grained to fine-grained subarkose

Each of these conceivably could be either arenites or wackes, but in the field the first three occur only as arenites.

3.5.1.1 Conglomeratic subarkosic arenites

A continuum exists from grain-supported conglomerates through matrix-supported pebble and granule-bearing sandstones to coarse-grained sandstones. Commonly a

*Dott(1964) used the terms feldspathic and subfeldspathic; Pettijohn(1975) used arkosic and subarkosic

conglomeratic unit will fine upward into the other units. The subarkosic conglomerates from the study area are epiclastic (consisting of material derived from the weathering and transportation of older rocks), polymictic orthoconglomerates (grain-supported and composed of more than one rock type) (Pettijohn, 1975). A small percentage are oligomictic.

The conglomeratic units are generally 15-40 cm thick, but rare beds up to 1.5 m thick are present. The units are commonly lenticular, and occur at the base of channel sandstones and some splay deposits. Pebble-bearing sandstones may also occur at the base of trough cross-bed sets. There are, therefore, three scales of lateral continuity for the units: 5-50 cm for bedform lags, 3-40 m for splay and isolated channel lags, and greater than 100 m for lags of large laterally-migrating channels.

The subarkosic conglomerates are tan to brown when weathered and grey to slightly greenish-grey when fresh. Pink potassium feldspar grains, and dark grey and greenish-grey mudstone intraclasts may locally modify the color. In outcrop this is one of the more resistant units, except where organic matter is concentrated along bedding planes.

Internal bedding planes are usually poorly developed or absent, but upward fining is common. There are two scales of grading: 1-10 cm, and greater than 10 cm. The first case

suggests episodic influx of coarse material, or deposition at the base of migrating bedforms. In the second case the entire unit is graded, indicating a gradual decrease of flow velocity.

Bioturbation is rare in this lithotype. Transported plant fragments are common and locally abundant. Coalified branches and tree trunks up to three metres long are not uncommon. Flute casts, intraclasts, and the striking absence of preserved non-woody plant tissue attest to a turbulent transportation history. The tree trunks are aligned at all angles to the paleocurrent direction indicated by trough cross-bedding: from parallel to perpendicular, and randomly. When present, the greatest concentration of fossil woody material is generally in the lowest 1/3 of the conglomeratic units. In some lags this material may be abundant enough to form coaly stringers or lenses.

The grain size distribution for the subarkosic conglomerates and pebble-bearing sandstones is summarized below (see Appendix III).

| GRAIN SIZE | CONGLOMERATES | | PEBBLE-BEARING SANDSTONES | |
|------------|---------------|------|---------------------------|------|
| | RANGE | MEAN | RANGE | MEAN |

cont. on next page

¹ When the % of wood fragments exceeds about 10%, the lithotype technically changes from subarkosic to sublithic

| | | | | |
|---------------|--------|-----|--------|-----|
| Pebble | 20-30% | 25% | 5-15% | 10% |
| Granule | 25-80% | 55% | to 75% | 30% |
| Coarse Sand | 0-25% | 15% | to 65% | 40% |
| Med. Sand-Mud | 0-20% | 5% | to 40% | 20% |

the grain size distribution

Sorting is generally extremely poor to poor, and may be bimodal. For the conglomerates the granule and pebble fraction may reach 80-90 %, with medium to coarse sand filling in the rest. For the pebble-bearing sandstones, the medium to coarse sand size fraction may reach over 80 %, with pebbles (usually all of about the same size) comprising the remainder. In the first case sand may have filtered in after deposition of the coarser grains.

The typical composition of this group is listed below (see Appendix III for details).

| | CONGLOMERATE | | PEBBLE-BEARING SANDSTONE | |
|------------------------|--------------|------|--------------------------|------|
| | RANGE | MEAN | RANGE | MEAN |
| Polycrystalline Quartz | 2-10% | 4% | 2-12% | 5% |
| Monocrystalline Quartz | 52-70% | 62% | 55-75% | 65% |
| Feldspar | 6-18% | 13% | 10-15% | 12% |
| S.R.F.'s | 3-10% | 5% | 0-5% | 4% |

| | | | | |
|------------------|-------|----|-------|----|
| M.R.F.'s | 5-10% | 5% | 0-3% | 1% |
| Organic Matter . | 0-8% | 2% | 0-3% | 1% |
| Mud-Sized Matrix | 0-10% | 8% | 4-10% | 8% |
| Pore Space | 0-5% | 2% | 0-2% | 1% |

Potassium feldspar is about 10 times more abundant than plagioclase, and microcline is more common than orthoclase. The ratio of monocrystalline quartz (Qm) to polycrystalline quartz (Qpxl) is 5:1 to 18:1.

Many sedimentary rock fragments occur as rounded mudstone clasts, and are commonly compacted. When the clasts are squashed beyond recognition they are grouped as mud matrix. In most of the conglomeratic units the mudstone clasts are grey or greenish-grey; red mudstone clasts are rare.

Most monocrystalline quartz grains are angular to subrounded. Quartz grains above granule size and Qpxl grains tend to be slightly more rounded (subangular to rounded). Potassium feldspar grains are usually more angular than quartz grains (very angular to subangular). This may be due in part to their cleavage, frequent **subhedral** crystal form, and possibly, proximal source. Intrabasinal rock fragments are generally rounded. This is probably because most were unlithified at the time of transportation and deposition (i.e. mudstone intraclasts, organic matter). Extrabasinal rock fragments are commonly subangular to subrounded.

Grain shape varies with composition. Most mudstone intraclasts are disk-shaped. Quartz is commonly rod shaped (probably elongated close to the 'c' crystal axis), but equant grains are common. Euhedral and subhedral feldspar grains are present within igneous rock fragments, and solitary subhedral feldspar grains are also present. Most of the large rock fragments (greater than 1 cm) are rod-shaped.

Pebble-bearing sandstones frequently contain feldspathic clasts of granule or pebble size, without which they would be grouped as sublithic. The classification of some conglomerates also commonly depends on the presence of a few granitoid clasts or large feldspar grains. However, this group is significant because it indicates a definite and persistent influx of igneous plutonic source material that can be easily mapped. Since this lithotype is mostly found within the Lonchopteris zone it is understandable why that zone was equated with the 'Arkosic Grit' beds by early workers.

3.5.1.2 Coarse-grained to granule-bearing subarkosic arenite

The coarse-grained to granule-bearing sandstones constitute a minor group transitional between the pebbly sandstones and the coarse to medium-grained sandstones. Their mode of occurrence is similar to that of the previous lithotype: as lag deposits near the base of channel sandstones, splay deposits, and trough cross-beds. Bedding is lenticular, as with the other lags.

Trough cross-bedding is more common than in the conglomeratic units. Planar-tabular cross-bedding, fining-upward graded beds, and flute casts are also present.

When fresh, the color of this lithotype is light grey to grey, with pink potassium feldspar and dark grey quartz grains. The color when weathered is light grey to tan, and locally rust brown due to hematitic staining. The beds are resistant to weathering, but they decompose unevenly when clay and organic matter are selectively removed.

The grain size composition of several typical samples is given below:

| GRAIN SIZE | RANGE | TYPICAL* |
|-------------|--------|----------|
| Pebble | 0-5% | 3% |
| Granule | 15-80% | 45% |
| Coarse Sand | 30-85% | 35% |
| Medium Sand | 0-20% | 10% |
| Fine Sand | 0-10% | 5% |
| Mud | 0-10% | 2% |

* Based on hand sample analysis
and outcrop estimates.

Sorting is commonly poor to very poor. This lithotype was probably deposited under a relatively narrow range of shear

stresses where pebbles were left behind and finer material carried away as suspended load. Genetically, therefore, this lithotype is related to the previous unit as a lag deposit.

Monocrystalline quartz is much more common than Qpxl (2:1 to 8:1). When the ratio approaches 2:1 the Qpxl is usually in the form of "exotic" large granules or small pebbles (3.0-4.5 mm). Most of the granule size clasts in this lithotype are Qm and feldspar. The total quartz content (plus chert) ranges up to 80 %; feldspar to 17 %, and rock fragments to about 10 %. Organic matter is present in amounts up to about 8 %.

3.5.1.3 Medium-grained to coarse-grained subarkosic arenite

This lithotype occurs along with the previous two, and also at the lower part of some tabular sandstone splay deposits. These fine upward into medium-grained to very fine-grained sandstone, and are usually interbedded with mudstone (section 6.3).

The composition of this lithotype is homogeneous, and unlike previous lithotypes the addition of a small amount of non-feldspathic sand would not be likely to change the grouping

Color when fresh is light grey with darker grains giving the rocks a speckled appearance 'the 'salt and pepper' appearance described by Pettijohn et al., 1973, p. 187). When weathered the rocks are tan to brown. The lithotype is

very resistant to weathering. However, organic matter or mica flakes may align along thin bedding planes, and sheets of rock part along such planes. This poses a hazard not only to field geologists but to coal miners. Extensive bolting may be necessary when undercutting such units during mining (Moebis and Ellenberger, 1981).

Ripple cross-lamination is occasionally present, and trough cross-stratification is common. Graded bedding (scale: 1-10 cm) is abundant, and flute casts may be present. Two grain size distributions have been noted: unimodal and bimodal. Examples are listed below (from outcrop and hand sample data).

| | Unimodal | | Bimodal | |
|--------------------|------------|--------|---------|------|
| | RANGE | MODE | RANGE | MODE |
| | Grain size | | | |
| Granule and Pebble | 0-5% | 2% | 1-10% | 8% |
| Coarse Sand | 25-80% | 30-65% | 5-25% | 10% |
| Medium Sand | 20-70% | 35-60% | 20-70% | 55% |
| Fine Sand, Mud | 0-15% | 10% | 10-30% | 20% |

For the bimodal samples, conspicuous granules and pebbles are supported in a sand-sized matrix. These samples are similar to the pebble-bearing sandstones, but have fewer,

smaller pebbles and finer matrix. Sorting is very poor to poor. The unimodal samples are poorly to moderately well sorted.

Compositionally, the medium to coarse subarkose contains 60-80 % quartz, up to 15 % feldspar, and up to 12 % rock fragments. Qm is more abundant than Qpxl (4:1 - 15:1). Granule size fragments of Qpxl may lower the ratio. About 85 % of the feldspar occurs as solitary grains, compared to about 70 % for the coarser lithotypes. The most common rock fragments are mudstone intraclasts (almost always grey or greenish-grey), granitoid fragments of quartz and feldspar, stretched Qpxl, woody plant fragments, and rare siderite nodules.

The subarkosic sandstones described previously are all arenites, but in this lithotype the mud content occasionally exceeds 15 %. The clay may be either primary or due to the diagenetic dispersion of mudstone fragments. In these cases the subarkoses are considered wackes.

3.5.1.4 Fine-grained to medium-grained subarkosic arenites and wackes

This lithotype is volumetrically the most abundant unit below the Tracy seam. It comprises about half of the section south of False Bay, and about 1/3 north of False Bay to the Tracy. The lithotype is present in almost every sandstone body in that area, with the exception of lag deposits and finer units. The various depositional settings will be discussed in Chapter 6.

Grain size and composition are summarized below, based on data in Appendix III and outcrop estimates.

| GRAIN SIZE | RANGE | MEAN | COMPOSITION | RANGE |
|-------------|--------|------|-------------|--------|
| Coarse Sand | 0-10% | 4% | Q | 55-80% |
| Medium Sand | 25-70% | 55% | F | 8-15% |
| Fine Sand | 15-75% | 35% | R, F. | 0-8% |
| Mud | 0-17% | 6% | MATRIX | 0-15% |

The rocks are poorly to well sorted, depending on the amount of matrix present. Organic matter and/or mica plates may be present along bedding or lamination planes.

A wide variety of sedimentary structures is present. They include trough and planar cross-bedding, cross-lamination, ripple marks, primary current lineation, graded bedding, and flute casts. Bioturbation is common, and includes both root penetration and burrowing.

Color in outcrop is grey when fresh, and tan to brown when weathered. Locally the beds may be stained to a rust brown by hematite. In addition to parting along carbonaceous and micaceous bedding planes, the rocks may also part along current lineated surfaces. The rocks are very resistant to weathering and commonly the beds are underlain by recessive mudrocks. These factors compound the chance of rockfalls in cliff sections.

3.5.1.5 Very fine-grained subarkosic arenite and wackes

This lithotype is commonly found at the top of channel sandstone bodies, interbedded with siltstone and mudstone. Various types of lamination and cross-lamination are the most common sedimentary structures. Bioturbation by roots and rootlets is common. Where seatearths are present they are usually composed of this lithotype.

The general composition of these rocks is: quartz up to 80 %, feldspar to 17 % (as solitary grains only), rock fragments up to 5 % and organic matter up to 40%. The most common fragments are small intrabasinal mudstone clasts and plant fragments. Fossils may be abundant and well preserved. In a few cases wood was petrified by calcite and siderite. The clay matrix may reach 20 % as this lithotype grades into siltstone. Consequently, wackes are more common than in the coarser lithotypes. In other aspects this unit resembles the fine-grained to medium-grained subarkose.

3.5.2 Lithic and Sublithic Sandstones

These two groups are very similar and will be discussed together. To avoid repetition, only differences between these lithotypes and the corresponding subarkosic types will be discussed. Unless noted, all characteristics are the same as for the analogous subarkoses.

* When the organic content exceeds about 8 % the rocks become sublithic.

To be grouped as sublithic a sandstone must have between 5 % and 25 % lithic fragments, and more lithic fragments than feldspar. If the amount of rock fragments exceeds 25 % and they are more abundant than feldspar, the rock is considered a lithic sandstone (Dott, 1964).

Mudstone intraclasts and plant fragments are grouped as rock fragments, and their presence in rock samples acts to shift the classification of the rocks towards the RF pole in Figure 3-1. Rocks that outcrop south of False Bay with feldspar contents up to 15 % are therefore grouped as lithic or sublithic if they contain an abundance of those constituents. (Under Dott's system a rock with up to 49 % feldspar can be classified as lithic if there are more lithic fragments than feldspar).

Lithic and sublithic rocks dominate the section above the Coalbrook seam, and are present between the Coalbrook and Tracy seams. No rocks with more than 10 % feldspar were found above the Coalbrook.

3.5.2.1 Conglomerate and Pebble-bearing coarse lithic and sublithic arenite

These lithologies are characterized by the diversity of their constituents as compared to the subarkoses. The lithic content may reach 85 % in some cases, but is generally between 15-30 %. Red mudstone and siderite nodules become important as intraclasts north of False Bay, and they become more common higher in the section. All of the other

constituents listed in Table 3-1 are also present. About 90% of the conglomeratic beds contain predominantly intrabasinal material either as plant fragments, mudstone clasts, or siderite pebbles. This contrasts sharply with the subarkosic conglomerates, which are in nearly all cases dominated by extrabasinal material.

Several distinct types of conglomerates and pebble-bearing coarse sandstones have been noted:

- (a) Intrabasinal; consisting of mudstone, siderite and coal clasts;
- (b) Intrabasinal oligomictic with only siderite clasts, and
- (c) Extrabasinal, with lithic fragments of extremely diverse origin.

Type (a) suggests local floodplain scour and deposition. Type (b) probably resulted from reworking of type (a), which concentrated the more durable siderite intraclasts. Since plant fragments and mudstone are abundant throughout the study area, lack of source supply is an unlikely explanation for their absence. Furthermore, the siderite conglomerates are almost always present within channel sandstones (not at the base), where reworking would be most probable. Type (c) is the least common but most compositionally diverse. Unlike the lenticular thin beds of all previous conglomerates, this type occurs in beds up to two metres thick that are laterally persistent over at least 500 m without significant thinning. The beds are interpreted as the lags of very large

rivers, which carried material derived from far outside the area of Morien deposition (smaller type a lags probably belong to lesser order rivers that drained only areas underlain by Morien deposits). These rocks are the most permeable in the study area, and hematite staining is locally common.

Polycrystalline quartz becomes increasingly important in the sand-sized fractions of all the sublithic and lithic sandstones above the approximate level of the Tracy seam. Whereas the ratio of Qm to Qpx1 is generally more than 7:1 for the subarkoses, it is almost always below 4:1 for the lithic and sublithic sandstones of the Linopteris obliqua zone. Finally, the percentage of metamorphic rock fragments is greater in rocks from this zone than the percentage of igneous plutonic fragments and associated Qm and feldspar.

3.5.2.2 Granule-bearing coarse-grained to very fine-grained lithic and sublithic sandstones

The coarse-grained to granule-bearing sandstones frequently contain red mudstone clasts, in addition to grey and greenish-grey mudstone clasts. Siderite pebbles are also common, as are plant fragments. Feldspar content for this and the remaining subtypes is 1-5 %. There are local patches of yellow staining from pyrite in carbonaceous material. The increase in the organic content enhances the chances of bed failure if the material is concentrated along bedding planes. The colour of the rocks is generally the same as for

the subarkosic coarse-granule sandstones, but there is a conspicuous lack of pink potassium feldspar grains.

The finer lithic and sublithic sandstones generally have feldspar contents from 1-5%, quartz from 52-80 %, (Qm:Qpxl under 4:1 and commonly 2:1), and rock fragments up to 35 %. Clay matrix may reach 25 %. Mica seems to be more common than in the subarkoses, and frequently reaches 5 %. Rust and Masson (1981) did not group these sets as lithic, because they did not consider plant fragments to be lithic fragments.

In outcrop the beds are occasionally stained red to reddish brown by hematite. The colouration is distinct from the surficial rust-brown staining in permeable units. The hematite occurs as a coating on the grains and as a pore filling cement.

3.6 MINOR SANDSTONE TYPES

In addition to the subarkosic, sublithic and lithic sandstones, very minor amounts of arkosic arenite and quartz arenite and wacke are present. The arkosic arenite occurs where there is a localized concentration of feldspar within the subarkosic sandstone, generally in the conglomeratic beds. The group is considered to be a subclass of the subarkosic lithotype, and not in itself a significant unit (much as the subarkoses rich in plant fragments are grouped separately as lithic sandstones, but are genetically related to the subarkoses).

60

The quartz arenites and wackes are even less common than the arkoses. They occur as very fine-grained to fine-grained sandstone in light grey to grey beds under 1 m thick. The beds may pass laterally into siltstones or mudstones. The upper surfaces of the beds exhibit a characteristic nodular weathering pattern. These are the hardest rocks in the study area, and possibly in the entire basin. They contain 85 % or more quartz (and chert), 5-20 % clay matrix, and 1-2 % organic matter, commonly as spores or rootlets. The cement is siliceous and occurs mainly as overgrowths on quartz grains, and at the points of grain contact. The cement may form 5 % of the sample. The beds are interpreted as leached paleosols and have many of the characteristics of ganisters (Percival, 1983). They will be discussed in greater detail in Section 4.4.7.

3.7 - MUDROCKS

Mudrocks comprise about 10 % of the section south of False Bay and about 42 % of the sections at Cape Morien and Cape Percé. They occur either as independent beds or as fine interlamination with very fine-grained to fine-grained sandstone. Siltstone, claystone, and mudstone, as well as clayshale and mudshale are present. Clay beds are also present, but may be the product of deep weathering of claystone or clayshale units.

The easiest way to divide the beds in the field is by colour. Three general groups have been recognized: light grey to black, greenish-grey to green, and reddish-brown to bright red. The greyish green mudstones are uncommon, while the other groups are abundant. Red beds generally contain little or no plant material, while the grey to black units are commonly carbonaceous and even grade into coal.

Samples of 60 beds from throughout the study area were analyzed using X-Ray diffraction to determine mineral composition. A Phillips diffractometer using Cu radiation was run from a two theta angle of 3 degrees to 65 degrees (Wainerdi and Uken, 1971). Other exotic lithic samples were also analyzed with this method. The peaks were interpreted by comparison with published peak height data (Chao, 1969). Dr. Chao (personal comm., 1982) aided in the interpretation of some questionable mineral peaks.

The results for 16 grey to black samples and 7 red samples are listed in Table 3-2. The grey and black mudstones consist of quartz, kaolinite, and illite. Quartz is ubiquitous in all of the mudstones and sandstones in the study area. The peak heights of kaolinite and illite were generally about the same, suggesting that the two clays occur in about the same proportion. In a few samples microcline occurs in minor or trace amounts, possibly as silt-size grains. Trace amounts of hematite and pyrite, and minor amounts of siderite and calcite were noted in a few

X-ray Determination of Mudrock Mineralogy
for Gray and Black Mudrocks
Minerals

| Sample | Kaolinite | Illite | Feld. | Hematite | Chl. | Other |
|--------------|-----------|--------|-------|----------|------|-------------|
| A | X* | X | / | / | T | M(Calcite) |
| B | X | X | M | / | T | /) |
| C | X | X | / | / | / | / |
| D | X | X | / | / | / | / |
| E | X | X | / | / | / | / |
| F | X | X | / | / | / | / |
| G | X | X | T | / | / | M(Siderite) |
| H | X | X | / | / | / | / |
| I | X | X | / | T | / | T(Pyrite) |
| J | X | X | M | / | T | / |
| K | X | X | T | / | X | / |
| L | X | X | T | / | / | / |
| M | X | X | / | / | / | / |
| N | T | M | / | / | / | / |
| O | X | X | T | / | T | / |
| P | X | X | M | T | M | / |
| Red Mudrocks | | | | | | |
| Q | M | M | / | M | / | / |
| R | M | M | / | / | / | M(Ankerite) |
| S | X | X | / | X | / | M(Calcite) |
| T | M | / | / | X | / | / |

| | | | | | | |
|---|---|---|---|---|---|---|
| U | X | X | / | T | / | / |
| V | X | X | / | T | / | / |
| W | X | X | / | / | / | / |

* All samples contain abundant quartz.

* (Al 2 Si 2 O 5 (OH) 4]) * (KAl[2](AlSi[3]O[10](OH)[2])

* (Mg,Fe)[3](Si,Al)[4]O[10](OH)[2](Mg,Fe)[3] (OH)[6]

* The presence of strong primary and secondary diffraction peaks is indicated by an X to signify an abundant mineral. If only the primary peak is strong, an M indicates that only a minor amount of the mineral is present. If the primary peak was almost indistinguishable from the background, a T is used to signify a trace amount of the mineral. The terms are arbitrary and not quantitative. All quartz is alpha type, and the feldspars are not potassium rich.

samples. Chlorite is occasionally present, but in minor or trace amounts. The origin of the clay minerals will be discussed in section 3.9.

The red mudstones are also composed of quartz, kaolinite, and illite. No feldspar, chlorite or siderite were found in the seven analysed samples. It is probable that these minerals are present in the group as a whole, and would be detected if enough samples were collected. The most significant difference between the two mudstone groups in the presence of hematite in most of the red mudstones (5 out of 7). Other samples may contain hematite in amounts below the detection limits of the diffractometre. This observation is in agreement with that of Van Houten (1968), who concluded that although black and red mudstones may contain about the same quantity of iron, the iron in the red mudstones was oxidized to hematite.

3.8 MAJOR DIAGENETIC FEATURES

A thorough investigation of the diagenetic history of the study area is beyond the scope of this study. However, several obvious diagenetic features are noteworthy. These include:

Compaction - of clay minerals, mica, sedimentary mudstone clasts, phyllite, and plant fragments. The soft material is commonly compressed, and the clasts commonly wrap or bend around harder grains. In some cases the mudstone clasts are

so deformed that they become indistinguishable from the clay matrix.

Alteration - most commonly affects feldspar grains. Usually a clay (probably kaolinite) replaces part or all of the grain. All stages are present, and different stages are commonly found in the same thin section. This suggests that at least some alteration took place before deposition. A second type of alteration is of microcline to calcite. This may have occurred under high pH conditions with silica leached from the feldspar lattice (Dapples, 1967). Alteration is probably commonplace among the clay minerals, but no SEM or Electron Microprobe work was carried out to confirm this. Finally, pyrite commonly alters to melanterite, siderite to hematite, and hematite to limonite. Zodrow et al. (1979) have detected other minerals related to pyrite alteration from the Ptychocarpus unitus zone at various locations within the basin.

Authigenesis - of the following minerals was noted: calcite, siderite, ankerite, pyrite, hematite, and silica. All but ankerite were present as pore filling cement. Both micritic and fibrous siderite were present. The latter is probably a recrystallized form of the former. Silica was the only mineral observed to form overgrowths. The primary cementing agents are silica and clay sized material, with minor patches of calcite.

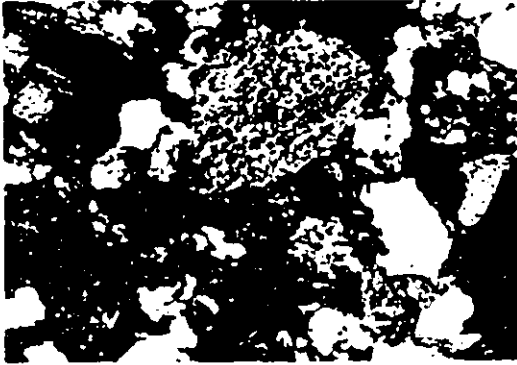
Figure 3-2

Photomicrographs of thin-sections. All photographs for Figure 3-2 and 3-3 were taken using cross-polarized light. Exact stratigraphic positions of the samples in these figures are given in Appendix I.

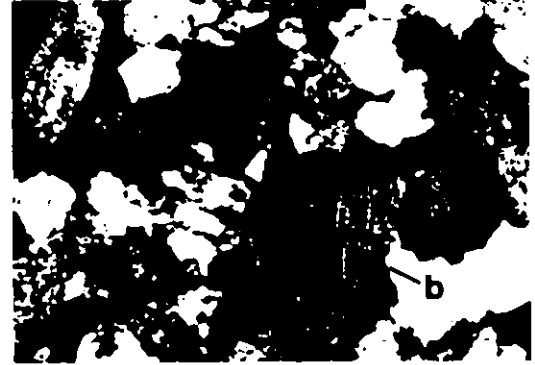
Scale:

- A) Lithic arenite showing well-rounded low rank metamorphic rock fragment (M.R.F.) near top center (a).
- B) Subarkosic arenite with large microcline grain (b). South False Bay section.
- C) Cross-section of a siderite nodule showing fibrous crystals (Cape Percé section).
- D) Interlaminated organic matter (black) and calcite (light coloured) of algal origin. From Core A-45.
- E) Lithic arenite with abundant polycrystalline quartz. From the Cape Morien (east half) section.
- F) Graphic texture: quartz and potassium feldspar intergrowths in a granitoid clast (c), from the South False Bay section.

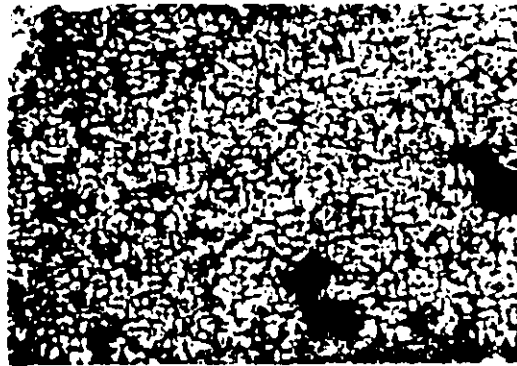
A



B



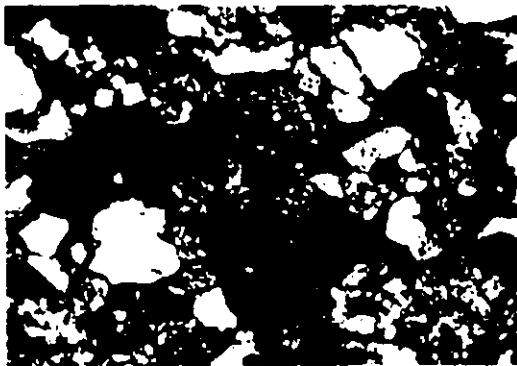
C



D



E



F

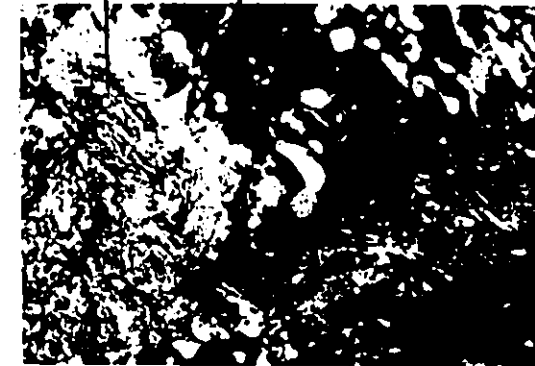




Figure 3-3

Photomicrographs of thin sections, cont.

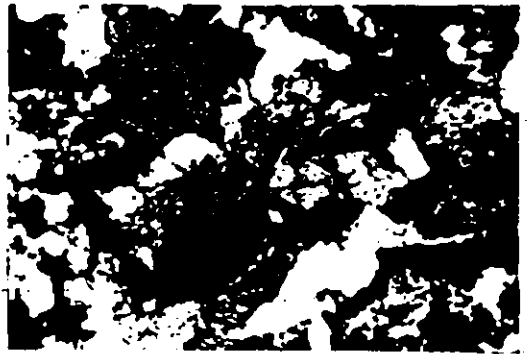
Scale: 

- G) Microcline (d) and large monocrystalline quartz grain in a subarkosic arenite. South False Bay section.
- H) Compaction of  in a lithic arenite. Cape Morien (west half) section.
- I) Siderite crystals (e) replace a rootlet in very fine grained sublithic arenite. Siderite is probably recrystallized after micritic siderite.
- J) Large siderite crystals cementing grains in a sublithic wacke.
- K) Overgrowth on monocrystalline quartz grain (f) showing silica cementation along point, line, and tangential contacts.
- L) Silica cementation; grains show "dirty" boundaries.

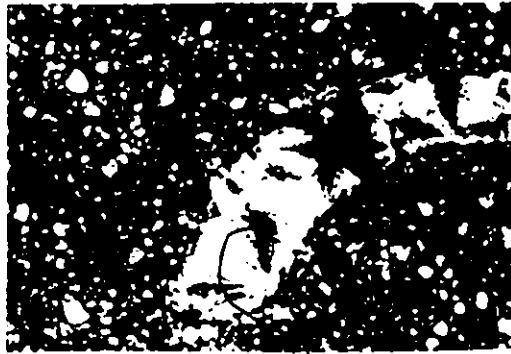
G



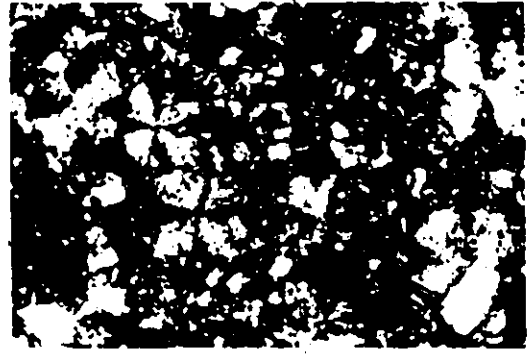
H



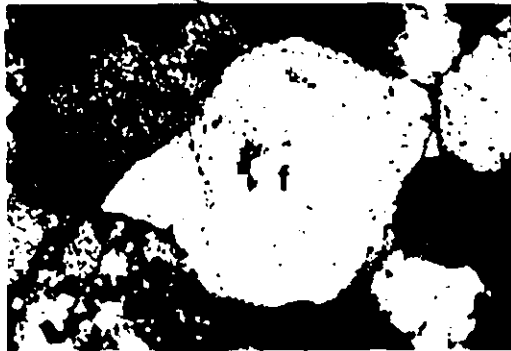
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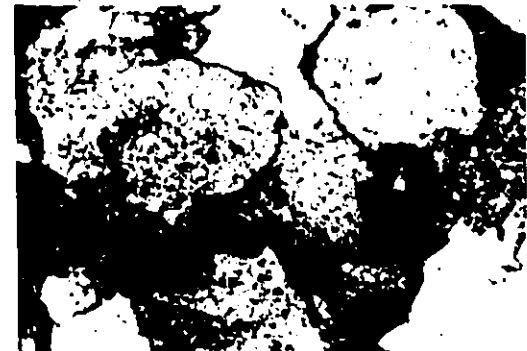
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3.9 SOURCE AREA

Although it is almost impossible to trace individual clasts to their source beds, groups of clasts do provide a general picture of the source areas. Four clast groupings have been recognized within the study area: (a) intrabasinal, characterized by mudstone and siderite intraclasts, and plant fragments; (b) extrabasinal granitoid, with clasts of graphic (syn. granophyric) textured rocks, large subhedral feldspar grains, and an abundance of large monocrystalline quartz; (c) extrabasinal sedimentary, the most common being red sandstone or siltstone and grey fine-grained sandstone; and (d) metamorphic clasts, including quartzite and phyllite with minor gneiss and schist.

In order to relate the three extrabasinal clast types to possible sources, the lithological units older than the Morien Group are listed in Table 3-3 (modified from Hayes et al., 1938):

Table 3-3

Pre-Morien Units

- 11 - Point Edward Formation (Pennsylvanian) - red and grey conglomerate, sandstone and shale, thin beds of fresh water limestone.
- 10 - Windsor Group (Mississippian) - limestone, anhydrite, gypsum, shale, sandstone, conglomerate.
- 9 - Windsor Group, Grantmire Fm. (Mississippian) - conglomerate, sandstone, shale.
- 8 - McAdam Lake Fm, (Devonian) - conglomerate, arkose, shale, tuff.
- 7 - Ordovician and Cambrian conglomerate, grit, sandstone, shale.
- 6 - Precambrian (?) Granite.
- 5 - Precambrian (?) Granodiorite, quartz monzonite.
- 4 - Precambrian (?) Quartz diorite
- 3 - Forchu Group (Precambrian) - pyroclastics; rhyolite, quartz latite, dacite, andesite.
- 2 - George River Group - (Precambrian) - marble and metadolomite.
- 1 - George River Group - (Precambrian) - quartzite, schist, gneiss, amphibolite.

The extrabasinal granitoid clasts probably came from unit 6, granitoid rocks of probable Precambrian age that outcrop to the south and west of the study area (see fig. 3-2). The extrabasinal sedimentary clasts were probably derived from units 8-11 inclusive. The George River Group (unit 1) is the most likely source for most of the metamorphic fragments. Some quartzite probably was reworked from older metasedimentary units, or (less likely) came from far outside the basin, because even cobbles 15 cm long are extremely well rounded.

The abundance of the four clast groups varies stratigraphically within the study area and possibly laterally across the basin as well. South of False Bay granitoid clasts predominate, and most lithic fragments are therefore feldspar-rich. This influence of a granitoid source decreases rapidly above the Coalbrook seam (including the west side of Cape Morien and the Cape Percé sections). In the same interval the percentages of polycrystalline quartz and metamorphic R.F.'s increase. In the Ptychocarpus unitus sections measured by Masson (Figure 1-2) these constituents were more abundant than sedimentary or igneous extrabasinal rock fragments (Rust and Masson, 1981). The various sedimentary rock fragments and large quartzite clasts predominate in thick lithic conglomerates above the Coalbrook seam. These conglomerates (described as 'type c' lithic conglomerates in section 3.5.2.1) are relatively


rare. The beds probably represent lag deposits from large channels that drained the farthest reaches of the Morien catchment area. Intraclastic fragments are present throughout the study area. They are common in the rocks south of False Bay, but increase in frequency and intraclast diversity higher up in the section.

There is strong evidence that the Bateston Fault is a post-Morien feature. No pyroclastic rock fragments (with associated sanidine, beta quartz, and abundant plagioclase) were found as sandstone constituents. This indicates that the Precambrian Forchu Group (unit 3 of Table 3-3) was not exposed at the time of Morien deposition. Furthermore, paleocurrent data from Bateston indicate drainage parallel to the faultline (Rust et al., 1982). If the fault had existed as a basin-margin feature during Morien deposition, paleocurrents would be expected to trend perpendicular to it. The Forchu volcanics were probably exposed as a result of post-Morien faulting.

No anhydrite, gypsum, or carbonate clasts were found as constituent fragments, which is surprising, because the Windsor Group (unit 10 of Table 3-3) lies unconformably below the Morien Group in many locations (Hayes et al., 1938). It is probable that the Point Edward Formation (unit 11) covered a much larger area than at present. The presence of Riversdale age rocks above the Point Edward Formation in the subsurface even suggests that rocks younger

than the Point Edward Formation, present at the time of Morien deposition, have been subsequently eroded from the area.

This explanation cannot fully account for absence of Windsor Group clasts in the lower Morien because there are places where the Morien directly overlies the Windsor. Environmental factors at the time of weathering, erosion and deposition must have eliminated the chances of survival for these clasts (no "ghost" grains were found, so diagenetic removal of the minerals is unlikely). As discussed later, the depositional environments of the rocks in the study area are ideal for removing evaporites and, to a slightly lesser extent, carbonates. Chapter 4 will outline the lithofacies that constitute the depositional environments in this part of the basin, and Chapter 5 will deal statistically with their patterns of occurrence. Finally, the depositional models will be outlined in Chapter 6.



Chapter IV
LITHOFACIES TYPES

4.1 INTRODUCTION

In this chapter the lithotypes from the study area (Ch. 3) and their sedimentary structures will be integrated with the lithofacies codes of Miall (1978). The vertical sequence of lithofacies will be analyzed to detect repetitive assemblages that can be compared with existing facies models (Ch. 5). These models, in turn, will be compared with other sedimentologic evidence (i.e. lateral and vertical bed relationships, fossil content, paleocurrent data, etc.) to provide a detailed interpretation of the depositional history of the study area. When similar analyses of other parts of the Sydney Basin are completed a unified regional depositional history of the basin may emerge.

4.2 LITHOFACIES: USE AND DEFINITIONS

Miall (1978) compiled a code of ^{fluvial} lithofacies to combine lithologic and sedimentary data in a meaningful way. Each lithofacies is interpreted to be the product of a specific set of depositional conditions. The code system is useful, because interpretations can be made by studying lithofacies relationships (Walker, 1981). However, the system is "...not

"a panacea for sorting out the complexity of fluvial deposits..." (Miall, 1978, p. 599) because the same lithofacies can be found in several depositional environments. All available data must be integrated before sound interpretations can be made.

The following lithofacies are found in the study area. They are listed with the definitions from the original compilation (Miall, 1978):

Table 4-1
Lithofacies from the lower Morien Group in the study area

| Facies code | Lithofacies | Sedimentary structures | Interpretation |
|-------------|---|--|---|
| Gm | massive or crudely bedded gravel | horizontal bedding imbrication | longitudinal bars, lag deposits, sieve deposits |
| Sm | sand, medium to very coarse | massive | channel, splay deposits |
| St | sand, medium to v. coarse, may be pebbly | solitary (theta) or grouped (pi) trough crossbeds | dunes (lower flow regime) |
| Sp | sand, medium to v. coarse, may be pebbly | solitary (alpha) or grouped (omikron) planar crossbeds | linguoid, transverse bars, sand waves (lower flow regime) |
| Sr | sand, very fine to coarse | ripple marks of all types | ripples (lower flow regime) |
| Sh | sand, very fine to very coarse, may be pebbly | horizontal lamination, parting or streaming lineation | planar bed flow (l. and u. flow regime) |
| Sl | sand, fine | low angle ($<10^\circ$) crossbeds | scour fills, crevasse splays, antidunes |
| Sc | Erosional scours with intraclasts | massive | scour fills |
| Fl | sand, silt, mud | fine lamination, very small ripples | overbank or waning flood deposits |
| Fm | mud, silt | massive, desiccation cracks | overbank or drape deposits |
| Fr | silt, mud | rootlets | seatearth |
| C | coal, carbonaceous mud | plants, mud films | swamp deposits |

For the purpose of this study facies Fsc and Fcf have been discarded. Fsc connotes "Fine, silty clay" and Fcf "Fine clay with fresh water foss. s". The present author believes that these codes detract from the code system for the following reasons: 1) The first letter of the code immediately identifies the grain size of the units (F for fine-grained, S for the sand size, etc.). Adding s and c for "silty" and "clay" is both unnecessary and redundant. 2) All of the other facies codes are distinguished by a sedimentary structure (or in the case for Fr a biogenic structure) that helps separate the mode of origin of the facies from all others. Facies Fsc has no such criteria, and 3) Fcf is so rare in the study area that it is not helpful. When fine-grained sediments are carbonaceous they are grouped here with facies C. When they are laminated or massive they are grouped with Fl or Fm. 4) Lastly, the interpretation given for Fcf implies that fine-grained deposits with molluscs are always backswamp pond deposits. There are probably no real criteria to separate the preserved record of "backswamp" deposition and "pond" deposition, and an artificial criterion is misleading.

* Ponds are commonly defined as permanent bodies of water shallow enough for rooted vegetation to grow, even in the deepest part.

4.3 INTEGRATION OF LITHOTYPES, SEDIMENTARY STRUCTURES AND LITHOFACIES

Table 4-2 relates the lithotypes described in Chapter 3 to the lithofacies codes in Table 1. Lithofacies are listed in order of frequency within the lithotypes.

Table 4-2

Relationship between Lithotypes and Lithofacies (of Miall, 1978)

| LITHOTYPE (Ch. 3) | LITHOFACIES |
|--|-------------------------------|
| 1) Pebble-bearing sst. to Conglomerate | Gm, Se, St |
| 2) Coarse-grained to Granule-bearing sst | Se, Sm, St |
| 3) Medium to Coarse sst. | St, Se, Sm, Sh, Sp |
| 4) Fine to Medium sst | St, Sm, Sr, Sh, Se, Sl, Sp |
| 5) Very Fine to Fine sst. | Sr, Fl, Sl |
| 6) Mudstone/Mudshale | Fm, Fr, Fl |
| 7) Siltstone | Fm, Fr, Fl |
| 8) Claystone/Clayshale | Fm, Fr, Fl |
| 9) Vf-Fine grained quartz arenite | Fr |

As mentioned, the lithofacies are characterized by their grain size (G, S, F) and dominant sedimentary structure (e.g. trough cross-bedding) or biogenic structure by fossil content (for Fr). However, in the field mappable units commonly show more than one structure. A 5 m thick trough cross-stratified sandstone unit (St) may, for example, show minor but significant amounts of ripple cross-lamination (Sr) or erosional scour surfaces (Se). When possible these are recorded as separate units. Table 4-3 summarizes the major sedimentary structures and the lithofacies associated with them. To maintain consistency the table is modeled after Table 1 of Rust and Masson (1981) for the Ptychocarpus unitus zone.

Table 4-3

Integration of Lithotypes, Lithofacies, and Sedimentary Structures

Sedimentary Structures Lithotypes
Lithofacies

Stratification -

- | | | |
|------------------------------|-------|--------------------|
| 1) Parallel-Horizontal | 1,4-9 | Gm, St, Sh, Fl, Fr |
| 2) Parallel w/Undulating Top | 5 | Sr, Fl |

| | | |
|-------------------------|-------|-------------------|
| 3) Wedge Shaped Beds | 4-6,9 | Fl |
| 4) Lenticular | 1-9 | All lithofacies |
| 5) Lamination- | | |
| A) Parallel | 4-7 | Fl,C |
| B) Wavy-Continuous | 4-7 | Sr,Fl,C |
| C) Wavy-Discontinuous | 4-7 | Sr,Fl |
| D) Algal Origin | 1' | Fl |
| 6) Massive | 1-9 | Gm,Sm,Fm,Fr |
| 7) Graded-Fining Up | 1-6 | Gm,Se,Sm,St,Sr,Fl |
| 8) Graded-Coarsening Up | 6 | Fl |

Cross-stratification

| | | |
|-----------------------------------|-------|-------------|
| 9) Cross-bedding | | |
| A) Trough | 2,5 | St |
| B) Planar | 3,4 | Sp,Sr |
| C) Low Angle | 4,5 | Sl |
| 10) Cross-Lamination | | |
| A) Asymmetric in cross section | 3-5,7 | Sr,Fl,St,Sh |
| B) Interference | 4,5 | Sr,Fl,Sh |
| C) Flaser | 5,6 | Fl,Sr |

Current marks

| | | |
|------------------|-----|----------|
| 11) Flute Casts | 1,2 | Gm,Se,St |
| 12) Groove Casts | 1,2 | Gm,Se,St |
| 13) Tool Marks | 1-3 | Gm,Se,St |

Current Lamination

14) Primary Current

Lamination 3,4

Sl, Sh, St, Sr

15 Plant Fragment Lamination 2-4

Gm, Se, St

Bioturbation

16) Roots 4-9

All but Gm, Se

17) Burrows 3-7

All but Gm, Se

Other Structure

18) Loading, Convolute

Bedding 4-8

Fl, Fm

19) Load Casts 1-3

Gm, Se, St

20) Mudcracks 6, 7, 9

Fl, Fm, Fr

21) Deep Cracks 4-6, 9

Fm, Fl, Fr

22) Mottling 4-8

Fr, Fl, Fm, Sr

23) Nodules 6-8, 9

Fl, Fm, Fr

Notes: Only present in 3 cm of core, and not described as
a separate lithotype. See Masson and Rust (1983)

4.4 LITHOFACIES DESCRIPTIONS AND INTERPRETATIONS

4.4.1 Lithofacies Gm

This lithofacies is a massive to crudely bedded conglomerate. It makes up less than 2% of the entire section, and is more common south of False Bay than in the other sections. The framework may be supported by pebble sized clasts or by coarse sandstone. Bedding is almost always lenticular, but in rare cases it is parallel and continuous for at least 500 m. The undersides of most beds show evidence of scour into the underlying unit(s), which are commonly mudstone. The lower surface of many beds have an undulatory appearance, with amplitudes of 20-40 cm. This results primarily from scour and fill, but it may also be caused (or enhanced) by penecontemporaneous differential compaction between the coarse units and underlying mudstone. Load casts are common. Flute casts and groove casts are present, but uncommon. Graded bedding (fining upward) is very often present in the upper part of the beds.

Intraclasts are present in almost every unit, and make up a major part of some beds. South of False Bay the most common types of intraclasts are grey and greyish-green mudstone, and woody plant fragments. The latter are often in the form of tree trunks that range up to 5 m in length. The branches and trunks may be mutually aligned, but this orientation is variable with respect to the paleocurrent direction measured in nearby trough cross-bedding.

In the sections measured at Cape Morien and Cape Percé intraclasts of red mudstone and pebble-sized siderite nodules are common, in addition to the other types of mudstone and plant fragments. Maximum grain size (excluding intraclasts) averages about 2 cm, but in different beds clasts 4, 10 and 15 cm are present.

Lithofacies Gm is interpreted as a fluvial lag deposit on the basis of large grain size, generally massive beds, poor sorting, intraclasts of floodplain origin, and ubiquitous association with other channel deposits (Sec 4.4.2, 3).

Three types of lags have been recognized: 1) Predominantly mudstone intraclastic, probably resulting from local floodplain scour and deposition; 2) Reworked intraclastic siderite lags (Figure 4-1), and 3) Predominantly extrabasinal, with large clasts (to 15 cm) of diverse origin (Figure 4-2). These include extremely well rounded cobble-size quartzite.



Figure 4-1 Siderite lag within channel sandstone. Note scoured base at left. Scale: 1 m.



Figure 4-2 Lithofacies Gm (West side of Cape Morien).

In type 3 lag deposits the beds are laterally extensive over at least 500 m. Beds are thicker than for the other types, up to 3.4 m in some cases. The lags are probably deposits of big, deep rivers that drained a large portion of the Morien catchment basin. Noneck Point (Fig 1-1) is composed of one of these lags and its associated 7.5 m thick channel sandstone package.

4.4.2 Lithofacies Se (Fig. 4-3,4)

This facies is composed of medium to coarse pebble-bearing sandstone. It is characterized by erosional scours overlain by intraclasts. Mudstone, plant fragments, or siderite nodules may form layers of debris over the scour, or in other cases only few intraclasts are present. The clasts range in size between 0.5 and 2 cm for siderite pebbles to 10 cm or more for plant fragments and mudstone clasts. The facies is found near the base of most channel deposits, and at the base of some splay channels. When found near the top of channel deposits Se may indicate reactivation.

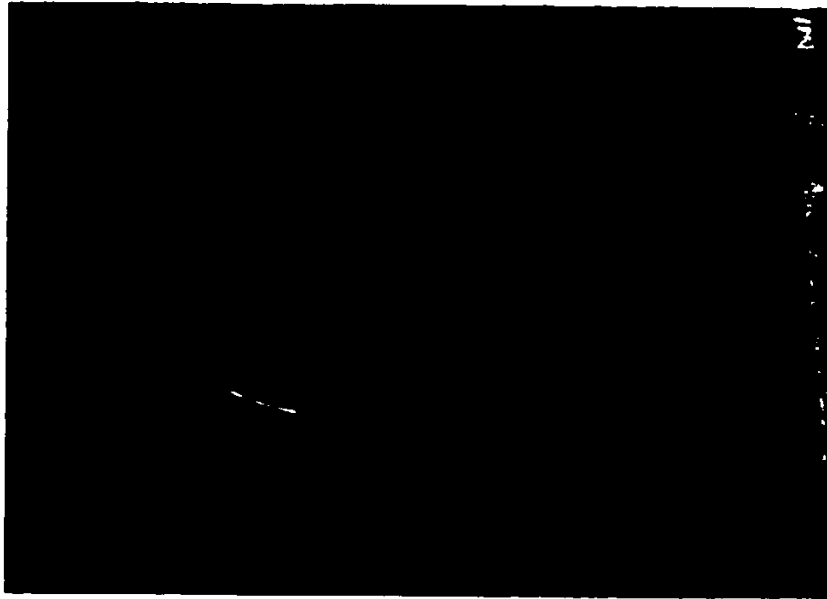


Figure 4-3 Lithofacies Se: greyish -green mudstone intraclasts and limonite coated siderite nodule (to the right of hammer handle).

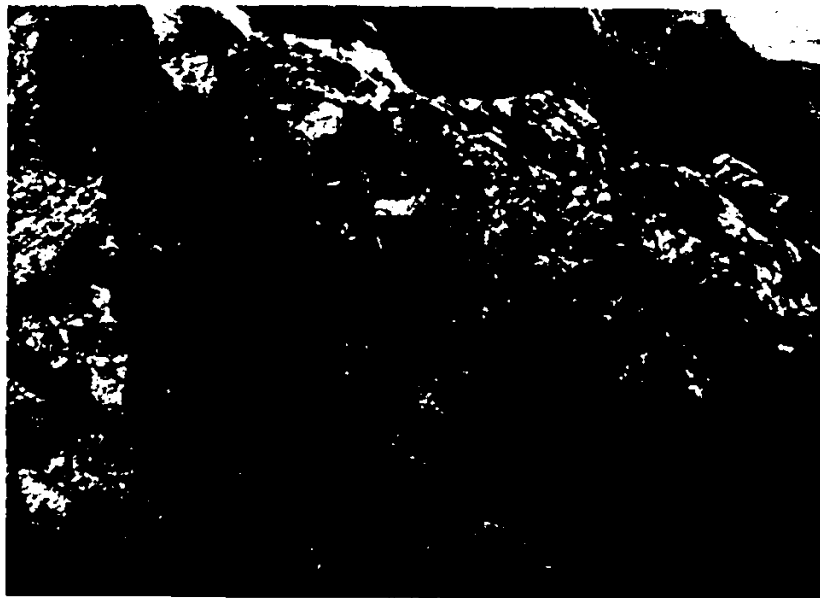


Figure 4-4 Plant fragments as intraclasts. Note variable alignment.

4.4.3 Lithofacies St

This lithofacies is comprised of fine to coarse sandstone but also in granule-bearing and pebble-bearing sandstone. It is characterized by the presence of trough cross-stratification, which forms solitary (or more commonly) grouped sets. Individual troughs range from 6 to 110 cm in thickness (Figure 4-5), but in most cases they are between 10 and 35 cm thick. Width varies from about 20 to 250 cm. Width to depth ratios are usually between 2.5 : 1 and 4 : 1.

This is the most common facies in the section south of False Bay, and is found in almost every thick sandstone body in the other sections as well. The troughs commonly contain coarse material at their bases and fine upward. In some cases pebbles of extrabasinal quartz and intraclasts of mudstone, siderite and plant fragments are concentrated as lags. Most troughs have erosional bases.

Lithofacies St is produced by the migration of sinuous-crested megaripples. It is the major constituent of channel sandstones and is common in levee and splay deposits. The most commonly associated lithofacies are Sh and Sr, which normally follow St (expressed as St-Sh, or St-Sr). When Sp is present it is commonly enclosed between sets of St (St-Sp-St).



Figure 4-5 Large scale trough cross-beds (scale: 1m). South False Bay section.



Figure 4-6 Facies Sp in South False Bay section. Scale: 1 m.

4.4.4 Lithofacies Sp (Fig. 4-6)

Planar cross-stratified fine to coarse sandstone characterizes lithofacies Sp in the study area. It is the least common of the major lithofacies (Se, St, Sr, Sh, Sm, Fl, Fm and Sp, occurring only 6 times south of False Bay and 11 times altogether. Seven of the 11 beds are enclosed by beds of lithofacies St. In one case Sp overlies Gm and is overlain by St, in sets about 50 cm thick. This unit may be the deposit of a sandwave or small migrating bar. The paleocurrent direction of the unit was parallel to the channel trend, and to the mean trough direction. In other cases the planar cross-beds usually occur in 5-25 cm sets and probably result from the migration of straight-crested megaripples.

4.4.5 Lithofacies Sh and Sl.

Horizontally laminated sandstone, commonly with primary current lineation, characterizes lithofacies Sh. It is most common in fine to medium-grained sandstone, but can occur in very fine to very coarse sandstone. The laminations may be produced by very fine particles of organic matter or mica flakes. Units range from 10 cm to 2 m thick. The lithofacies is most common near the top of channel sequences, and may grade into Sl. The beds are produced by high velocity flow under shallow water depth (Harms and Fahnestock, 1965).

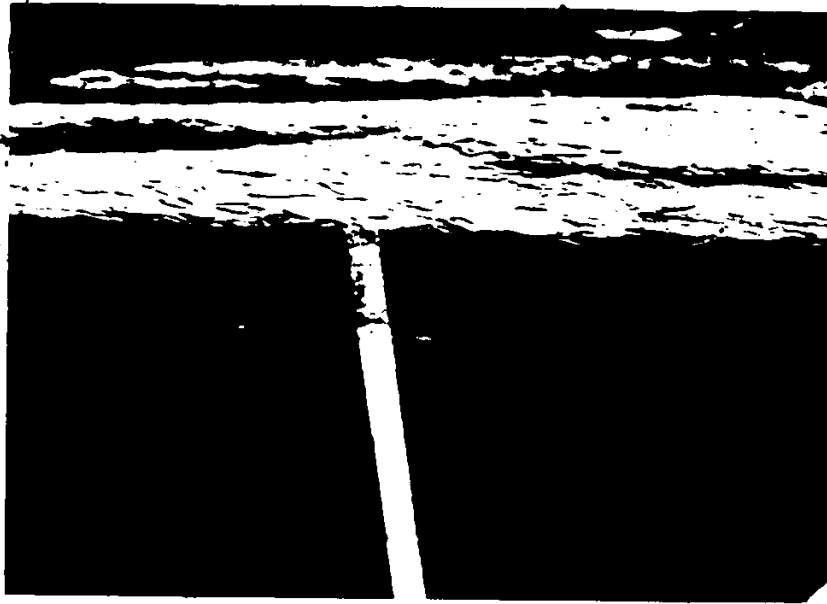


Figure 4-7 Facies Sr at top of the S.F.B. section. Scale units: 10 cm.

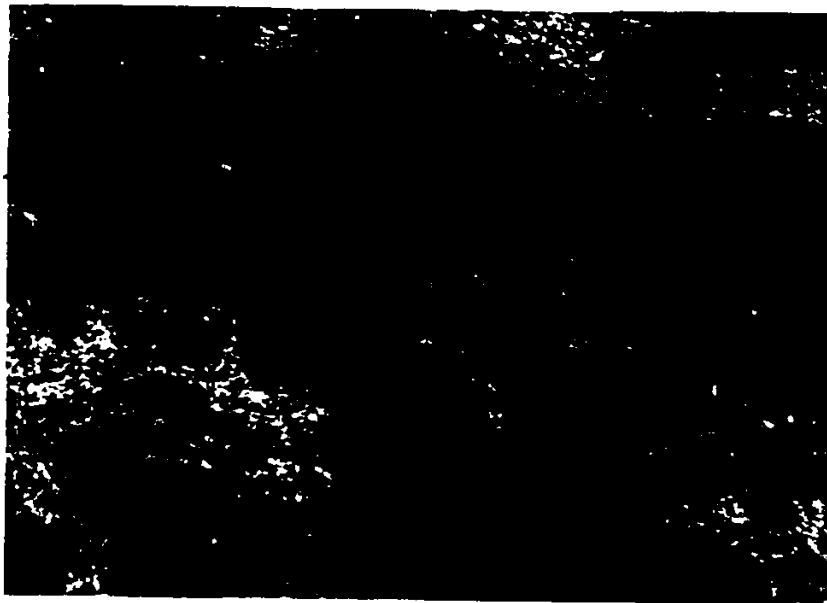


Figure 4-8 Tubular to dendritic mottling produced by reduction of iron around roots in red mudstone. Bioturbation increases upward. Hammer: 30 cm.

Lithofacies S1 occurs in the same depositional setting as Sh, but the beds fill broad scours. This results in low angle (<10 degrees) dipping beds (Rust, 1978).

4.4.6 Lithofacies Sr (Fig. 4-7)

Ripple cross-lamination is present in a wide range of lithotypes, from mudstone to coarse sandstone. The ripples are all asymmetric, but show great diversity in all other aspects. Most ripple marks show sinuous in-phase crestlines but straight crested and (rarely) linguoid forms are present. Wavelength is usually 5-30 cm, and ripple heights 1-3 cm. Most ripple indices are between 5 and 10. In cross section the beds may show climbing ripple laminae in-phase or in a drift mode. In-phase units are much more common than ripple drift beds, and Type 1 (of Rieneck and Singh, 1980, p. 110) are more common than Type 2 ripple drift.

Lithofacies Sr is present in more depositional settings than any other facies. It is commonly found within channels, levees, splays, and in almost every floodplain setting.

4.4.7 Lithofacies F1 and Fm

These two lithofacies are closely associated and will be treated together. F1 is characterized by interlamination or thin interbeds of fine sandstone to siltstone with mudstone. Laminated mudrocks are also included. The colour of the siltstone or fine sandstone corresponds with that of the

finer units, and may be reddish-brown or grey. The laminations may be straight or wavy, and if wavy may be continuous or discontinuous. Although wavy continuous lamination is rare, in one unit it is extremely well developed and traceable over 19 m. Beds of F1 range in thickness from 5 cm to 3 or 4 m, but most are between 30 cm and 1.5 m thick.

Lithofacies F1 is associated with a wide variety of depositional settings: Floodplain drape deposition, abandoned channel fills, pond and swamp deposits, and levees (Chapter 6). Fossils are common and locally abundant, including plant spores and fronds, and rarely, freshwater molluscs. When the latter are present other workers (McLean and Jerzykiewicz, ^{in Miall, 1978}) prefer to group the beds as a unique lithofacies, 'Fcf' (Sec. 4.2). Fossils include Anthracomya and fresh water ostracods (Carbonita fabulina, identified by M. Copeland, pers. comm., 1983). Appendix II lists plant types that have been previously found and identified in the study area (from Bell, 1966; Zodrow and McCandish, 1980).

Lithofacies Fm is massive mudstone and occurs in units from 1 cm to 5 m thick. Bioturbation by rootlets and roots is common, and traces of lamination in some units show that Fm may occasionally originate as F1. When the degree of root penetration reaches the point where the units have a hackly fractured appearance the beds are grouped as Fr. Mudshales that originate as massive mudstones but show

diagenetically produced lamination are grouped with F1, even though they are genetically related to Fm. The massive mudstone and the mudshales are formed under waning flood or stagnant water conditions. The latter is especially true of the claystones and clayshales.

Both F1 and Fm are commonly interbedded with units of Sr. they also may show mudcracks, and rarely, raindrop imprints. Siderite is common in nodules or thin beds, and locally, ankerite is present. Rootlets that are replaced by siderite form small tubes when the organic matter weathers out. These tubes and wood petrified by siderite indicate an early diagenetic origin for the mineral.

Green mottles are common within red units (Figure 4-8). They form a variety of shapes but most frequently are tabular (when formed around roots) or spheroidal (when formed around small plant fragments). The green colour probably results from the local reduction of ferric to ferrous iron in the presence of organic matter (Van Houten, 1968). Another distinctive feature of these lithofacies, and especially Fm, is the presence of a pattern of deep, interconnected cracks (Figures 4-9,10). In plan the cracks are polygonal, and they extend down as far as 1 m or more. The cracks are commonly filled with a slightly different sized material (either coarser or finer) than the rest of the bed, and this weathers out preferentially. The cracks are almost always found in red units; their filling being

green in these cases. The cracks may be super-imposed on root-induced colour mottles. The cracks are also present in the arkosic wackes, where the filling weathers out to form a characteristic nodular appearance (see next section).



Figure 4-9 Polygonal mottling pattern produced by green siltstone filling cracks in red mudstone. Cape Morien (east side).

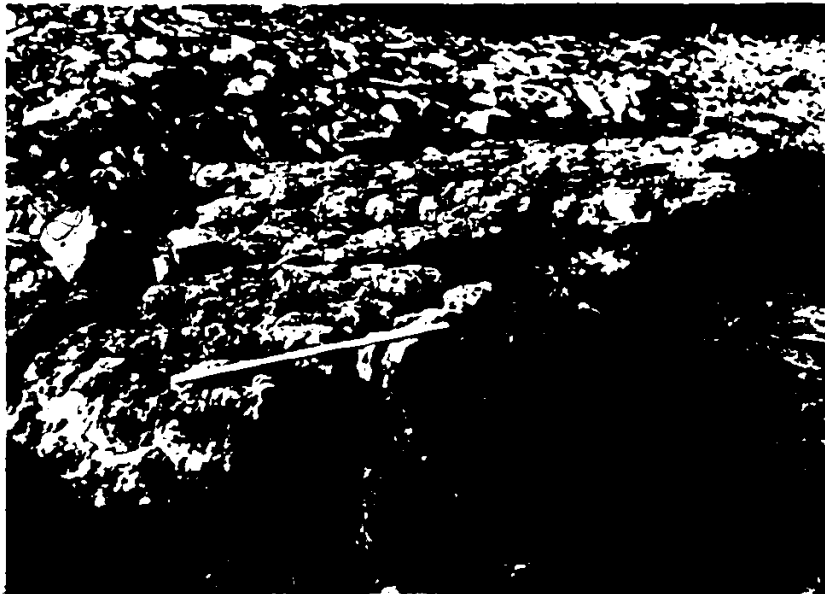


Figure 4-10 Similar cracked pattern weathered to form a nodular pattern. Unit is a silicic paleosol (Ganister?).

4.4.8 Lithofacies Fr

This is a widespread but volumetrically insignificant facies composed of fine sandstone to claystone/clayshale. It is characterized by a hackly fractured appearance produced by intensive rootlet development. Miall (1978) used the term 'seatearth' but here any heavily rooted unit is included regardless of whether or not it is overlain by coal. X-Ray diffraction analysis showed that some samples consist mainly of quartz and kaolinite, a feature common in Carboniferous paleosols and especially seatearths (Greensmith, 1979). The units range from about 10 cm to 1 m thick, and commonly show a downward decrease in bioturbation and grain size. Units of Fr are usually laterally continuous but other units with fewer roots (F1 or Fm) are mostly less extensive along strike.

A special class of rooted beds has many of the characteristics of ganisters (Percival, 1983), including:

1. The presence of rootlets, which decrease in abundance with depth
2. The absence of sedimentary structures
3. The presence of abundant kaolinite
4. Lack of marine fauna
5. Bed thickness between 20 cm and 1 m
6. Angular to subrounded grains
7. Fine grain size (unlike many silcretes)

8. Composition: the beds are lithologically quartz arenites or wackes

These units are composed almost exclusively of quartz and kaolinite. They are interpreted as highly leached pedogenic horizons, indicative of abundant rainfall and well drained topography.

4.5 PROPOSAL FOR A NEW LITHOFACIES CODE, SM

In most cases channel sandstones consist of the lithofacies Se, St, Sh, Sr, and varying amounts of Gm, Fl, Sl, and Sp (See Chapter 5). In some cases however, thick, massive sandstone units are present, and a new lithofacies code designated Sm is proposed to represent the deposits. The logic and consistency of the lithofacies code system would be maintained by making Sm the sand sized analog of Gm (massive to crudely bedded gravel) in the same way that Gt and Gp are analogous to St and Sp.

The units are composed of fine to coarse sandstone in lenticular or tabular units from .5 m to 7 m thick. Massive splay sandstones are generally from .5 to 2.5 m thick, and channel deposits are thicker. Some Se or St may be present at the base of the units, and Sr or Sh may overlie them (Se--St to Sm--Sh--Sr). The beds fracture easily and break off in blocks, up to several 10's of kilotons. The fractures are perpendicular to bedding planes (i.e. not a depositional feature) and usually sub-parallel to the cliff face.

4.6 SUMMARY

The lithologies described in Chapter 3 can be assigned to lithofacies on the basis of sedimentary structures and grain size. The lithofacies reflect a limited set of depositional conditions but can be formed in more than one environment. Consequently, all available data must be integrated to produce sound interpretations of the depositional settings.

The lithofacies code of Miall (1978) was modified for the lithotypes in the study area. Facies Fsc and Fcf were dropped, and a new code, Sm, was added. In the next chapter the sequences of lithofacies will be examined and interpreted.

Chapter V

MARKOV CHAIN ANALYSIS OF FACIES TRANSITIONS

5.1 INTRODUCTION

A. Markov, a nineteenth century Russian mathematician, developed a series of procedures to examine consonant and vowel patterns in the poems of Pushkin (Iosifescu, 1980). Harbaugh and Bonham-Carter (1970) paid tribute to his efforts by defining a Markov process as a "natural process which has a random element, but also exhibits an effect, in which previous events influence, but do not rigidly control, subsequent events" (p. 98). A Markov chain is a Markov process in which the probability of transition from one state in the chain to the next depends on the previous states (Till 1979, p. 15). A first order Markov chain is one in which only the immediately preceding state influences the following state. If earlier states influence the following state the chain has a higher order. An example of a Markov Chain is the weather, which will, on any day, most probably be like that of the day before.

In sedimentology and stratigraphy Markov analysis can be used to determine if facies transitions are random or part of a Markov chain. If non-random, the sequence of transitions can be compared to a sequence predicted by "Gottner's law", and an

interpretation can be made. On a large scale, laterally extensive units such as coal cyclothems have been analyzed (Doveton, 1971). On a smaller scale, Markov analysis can be used in conjunction with facies models to establish a detailed and specific environment of deposition (Walker, 1981, ch. 1). Examples of other stratigraphic applications are given by Gingerich (1969), Hattori (1973), Miall (1973), Murray and Wood (1972) and Segun and Hart (1977). Other stratigraphic applications are given by Dacey and Krumbein (1970).

Statistical aspects of Markov analysis are discussed by Anderson and Goodman (1957), Billingsly (1961), Gingerich (1969), Harbaugh and Bonham-Carter (1970, p. 98-168), and Agterberg (1974). Other statistical treatments have recently been proposed by Carr (1982).

5.2 THEORY

The basic procedure used for most Markov chain studies can be summed up in three steps. First, transitions between facies are recorded from field data. An "Embedded" Markov chain uses bed to bed transitions (Dacey and Krumbein, 1970). In an alternate method the facies type is recorded at a fixed interval. This places emphasis on the abundance of each facies type and not on the transition frequencies. In the second step, a random set of transitions is generated. Finally, the random data are compared to the field data statistically. A null hypothesis H_0 assumes that all

measured transitions are random. The alternative H_1 is that the sequence is a Markov chain. A Chi Square statistic is used to determine if there is a significant difference between the measured and random data. If so, H_0 is rejected and the sequence can be considered Markovian.

5.3 ANALYTICAL PROCEDURE

Data were analyzed with the aid of a computer program modified from one written by A.D. Miall and titled "Embedded Markov Chain Analysis" (available on request).

The data were obtained by recording vertical transitions between facies from the field data. Seven major facies were used, as defined in the previous chapter. These are: St, Sr, Fl/Fm, Sh, Se, Sp and C. Transitions were recorded in the form of a Transition Count Matrix (see Miall, 1973) denoted $f[i,j]$. The lowest bed in a sequence is represented by a row $[i]$ and the following bed by a column $[j]$. For example, data from the Lonchopteris zone in the South False Bay section produced the following T.C.M.:

Table 5-1

South False Bay Transition Count Matrix

| | St | Sr | Fl/Fm | Sh | Se | Sp | C |
|-------|----|----|-------|----|----|----|---|
| St | 0 | 5 | 3 | 10 | 5 | 5 | 0 |
| Sr | 0 | 0 | 11 | 3 | 1 | 0 | 0 |
| Fl/Fm | 3 | 5 | 0 | 0 | 5 | 0 | 4 |

| | | | | | | | |
|----|----|---|---|---|---|---|---|
| Sh | 6 | 5 | 1 | 0 | 2 | 1 | 0 |
| Se | 15 | 0 | 0 | 1 | 0 | 0 | 0 |
| Sp | 3 | 0 | 0 | 1 | 2 | 0 | 0 |
| C | 0 | 0 | 3 | 0 | 1 | 0 | 0 |

Facies St can have no transitions to itself by definition. There are five transitions from St to Sr ($f[1,2]$ = matrix f , row 1, column 2), 11 transitions from Sr to Fl/Fm ($f[2,3]$), none from Sr to St ($f[1,2]$) etc. Altogether there are 102 recorded facies and 101 transitions.

A Transition Probability Matrix (T.P.M.) is generated from the Transition Count Matrix (T.C.M) using the following equation:

$$P[i,j] = f[i,j] / s[i]$$

where $S[i]$ is the sum of the i th row of matrix $f[i,j]$. Matrix $P[i,j]$ for the South False Bay section is:

Table 5-2

South False Bay Transition Probability Matrix

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|------|------|------|------|------|------|------|
| 1 | .000 | .172 | .102 | .345 | .172 | .207 | .000 |
| 2 | .000 | .000 | .733 | .200 | .067 | .000 | .000 |
| 3 | .176 | .294 | .000 | .000 | .294 | .000 | .235 |
| 4 | .400 | .333 | .067 | .000 | .133 | .067 | .000 |
| 5 | .936 | .100 | .000 | .063 | .000 | .000 | .000 |

| | | | | | | | |
|---|------|------|------|------|------|------|------|
| 6 | .500 | .000 | .000 | .167 | .333 | .000 | .000 |
| 7 | .000 | .000 | .750 | .000 | .250 | .000 | .000 |

The sum of each row [i] is 1.000.

If a Markov chain is present it may be masked by random facies transitions. To help filter out this random factor a Difference Probability Matrix is constructed as follows:

$$d[i,j] = p[i,j] - r[i,j]$$

where $r[i,j]$ is the Independent Trials Probability Matrix (I.T.P.M.).

$$r[i,j] = s[j] / (t - s[i])$$

The terms $s[j]$ and $s[i]$ represent the column and row sums of $f[i,j]$, and t is the total number of transitions in $f[i,j]$. The

I.T.P.M. for the South Falls Bay section is presented in Table 5-3.

Table 5-3

Independent Trials Probability Matrix for S.F.B. Section

| | | | | | | |
|-------|-------|-------|-------|-------|-------|-------|
| 0.000 | 0.205 | 0.233 | 0.205 | 0.219 | 0.082 | 0.055 |
| 0.333 | 0.000 | 0.195 | 0.172 | 0.184 | 0.069 | 0.046 |
| 0.341 | 0.176 | 0.000 | 0.176 | 0.188 | 0.071 | 0.047 |
| 0.333 | 0.172 | 0.195 | 0.000 | 0.184 | 0.069 | 0.046 |
| 0.337 | 0.174 | 0.198 | 0.174 | 0.000 | 0.070 | 0.047 |
| 0.302 | 0.156 | 0.177 | 0.156 | 0.167 | 0.000 | 0.042 |
| 0.296 | 0.153 | 0.173 | 0.153 | 0.63 | 0.061 | 0.000 |

Table 5-4 shows the Difference Matrix for the section. Negative values in $d[i,j]$ represent transitions that are highly improbable, and are discarded.

Table 5-4

Difference Matrix for S.F.B. Section

| | | | | | | | |
|---|-------|-------|-------|-------|-------|-------|-------|
| 1 | .000 | -.033 | -.129 | .139 | -.047 | .125 | -.055 |
| 2 | -.333 | .000 | .538 | .028 | -.117 | -.069 | -.046 |
| 3 | -.165 | .118 | .000 | -.176 | .106 | -.071 | .188 |
| 4 | .067 | .161 | -.129 | .000 | -.051 | -.002 | -.046 |
| 5 | .600 | -.174 | -.198 | -.112 | .000 | -.070 | -.047 |
| 6 | .198 | -.156 | -.177 | .010 | .167 | .000 | -.042 |
| 7 | -.296 | -.153 | .577 | -.153 | .087 | -.061 | .000 |

The highest transition probabilities from the difference matrix are listed in Table 5-5. This table will be used to construct a Facies Transition Diagram to provide insight into the processes active at the time of deposition (Walker, 1981).

Table 5-5

Most Probable Transitions

| <u>From</u> | <u>To</u> | <u>Value</u> |
|-------------|-----------|--------------|
| Se | St | .600 |
| C | Fl/Fm | .577 |
| Sr | Fl/Fm | .538 |
| Sp | St | .198 |
| Fl/Fm | C | .188 |

| | | |
|-------|----|------|
| Sp | Se | .167 |
| Sh | Sr | .161 |
| St | Sh | .139 |
| St | Sp | .125 |
| Fl/Fm | Sr | .118 |
| Fl/Fm | Se | .106 |
| C | Se | .087 |
| Sh | St | .067 |
| Sr | Sh | .028 |
| Sp | Sh | .010 |

Results will be discussed in Section 5-4.

The Chi Square tests were carried out to check if the "greater than random transitions" in Table 5-5 were not themselves the result of a random occurrence. The first was recommended (Singerich (1969), p.551):

$$(1) \text{ Chi Square} = \sum_{i,j} (f[i,j] - s[i] r[i,j])^2 / s[i] r[i,j]$$

$$\text{Degrees of Freedom} = n^2 - 2n$$

where n is the number of rows or columns in f[i,j].

The second equation was recommended by Harbaugh and Bonham-Carter (1970, p. 121):

$$(2) \text{ Chi Square} = 2 \sum_{i,j} x \log[e] (p[i,j] / (s[j] / f[i,j]))$$

$$\text{Degree of Freedom} = (n-1)^2 - n$$

Equation (2) applies when each element of f[i,j] is less than 5. Since this is generally the case, it has been emphasized in this study.

The Null Hypothesis is that the vertical sequence of transitions was produced by a random series of events. For the section South of False Bay, equation (1) gives a Chi Square value of 108.4 with 35 degrees of freedom. The confidence limits for Chi Square with 35 degrees of freedom are as follows:

| 90.0% | 95.0% | 99.0% | 99.5% |
|-------|-------|-------|-------|
| 46.1 | 49.8 | 57.4 | 60.3 |

The Chi Square value for equation (2) is 150.0 with 29 degrees of freedom.

The corresponding confidence limits are:

| 90.0% | 95.0% | 99.0% | 99.5% |
|-------|-------|-------|-------|
| 39.1 | 42.6 | 49.6 | 52.4 |

Both equations indicate that there is less than 1 chance out of 200 (or .5 chances out of 100) that the transitions were randomly generated.

5.4 APPLICATION TO MEASURED SECTIONS

Markov Chain Analysis was carried out on all of the measured sections. In addition, separate sections were linked together and analyzed. Technically this would produce a flaw in the statistical test because the number of recorded transitions would not be one less than the number of facies. This has been accommodated by linking separate sections with transitions. By comparing the results from individual and composite sections it was found that the added transitions did not significantly alter the outcome of the analysis. Composite sections were only used to generate Facies Transition Diagrams (FTD's) and not for determining transition probabilities.

The following sections were run separately : South False Bay, North of False Bay to the Coalbrook seam, Coalbrook seam to north of Noneck Point, Cape Morien; east side, Cape Morien, west side Cape Morien, and Cape Percé. Composite sections were made of Cape Morien north of False Bay (east and west sides), and for the entire Alternating Facies assemblage (Cape Morien plus Cape Percé) (see Fig 1-1).

Facies Transition Diagrams were prepared from the most probable transitions in the difference matrices. The transition diagrams do not take into account the relative abundance of each facies, so composite stratigraphic sections were drawn from the diagrams and field data to give a more representative picture of the sequences. Composite

sections were compared with published data to aid in interpreting the depositional environment of the units. the sections were also compared to each other to determine if there are any significant vertical or lateral changes present.

5.5 ANALYTICAL RESULTS

Probability data, facies transition diagrams and composite sections for the South False Bay, Cape Morien and Cape Percé sections are presented below.

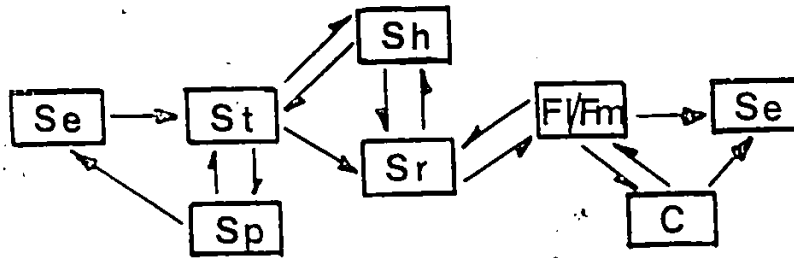
5.5.1 South False Bay section

The most probable transitions in this section are listed in Table 5-5. A facies transition diagram and composite section are shown below (Figure 5-1).

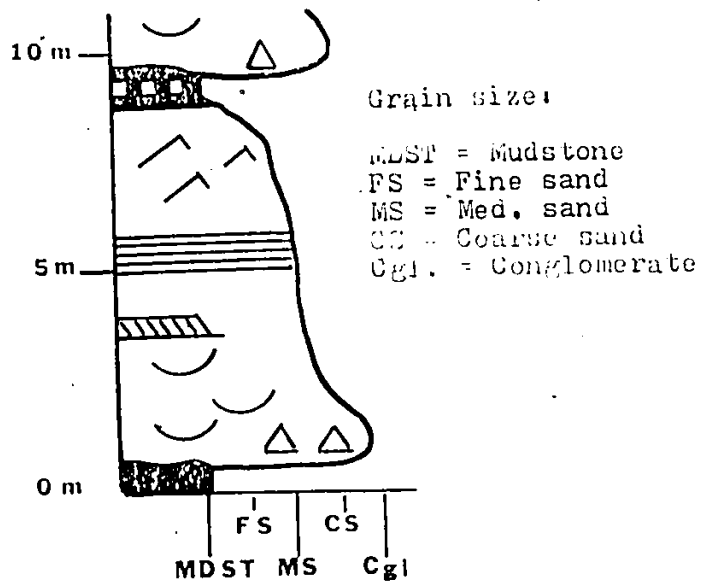
Figure 5-1

South False Bay Section

Transition Lithofacies Codes from Chapter 4



Facies Transition Diagram



Composite Section

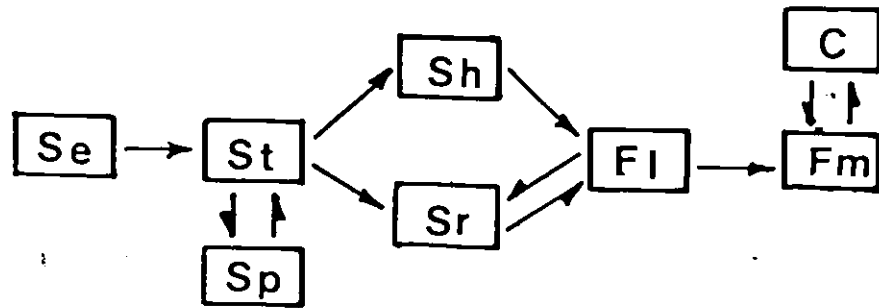
An erosional base may follow any other facies but usually cuts into facies Fl/Fm or C. Trough cross-stratified sandstone follows Se, and is associated with horizontally bedded sandstone. If Sp is present it is closely associated with St. Ripple cross-laminated fine sandstone may follow St or Sh. The sequence Se-St(Sp)-Sh-Sr is interpreted as the product of in-channel deposition. Facies Sr may also be included as an overbank deposit and is commonly followed by Fl/Fm, and Coal (if present). The fine facies (Fl/Fm) do not comprise more than 10 % of the section. St is the most abundant facies, whereas C and Sp are the least common.

5.5.2 Cape Morien section (east side)

Figure 5-2 shows the F.T.D., most probable transition data and composite stratigraphic section for the east side of Cape Morien. The transition diagram is similar to the one from South of False Bay, but there are important differences. Facies Se usually follows Fl/Fm and is followed by St. If Sp is present it is closely associated with St. St may be followed by either Sh or Sr, and these facies pass into Fl/Fm. Coal is usually confined to facies Fl/Fm.

The composite section points out the major differences between this section and the S.F.B. section, and illustrates the importance of integrating facies abundance data with transition data for a more accurate appraisal of a unit. The South False Bay section contained less than 10 % Fl/Fm, compared to 50 % or more for the Cape Morien section.

Figure 5-2 Cape Morlen



Chi squared value (eq. 1) - 189

99.5% Confidence Limits 97

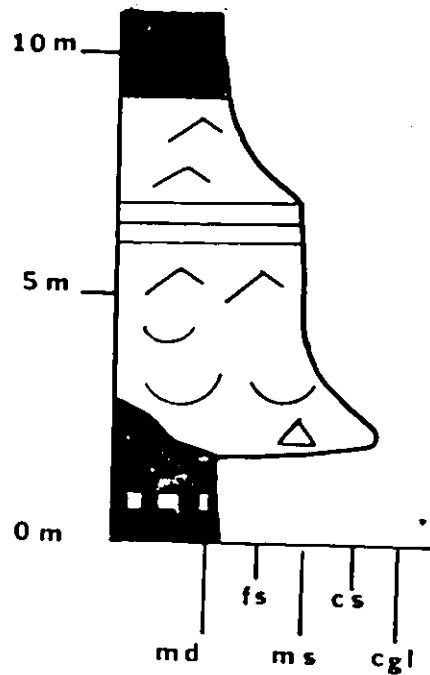
Chi squared value (eq. 2) - 309

99.5% Confidence Limits 58

Most Probable Transitions

Transitions: 297

| From | To | Probability |
|-------|-------|-------------|
| Sp | St | .800 |
| Se | St | .559 |
| C | FI/Fm | .451 |
| Sr | FI/Fm | .180 |
| St | Sr | .176 |
| Sh | FI/Fm | .173 |
| FI/Fm | G | .156 |
| St | Sh | .137 |
| FI/Fm | Se | .135 |
| Sh | Sr | .086 |
| Sr | Sh | .053 |
| St | Sp | .025 |
| C | Se | .002 |



5.5.3 Cape Percé section

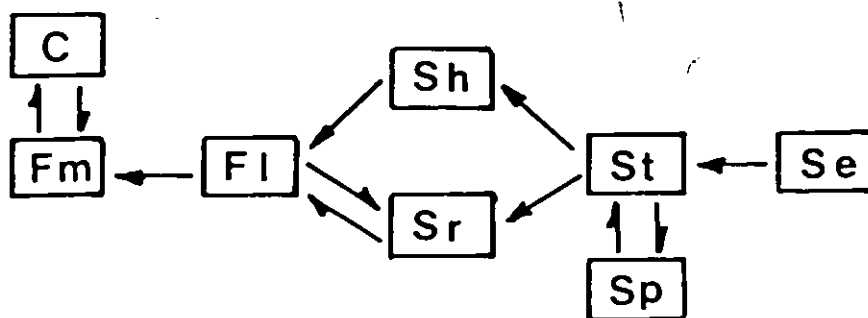
In this section 115 transitions were recorded. The F.T.D. (Figure 5-3) shows two separate preferred transition paths. One is Se-St-Sh, and is inferred to represent in-channel deposition. The second is Sr-Fl/Fm with coal confined to the latter. This series is the product of overbank deposition. The composite section is very similar to the one from Cape Morien, but contains a slightly higher amount of fine material.

5.5.4 Composite sequence of Cape Morien and Cape Percé

This section (Figure 5-4) represents the Alternating Facies Assemblage and was generated to depict a "typical" transition sequence for comparison with the South False Bay Sandstone Facies Assemblage. There are 414 transitions in this combined section. It was formed by joining the Emery seam from the top of the Cape Morien section to facies Fl/Fm at the base of the Cape Percé section. The facies transition diagram resembles the one in Figure 5-7 in part because of the dominance of the Cape Morien section (297 transitions) over the Cape Percé section (115 transitions).

*see Appendix 1

Figure 5-3 Cape Perce



Chi squared value (eq. 1) - 101

99.5% Confidence Limits: 60

Chi squared value (eq. 2) - 145

99.5% Confidence Limits: 58

Most Probable Transitions

Transitions: 115

| From | To | Probability |
|-------|-------|-------------|
| Se | St | .800 |
| Sp | St | .479 |
| C | FI/Fm | .369 |
| Sr | FI/Fm | .327 |
| FI/Fm | C | .235 |
| St | Sh | .195 |
| Sh | Se | .056 |
| Sp | FI/Fm | .039 |
| Sh | St | .025 |
| St | Sp | .018 |
| Sh | Sr | .015 |
| Sr | Sp | .013 |
| FI/Fm | Sr | .004 |

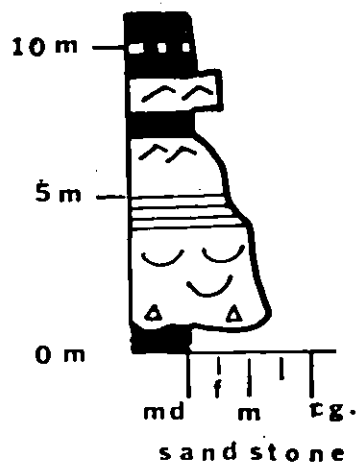
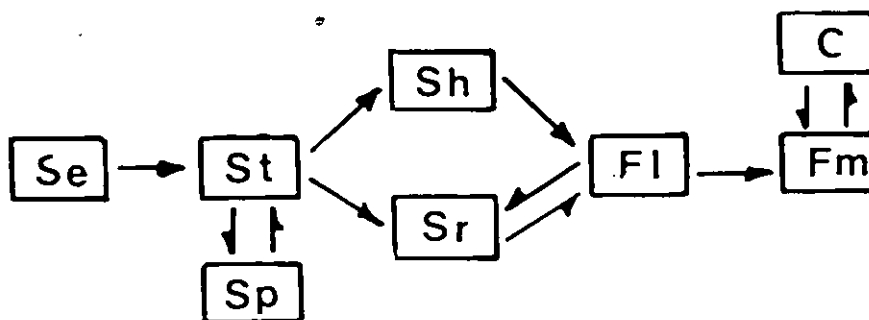


Figure 5-4 Cape Morlem and Cape Perce



Chi squared value (eq. 1) - 268

99.5% Confidence Limit: 160

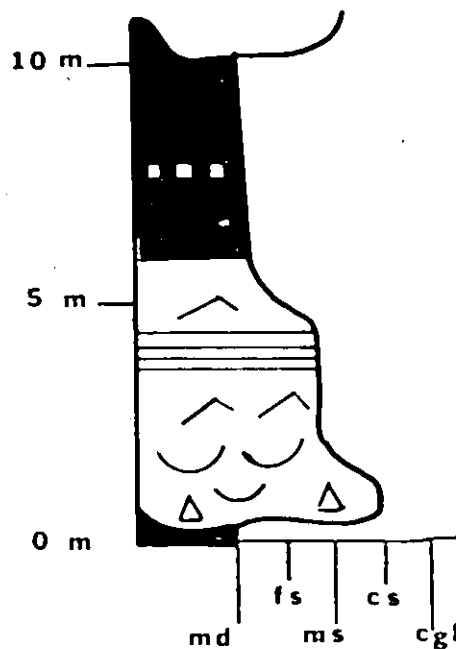
Chi squared value (eq. 2) - 427

99.5% Confidence Limit: 22

Most Probable Transitions

Transitions: 434

| From | To | Probability |
|-------|-------|-------------|
| Sp | St | .604 |
| Se | St | .598 |
| C | FI/Fm | .425 |
| Br | FI/Fm | .223 |
| St | Sr | .181 |
| FI/Fm | C | .179 |
| St | Sh | .123 |
| Sh | FI/Fm | .128 |
| FI/Fm | Se | .094 |
| Sh | Sr | .069 |
| Sr | Sh | .037 |
| St | Sr | .022 |
| C | Se | .017 |



5.6 DISCUSSION

The composite stratigraphic sections from the Sandstone Assemblage (Fig 5-4) and the Alternating Facies Assemblage were compared with published sections from modern and ancient fluvial systems to aid in interpretation. The Sandstone Facies Assemblage (Figure 5-1) resembles the modern South Saskatchewan channel succession of Cant and Walker (1979), and depositional type S[2] for ancient fluvial systems (Rust, 1978). Sections from the Alternating Facies Assemblage are similar to the meandering fluvial facies model of Allen (in: Walker, 1981, p. 24). All of the sections were then compared to evaluate vertical and lateral differences in facies transition probabilities and relative facies abundance.

5.6.1 Comparison with existing models

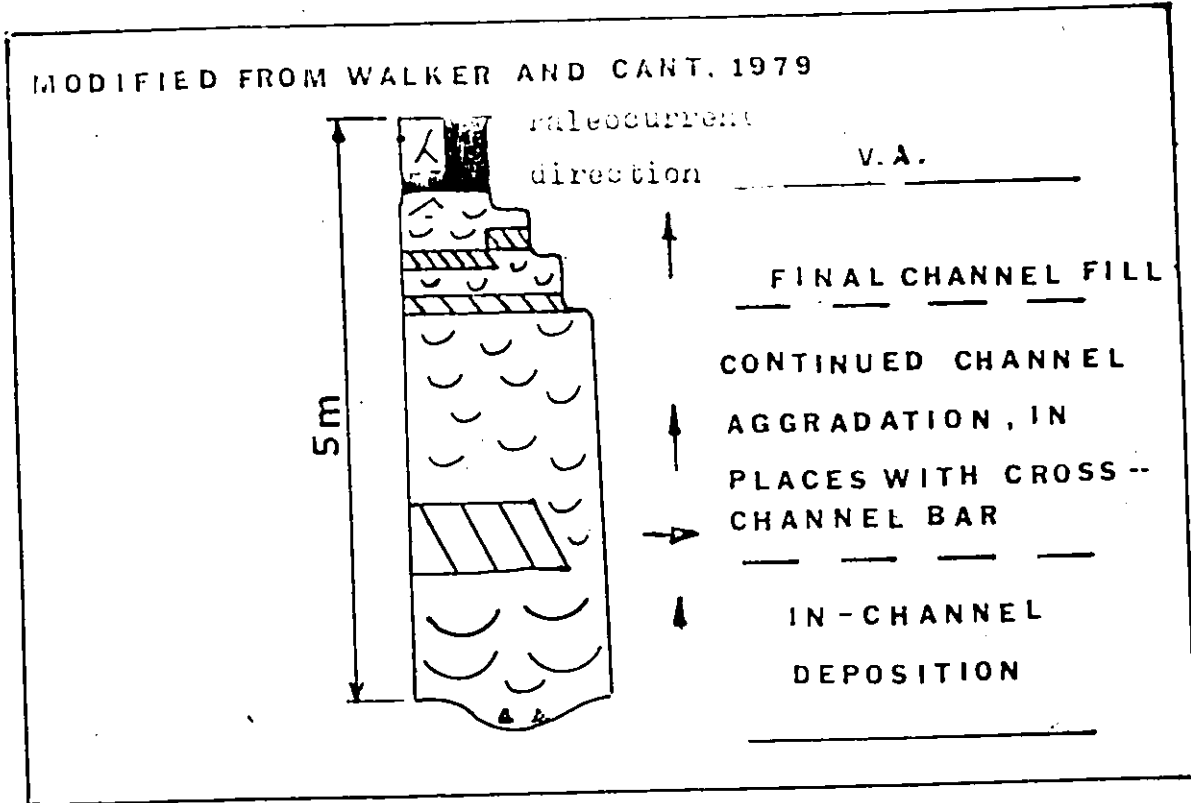
Figure 5-5 shows a composite section from the channel of the South Saskatchewan River (Cant and Walker, 1979). Trough cross-stratified sandstone with intraclasts overlies a scoured base, and is followed by St without intraclasts. The sequence Se to St is interpreted by Cant and Walker to represent the scoured channel base with subaqueous dunes migrating downstream. Planar-tabular cross-bedded sandstone (Sp) in the upper part of the succession results from deposition on a cross-channel bar. This feature is not well represented in the measured sections. Smaller scale troughs

fill in much of the channel, and are followed by finer channel fill deposits and sand flat deposits (facies Sr, Sp, Fl, Fm).

The most significant similarities between this section and the South False Bay section (Figure 5-1) are the presence of a fining-upward St sequence above a scoured base, and the proportion of fine material to sandstone. A difference is the relative lack of planar-tabular cross-stratification in the S.F.B. section. This is probably a function of relatively deeper channels in the section south of False Bay, resulting in less frequent bar development. The sandstone units are also thicker at S.F.B. than in the South Saskatchewan, which also points to deeper channels.

The South False Bay section fits into the Distal Sandy Braided deposit (Type S[2]) of Rust (1978). Type S[2] is characterized by "fining-upward cycles, lateral continuity, and a significant primary mud content ... They are transitional to deposits of meandering systems." (Rust, 1978, p. 605). He goes on to point out that there are no definitive characteristics that separate distal braided from meandering deposits, although deposition of Sp and variance of St orientations with respect to channel trend are factors.

Figure 5-5



South Saskatchewan River facies model.

Facies defined in Appendix 1 key
 V.A. = Vertical Accretion

Lateral continuity increases upward in the South False Bay section, as demonstrated by the mapped extent of the McAulay and Shoemaker coal seams. The latter has a considerably greater extent than the former. (Lateral continuity of the coal seams increases throughout the Lonchopteris obliqua zone as well, and seams in the Ptychocarpus unit zone extend at least across the entire land portion of the basin (based on Meyer et al., 1998)).

The stratigraphic position of the Sandstone Facies Assemblage also supports the distal braided interpretation. Earlier conformable deposits from the Lonchopteris zone in the southwest part of the basin and at Bateston are coarser, and exhibit the characteristics of more proximal braided deposits (Rust et al., 1982). Younger deposits at Glace Bay, Point Aconi and Port Morien have been interpreted as meandering river deposits (Rust and Masson, 1981; Duff et al., 1982; Dilles and Rust, 1983).

The Alternating Facies Assemblage (Figure 5-4) resembles the meandering river facies model of Allen (in: Walker, 1981, p. 24). This classic sequence begins with a scoured base followed by either trough cross-stratified sandstone (representing downstream dune migration) or horizontally bedded sandstone (plane bed deposition, facies Sh). These facies are followed by smaller scale St, Sr and finer facies with rootlets and pedogenic nodules. The sequence is divided into channel floor, point bar, bar top

and overbank. In Allen's model about 50 % of the section consists of fine-grained overbank material in facies Fl, Fm, Sr, and C.

The Alternating Facies Assemblage in Figure 5-4 closely resembles this model. Both show the same fining-upward Se-St(Sh)-Sr-Fl/m sequence. One difference is the tendency for Sh and Sr to alternate in the measured sections. This is attributed to deposition near the point bar tops, and possibly in channel-proximal levees. Another difference is that the classic sequence lacks coarse members in the overbank series that are interpreted here as levee, crevasse splay and small channel deposits.

5.6.2 Vertical and lateral changes in facies transition data

Facies transitions in sections measured South of False Bay, at Cape Morien and Cape Percé show striking similarities and more subtle differences. Similarities result from fundamental fluvial processes that operate throughout the study area. Transition probability differences may reflect local variation in the proportion of depositional processes and/or variation in the number of facies measured at each locality. The latter is not considered to be a major factor because over 100 transitions were measured in each section. This is large enough to produce a reliable statistical outcome (Till, 1979).

The most probable transitions in all of the measured sections are Se-St, Sp-St, C-Fl/Fm, and Sr-Fl/Fm. The transition from Se to St represents conditions at the base of channels, or at the base of some splay deposits (section 6.2). Other facies that would be expected to follow Se would be Sp or Sh but most often St follows.

Planar-tabular cross-stratified sandstone was recorded in solitary or grouped sets up to 60 cm thick. These are interpreted as the product of bar migration. Smaller scale Sp sets (up to a few cm in thickness) may be bar top or "sandflat" deposits. At the time of deposition the bar deposits were closely associated with dunes, resulting in high probability for the transitions St-Sp-St. One implication of the data is that most of the observed Sp sets were deposited as bars, because transitions from Sp to the finer facies are rare.

In all of the sections coal showed a strong tendency to follow facies Fl/Fm. This was expected since coal tends to accumulate in association with fine-grained material, where compaction forms areas suitable for peat accumulation (Fisk, 1960). Fisk's observations were made on delta distributaries, but they also apply to river flood plains. The transition from Sr to Fl/Fm is interpreted as the result of waning flow conditions. Other Sr transitions are to Sh and St, and indicate increasing energy of flow. One other highly probable transition common to all of the sections is from St to Sh.

Lateral (between C.M. and C.P.) and vertical (from Lonchopteris to Linopteris obliqua) changes in transition probabilities and facies proportions can be seen in Figures 5-1, 5-2, and 5-3. As mentioned, the amount of fine material is significantly less south of False Bay than in the Cape Morien section. A slightly higher amount of fine-grained material is present at Cape Percé than at Cape Morien. There is a corresponding change in facies transition probabilities reflecting the increased influence of overbank deposition compared to in-channel deposition.

Chapter VI

DEPOSITIONAL ENVIRONMENTS

6.1 INTRODUCTION

Statistical analysis of vertical transitions and facies abundance data are valuable tools for indicating cyclicity and possible depositional setting (Walker, 1981), but additional data are needed to verify and "fine tune" the interpretation. In this chapter specific lithofacies sequences will be interpreted on the basis of bed geometry, lateral and vertical transitions, paleocurrents and fossil evidence. The recorded sequences will then be compared with ancient and recent alluvial facies models. Finally, a comprehensive depositional history will be presented for the Lonchopteris and Linopteris obliqua rocks in the study area.

6.2 THE ALTERNATING FACIES ASSEMBLAGE (A.F.A.)

In section 5.6 the Alternating Facies Assemblage was interpreted as a meandering fluvial deposit on the basis of the facies present, their abundance and vertical transitions. Sets of lithofacies within the assemblage are interpreted here as channel, floodplain, and mixed deposits (Figure 6-1)

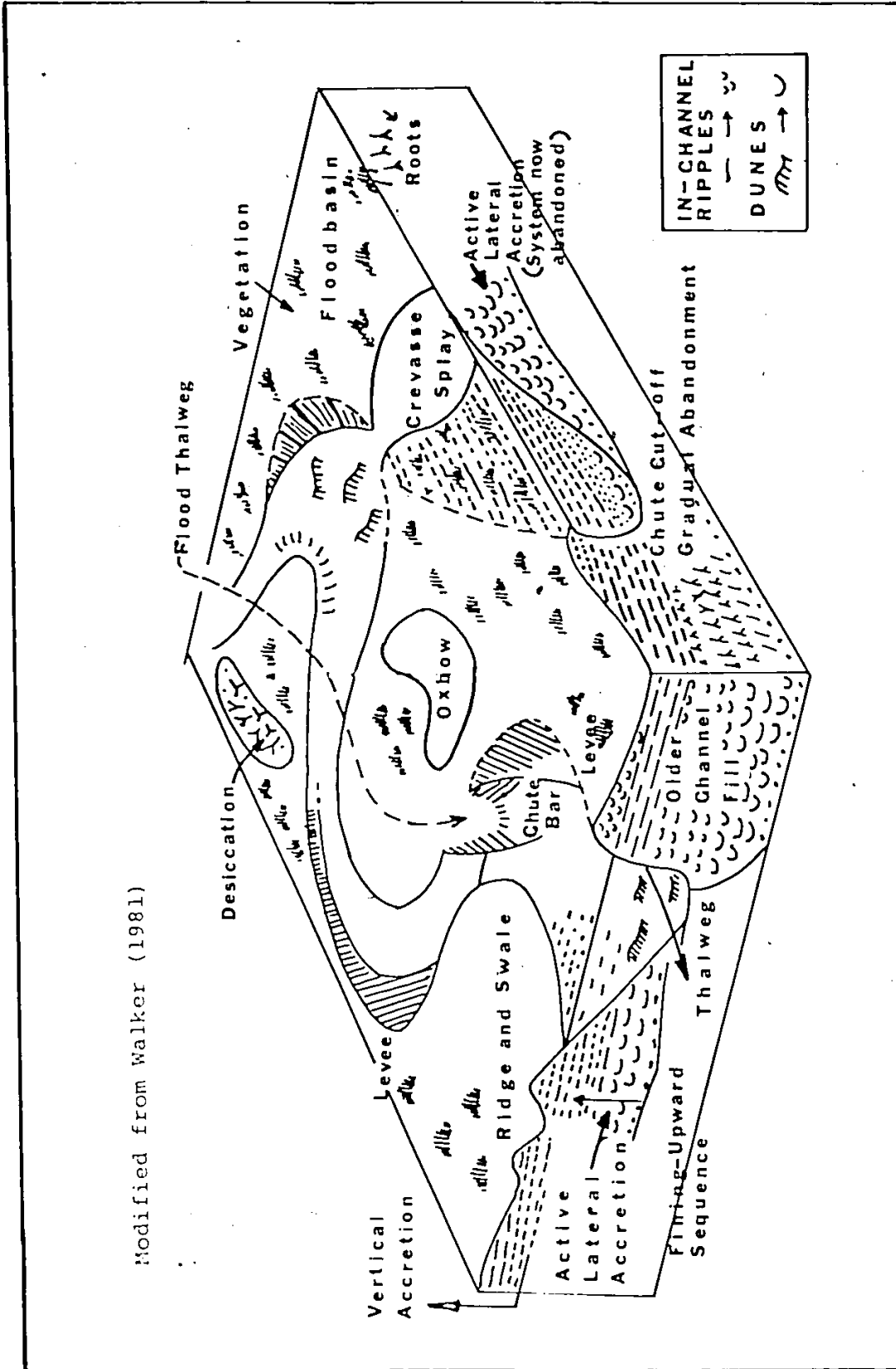


Figure 6-1. Meandering river depositional environments

6.2.1 Point Bar Deposits

Finning upward sandstone-mudstone packages 3.5 to 8.0 m thick with the general facies sequence Se-St-Sh/l-Sr containing lateral accretion surfaces are interpreted as point bar deposits of meandering channels. Deposits that are otherwise similar but lacking lateral accretion bedding are inferred to be of similar origin. A summary of previous studies mentioning epsilon cross-stratification concluded that not all meandering systems produce this structure. (Jackson, 1978). As described in the last chapter the bases of these units are usually erosion surfaces. Some channels scour up to 3.5 m into underlying beds. Large plant fragments and other floodplain debris are commonly present as lags at the base of the units (facies Gm). Together, facies Se and Gm may make up 20 % of the channel sequence, but 10-15 % is a more common proportion. Facies St is the dominant lithofacies, forming up to 80 % of some channels, in units up to 6 m thick. Trough cosets fine upward and show upward decrease in the scale of constituent sets, and a wide dispersion of unidirectional paleocurrents. Deviations of 45 degrees are not unusual in some cosets, but 10-15 degree differences are more common (Figure 6-2).

Figure 6-2



Figure 6-2. Channel deposit with lateral accretion surfaces. From the Alternating Facies Assemblage near Wadden Cove.



Figure 6-3. Fining-upward sandstone-mudstone channel fill. Beds at top drape over edge of channel. Cape Morien (west side).

Facies Sh/1 either follows St or is enclosed by beds of St (expressed as St-Sh/1-St). Sr is common near the top of most channel deposits, and the lithofacies frequently follows St or Sh. Paleocurrent directions measured on ripple marks show a greater variance than those of trough cross-beds. Together facies Sr and Sh/1 may form up to 35 % of the point bar deposits.

Individual point bar deposits may extend over 0.5 km or more, or may pass within a few 10's of metres into finer units of F1 or Fm. They usually pass vertically into the same fine-grained facies.

Lateral accretion (L.A.) surfaces are visible in some channel units because of thin beds (up to 15 cm) of finer grained material. These surfaces pass through the entire channel unit, dipping between 6 and 22 degrees. The dips are consistent with other measurements of epsilon cross-stratification (Jackson, 1978). Paleocurrents measured in facies St are nearly perpendicular to the dip direction of the L.A. surfaces. In one case the beds dipped towards 260 degrees, while the azimuths of 4 troughs averaged 004 degrees, a 104 degree divergence. Primary current lination on the trough base was parallel to the trough axes, but ripple cross-lamination azimuths varied widely (005-045 degrees). In another case the L.A. surfaces dipped towards 272 degrees, while 2 troughs read 070, and ripples were measured at 065 and 040. In other channels the exact dip

direction of the L.A. surfaces was more difficult to determine.

A 1.8 m block of fine-grained material is present on the east side of Cape Morien just north of Wadden Cove, at the base of a large channel. The block consists of thin bedded (1-8 cm) red and green mottled mudstone dipping 70-80 degrees. It overlies a lag deposit of mudstone intraclasts, plant and tree fragments, and is overlain by coarse to fine St units. The block is interpreted as the remains of an undercut riverbank that slumped into the channel and was covered by lateral accretion deposits. Another probable slump block is present within the sandstone facies assemblage, south of False Bay (Section 6.4, Figure 6-9).

Units of Sr up to 2 m thick are common at the top of channel sequences. They grade into facies F1 and Fm and are interpreted as bar top or levee deposits. In the former case paleocurrents are generally subparallel to the channel axis (and the mean trough azimuths), whereas paleocurrent directions in the latter are approximately perpendicular to the channel trend. Lateral continuity and uniformity of bed thickness indicate that most of the units are bar top deposits. They are commonly rooted, and some contain sand-filled tree molds with diameters up to 35 cm.



Figure 6-4. Scour filled with very fine sandstone and mudstone.
Scale is 1 m. Cape Percé section.

6.2.2 Abandoned Channel Deposits

Channel fill deposits within the Alternating Facies Assemblage are interpreted as products of chute cutoff, neck cutoff or avulsion. Smaller sandstone-filled channels are interpreted as splay channels. Together, four types of abandoned channels are present:

Type 1 - Mudstone to fine-grained sandstone fills scours from 1 to 4 m deep and 5-18 m wide. The beds consist of interbedded Sr, Fl and Fm (Figures 6-3,4). Stratification is parallel to the erosional base, but the upper strata drape over the edges of the channel, and higher beds are horizontal.

Similar deposits fine upward from medium sandstone (with small scale St) into fine-grained cross-laminated sandstones and then into Fl and Fm units. As above, the strata follow the contour of the channel base and pass upward into horizontal beds.

The deposits resemble Walker's (1981) chute cutoff depositional profile. Reoccupation of an old meander swale leads to gradual abandonment of the main channel, producing a thick sequence of cross-laminated fine sands followed by vertical-accretion mudstones.

Type 2 - Mudstone channel fills from 1-12 m wide and 2-4 m thick are present. The mudstone is either massive or rooted. If rooted, the roots originate in overlying horizontal paleosols and penetrate into the channel fill.

In some cases mudstone forms the entire fill while in others it overlies a thin channel sequence (Se-St). The deposits resemble neck cutoff deposits of Walker (1981), formed when a meander loop is abruptly abandoned and sealed by a sand plug. The primary discriminator between deposits of chute cutoff and neck cutoff is the ratio of Sr to Fl and Fm. A high ratio suggest chute cutoff.

Type 3 - Fining upward channel sequences from 4 to 6 m thick and up to 22 m wide are occasionally isolated as sandstone lenses within mudstone overbank units. This type is characterized by the complete point bar sequences of sedimentary structures (Se-St-Sr-Sh/l-Sm), and isolation within thick mudstone sequences. There is no gradual transition to mudstone at the top of these sequences. The deposits are interpreted as products of channel abandonment due to avulsion because they are situated within thick floodplain units, with no evidence of nearby channel deposition. The main water course probably shifted to a different part of the floodplain.

Type 4 - Well preserved lenses of mostly massive fine to medium-grained sandstone and mudstone filling scours forms type 4. The lenses are rarely more than 2 m deep (Figure 6-5). The top of the scour fill may form a wedge-shaped unit on either side of the trough which may extend for 100 m or more. The sand-bodies may be massive (Sm) or show a sequence of St-Sh-Sr. In one case (north of Campbell Pond) the lens

was laterally equivalent to a large channel deposit, separated by about 12 m. The scour fill may represent a tributary to the main channel or a crevasse splay channel. Unfortunately, the sandstone lens was massive and no diagnostic paleocurrents could be measured.



Figure 6-5. Scour filled with mudstone. Roots from overlying bed penetrate into the scour fill. Cape Percé section.



Figure 6-6. Well preserved tree within sandstone bed. The sandstone is interpreted as a splay deposit. Tree is 1.8 m.

6.2.3 Levee deposits

Allen (1965) described recent levee deposits as being "sinuous, ribbon-like, prismatic bodies of triangular cross-section, the base of the triangle being horizontal and the hypotenuse having a gentle slope away from the channels". Levees and crevasse splay deposits are formed at the channel/floodplain interface and are characterized by coarser sediment (fine to medium-grained) than other overbank deposits. Levees are formed by periodic deposition from floodwaters with additional material supplied by in-situ plants. Levee deposits are best distinguished by their lateral equivalence to channel deposits and their shape (the edge of some splay deposits may also be wedge-shaped, but usually this is on a smaller scale than for the levees). ^{Late Paleozoic and younger.} Levees support abundant vegetation, preserved as in-situ trees, rooted beds, coal stringers, and well preserved leaves and branches. Two types of levee deposits are present: channel proximal and distal. Proximal deposits contain the greatest percentage of sandstone and are thicker than the finer grained distal deposits. Facies include small scale St, Sr, Fl, Fr and Fm. Bioturbation commonly destroys original structures, producing massive beds (Sm, Fm). Distal levee deposits consist of interbedded fine sandstone and mudstone, with facies Sr, Fl, Fm and Fr most common. These deposits quickly pass into other overbank floodplain deposits. Both proximal and distal levee deposits frequently show desiccation cracks.

6.2.4 Crevasse Splay Deposits

Crevasse splay deposits from modern meandering rivers were summarized by Allen (1965) as being "narrow to broad, localised tongues of sediment, sinuous to lobate in plan, deposited over the lower slopes of levees and the outer margins of floodplains from crevasse-channels that tapped active streams in flood".

Tabular sandstone beds without erosional bases between .25 and 1.5 m thick are interpreted as splay deposits. The general lack of facies Se and St, the abundance of Sr, roots, desiccation cracks, and upright tree trunks distinguish splays from small channel deposits. Typically, splays consist of fine to medium-grained sandstone. Rarely, small scale troughs are present near the base, but Se is extremely rare. Ripple cross-laminated fine sandstone or massive sandstone make up most of the units. Large sandstone-filled in-situ tree trunks are occasionally preserved (Figure 6-6). The largest recorded upright tree trunk is over 2 m tall. Ball and pillow structures are occasionally present at the base of the splays.

Gersib and McCabe (1981) describe similar splay deposits from the Carboniferous Port Hood Formation at Cape Linzee, N.S. Two types were distinguished: splays without mudstone partings (their type 2) and splays with mudstone partings up to 8 cm thick (type 1 splays). In this study splays with thick mudstone partings are considered separate deposits;

otherwise the sequence of structures is similar for both studies.

6.2.5 Other floodplain deposits

Nonmarine fossil ostracods (Carbonita fabulina) and mollusks (Anthracomya) (Copeland, 1957; pers. comm., 1983) indicate that ponds or lakes developed within the coal swamps. The size of these water bodies is unknown, but the extremely rare occurrence of fauna, and the thin nature of the fossiliferous beds suggests that they were small and rare. However, the abundance of carbonaceous beds indicates that swamps were a common feature.

Both red (oxidized) and grey to black and greyish-green (reduced) mudstones are present at the same stratigraphic levels, as are siderite and hematite. As in the Fredericton sub-basin climate alone can not explain the distribution of colours (LeGallais, 1982). Fluctuating water levels and varying amounts of organic matter within the sub-environments are probably the main controls of colour. As with levee deposits, roots, trees, fossil leaves and desiccation cracks are present. Burrows are also present, and when beds of mudstone are thinly interbedded with fine sandstone differential compaction produces undulating beds.

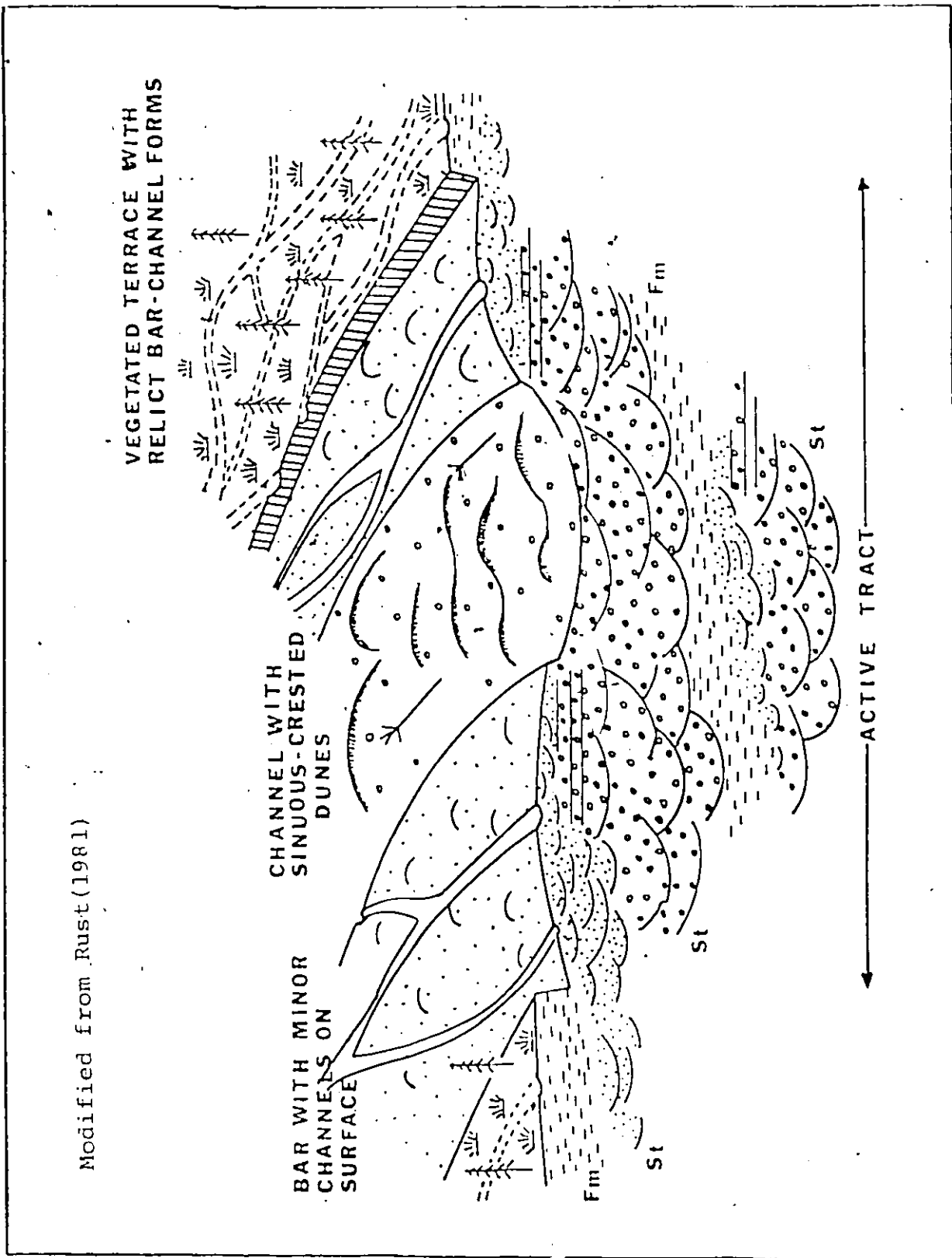


Figure 6-7. Sandy braided depositional environments.

6.3 THE SANDSTONE FACIES ASSEMBLAGE (S.F.A.)

In contrast to the well developed fining-upward sandstone-mudstone sequences of the Alternating Facies Assemblage, the S.F.A. shows a less varied set of depositional environments with poorly developed cyclicity. The major types of deposits are interpreted as channel and overbank (Figure 6-7). No levee deposits or lateral accretion surfaces are present. The lower 100 m of the 148 m S.F.A. section (Appendix I) contain overlapping lenticular channel sandstone deposits, distinguished from each other only by erosion surfaces. The upper 8 m contain a series of fining-upward sequences of sandstone-mudstone, similar to the A.F.A. deposits but with much less mudstone.

6.3.1 Channel deposits (0-100m)

The most common facies sequence in this section is Se-St-Sh or Sr. Sp is minor and in many cases Sh and Sr are absent. Mudstone forms under 10 % of the section, and is either greyish-green or black. The sandstone units are difficult to map because of their lenticular nature; erosion surfaces are common, and are often marked by greyish-green mudstone intraclasts and plant fragments. Flute casts are also common (Figure 6-8.) Logs up to a few metres long are common at the base of some channels, but conglomerate does not form more than 8 % of the section.

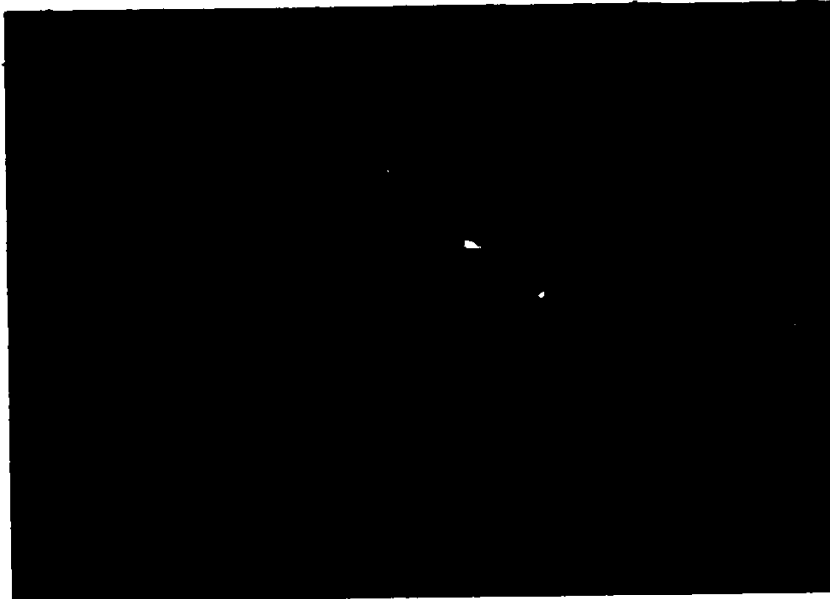


Figure 6-8. Flute casts at base of a channel sandstone. South False Bay section.



Figure 6-9. Steeply dipping fine - grained beds (near metre stick) are part of a slump block.

The measured sequence of lithofacies is similar to those measured at Bateston and South Bar. However, the lithology of the two sections is generally coarser than that south of False Bay, with under 5 % mudstone (Rust et al., 1982).

As pointed out in section 5.6, except for fewer Sp units, the lithology and sequence of sedimentary structures of the deposits are similar to facies models of the South Saskatchewan River (Cant and Walker, 1979). Another difference is lateral extent. Lower Morien deposits are at least 40 km wide, and probably were even more extensive before post-depositional uplift and erosion. Rust (1978) pointed out that braided rivers are confined between valley rivers walls. Fans and braidplains are unconfined, and are laterally more extensive than valley deposits. Consequently, only a fraction of their surface areas are inundated at peak discharge. On a geologic time scale, however, all parts of the fan or braidplain are essentially active.

Table 6-1

Lithotypes and facies assemblages of braided alluvium. Facies are arranged in order of approximately decreasing frequency from left to right. Symbols explained in text. (from Rust, 1978).

| Lithotype | Facies | Special characteristics |
|---|--|---|
| ----- | | |
| Gravel | | |
| Fac. assemblage G[1]: (alluvial fans) | Gms, Gm, St, Sp, Fl/Fm | Great lithological variation. Crude cycles may be present. |
| Fac. assemblage G[2]: (Proximal braided rivers and alluvial plains) | Gm, Gp, Sp, Sh | Gm dominant; usually with well-developed imbrication. Gp more abundant in pre-U. Paleozonic deposits. |
| Fac. assemblage G[3]: (Distal braided) | Gt, St, Gm, Sh, Fl | Fining-upward cycles. |
| ----- | | |
| Sand | | |
| S[1]: Fac assemblages: (Proximal braided rivers and alluvial plains) | Sh, Sp, Sr (Bijou Ck. type) Se, Sl, St(Ss)(Malbaie) | Sh dominant. Vertical and lateral variability. |
| Fac. assemblage S[2]: | Se, St(Ss), Sp, | Fining-Upward cycles. |

| | | |
|------------------|-----------|---|
| (Distal braided) | Sr, Fl/Fm | Transitional to deposits of meandering rivers. |
|------------------|-----------|---|

Silt

| | | |
|------------------|--------|---|
| (Distal braided) | Fl, Fm | Lack of association with sandy channel deposits. |
|------------------|--------|---|

Five braided lithotypes were distinguished on the basis of lithology, sedimentary structures, and overall diagnostic characteristics (Rust, 1978). Types G[1]-G[3], for example, are dominated by gravel (Table 6-1). Deposits at Bateston and South Bar were grouped as S[1] because of the dominating medium to coarse sandstone, abundance of facies Se and St, vertical and lateral variability, and poor cyclicity (Rust et al., 1982). The first 100 m of the South False Bay section is interpreted as a deposit transitional between types S[1] and S[2] because of the abundance of facies Se and St, minor presence of F1 and Fm, and increased tendency toward cyclicity. Because of the lateral extent of the deposits (over 40 km) the depositional setting is interpreted as a braidplain rather than a river valley or fan.

6.3.2 Channel deposits (100-148 m)

Three fining-upward channel sequences are present in this interval of the South False Bay section. Mudstone makes up about 25 %, compared to about 5 % for the first 100 m. The fining-upward cycles are well developed, beginning with erosional, intraclastic bases of coarse-grained to medium-grained sandstone. These grade into medium-grained units of facies St with some Sh and, rarely, Sp. Alternating ripple cross-laminated fine-grained sandstone and mudstone complete the sequences. The uppermost measured

bed was a 1 m unit of reddish-brown, rooted, fine-grained sandstone with mudcracks. This is the only red bed south of False Bay.

The section from 100-148 m is interpreted as a type S[2] braided deposit because of the amount of mudstone, well developed fining-upward sequences, and stratigraphic position between type S[1] deposits and meandering river deposits (of section 6.2).

6.3.3 OTHER DEPOSITS IN THE S.F.A.

Floodplain deposits in the sandstone facies assemblage consist of grey to greyish-green mudstone to fine-grained sandstone, and a few thin coal seams. The mudstone occurs in beds up to 4 m thick, but most are under 1 m thick. Ripple marks and cross-lamination are common in silt-size and coarser beds. Both the McAuley and Shoemaker coal seams overlie thin seatearths. As with floodplain deposits from the Alternating Facies Assemblage, rootlets and mudcracks are common.

The section between 83 m and 85 m (Appendix I, S.F.B.) is interpreted as a block of slumped floodplain deposits, inclined about 60-70 degrees, and preserved by overlying channel deposits. The unit is lenticular, pinching out over 35 m. Most of the lens is grey mudstone, but where best preserved alternating beds of mudstone and fine-grained sandstone are clearly visible (Figure 6-9).

Cross-lamination, rootlets and mudcracks are present. Beds are thin (most between 2 and 10 cm) but range up to 25 cm. There are no other mudstone units within 50 m below or 15 m above the lens. This attests to the rapidly shifting nature of the braided channels and the resultant low preservation potential of overbank deposits within this environment.

6.4 SUMMARY OF PALEOCURRENT DATA

Approximately 300 paleocurrent readings were recorded from facies St, Sr, and Sh from the study area. Figure 6-10 shows the distribution of readings for trough cross-sets, because they are considered to be the most reliable paleocurrent indicators (Potter and Pettijohn, 1963). Ripple cross-lamination and ripple mark readings are also shown. The mean orientation is towards the northeast (019 for troughs) with a vector magnitude of 83%. The data indicate that paleoflow was from the south or southwest, and that this direction was maintained throughout deposition of the Morien Group in this area. A similar picture is emerging for the whole of the Sydney Basin, although analysis is not yet complete (Rust et al., 1982; Duff et al., 1982).

Paleocurrent data for each measured section are presented in Figure 6-11. Although there is no significant difference in the mean paleocurrent direction, the range of readings is greater in the Alternating Facies assemblage than in the Sandstone Facies Assemblage. This is probably a function of

higher sinuosity channels in the former. Paleocurrents measured in ripple cross-laminated units show a very wide spread, probably representing overbank as well as in-channel deposition.

There is no indication that the Bateston Fault was active during the time of Morien deposition. Paleocurrents in the Bateston section (measured by Rust and Gibling, in Rust et al., 1982) are sub-parallel to the trend of the fault. If the fault had been active during deposition paleocurrents would be expected to flow away from the fault. It is concluded, therefore, that the fault is a post-Morien feature.

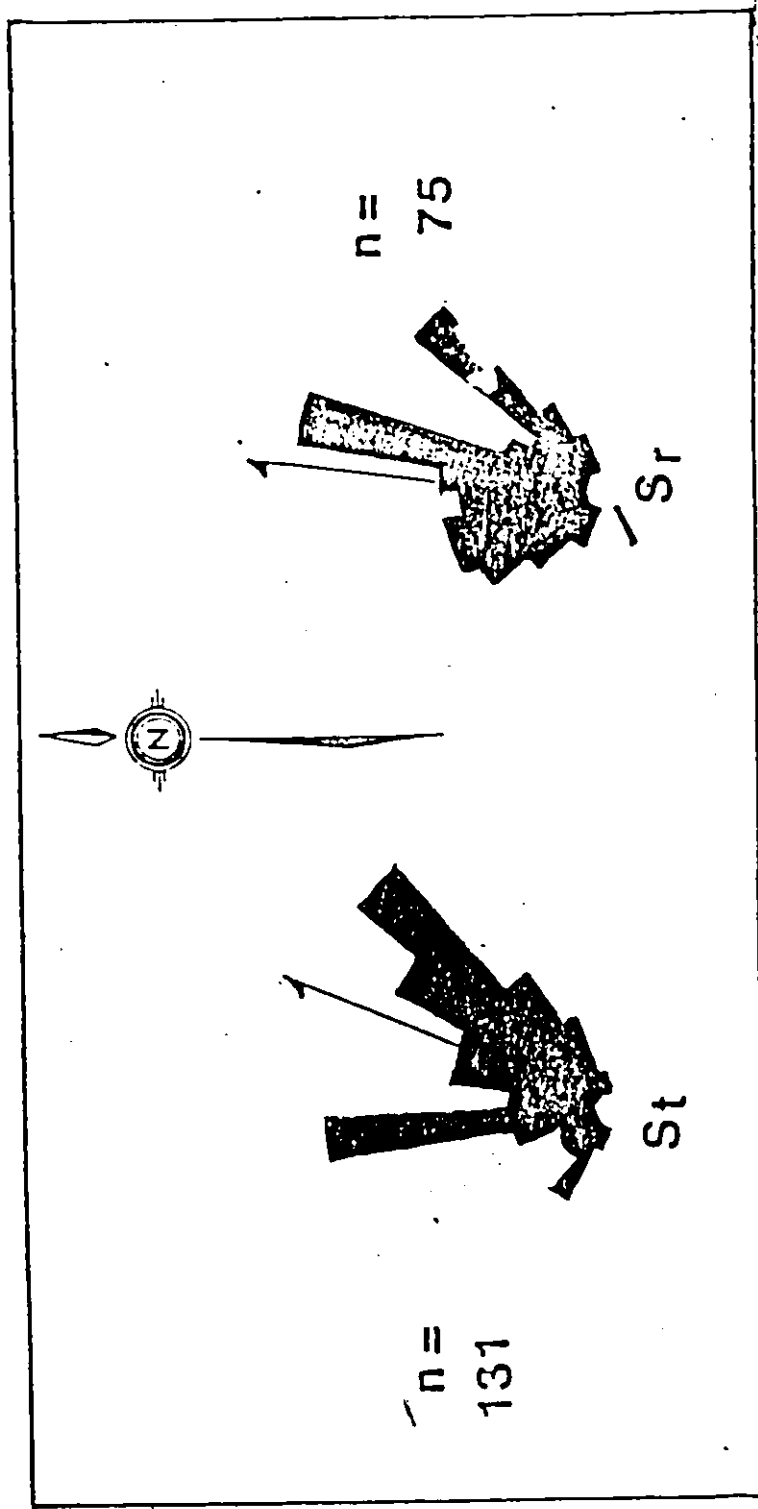
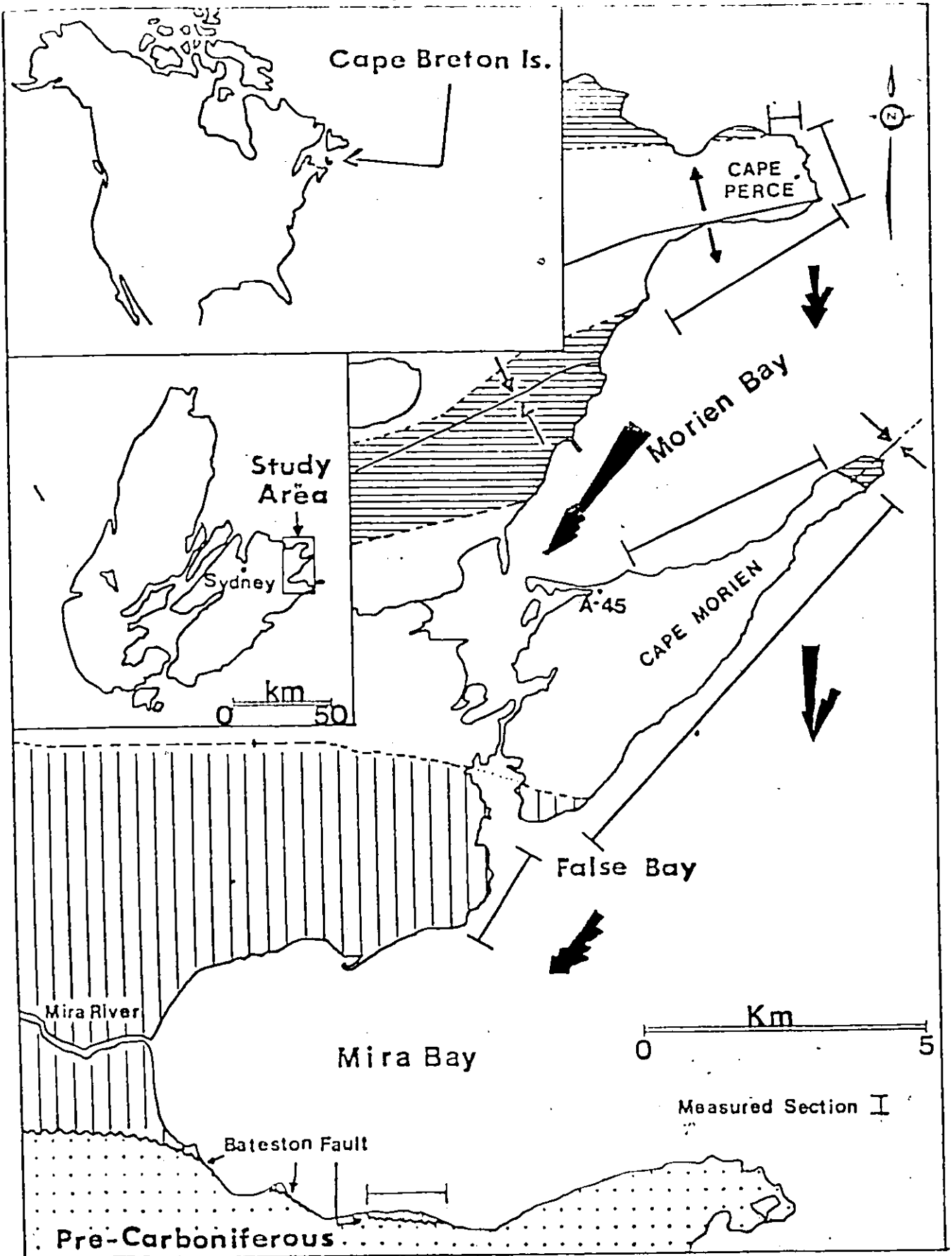


Figure 6-10. Paleocurrents from facies St and Sr from the lower Morier Group throughout the study area.

Figure 6-11. Paleocurrents from St in the Morien Group.



6.5 DEPOSITIONAL HISTORY OF THE STUDY AREA

The earliest deposits of the Morien Group in the study area are also the coarsest (section 6.3). The Sandstone Facies Assemblage represents deposition on a sandy distal braidplain, locally transitional to a meandering alluvial system. The braided deposits are similar to type S[2] deposits of Rust (1978) or the South Saskatchewan deposits of Cant and Walker (1979). The absence of abundant planar cross-strata suggests deeper channels than in the latter model, so that sandflats were developed less frequently. Vegetation accumulated on non-active parts of the braidplain, but was frequently washed away when channels shifted. As the basin filled the regional slope decreased and more stable alluvial plains developed. The McAuley and Shoemaker seams formed under these conditions. The latter is thicker and more laterally continuous than the former (Hayes et al., 1938), marking development of progressively larger swamps within the floodplain.

Older deposits at Bateston and in the southwest portion of the basin are even coarser, and they represent deposits transitional between types S[1] and S[2] of Rust (1978) (data from Rust et al., 1982). As mentioned in the previous section the Bateston fault is probably a post-Morien feature. The original margin of the basin probably extended a considerable distance to the south and southwest, where basin margin facies (type S1 and coarser) may have been deposited.

The transition from distal braided to meandering deposition occurred at different times in different parts of the basin. In outcrop in the study area the change is gradual and occurs between the top of the south False Bay section and the north False Bay section. There is no evidence for faulting between the two sections. The Sandstone Facies Assemblage is confined to the Lonchopteris megafloreal zone, but it does not extend into the uppermost part of the zone. At least 50 m of Alternating Facies Assemblage deposits are present at the top of the Lonchopteris zone.

On the western part of the basin between South Bar and Victoria Mines the transition from braided to meandering deposition takes place near the Linopteris / Ptychocarpus boundary (Rust et al., 1982). The deposition of 700 m (2300 ft.) of braided sandstone deposits in close proximity to about the same thickness of meandering deposits of alternating sandstone-mudstone indicates that depositional conditions (i.e. uplift, erosion; subsidence, deposition) were stable for the duration of the L. obliqua zone. It is anticipated that the facies change takes place progressively lower in the section from west to east but drillhole data (especially sandstone or mudstone isopach data) are needed to trace this change.

The amount of mudstone is greater in the upper part of the Cape Morien (west half) section and the Cape Percé

section than for other, stratigraphically lower sections of the Alternating Facies Assemblage. This is attributed to higher sinuosity channels and larger floodplains, a result of decreased depositional slope. Near the top of the linopteris obliqua zone coal seams become well developed. The abruptness of their occurrence, thickness, lateral extent, and the similarity of other strata above and below these coal seams suggests that climatic or other ecological factors triggered widespread peat development. However, more convincing evidence awaits further study.

The basin is therefore pictured as a gently downwarping area progressively filled from the south or southwest. As the basin filled the regional slope decreased and the drainage system changed from braided to meandering. This interpretation can be applied to offshore areas of the basin, which would be expected to fine towards the center along isochronous lines.

Chapter VII
SUMMARY AND CONCLUSIONS

The Upper Carboniferous Sydney Coal Basin occupies the northeast corner of Cape Breton Island, N.S., and extends offshore almost to Newfoundland. Structurally the basin is saucer shaped, and except for marginal folding and minor thrust faulting in the south, all beds dip toward the center. Three ~~mega~~floral zones recognized by previous authors are, from the base upward: the Lonchopteris, Linopteris obliqua and Ptycocarpus unitus zones. In the present study sections were measured within the lower two zones between Schooner Pond Cove and False Bay Head in the southeast corner of the basin. Four continuous sections were measured: from False Bay Head to False Bay, False Bay to Noneck Point (East side of Cape Morien), west side of Cape Morien north of Campbell Pond, and North of Long Beach to Donkin on Cape Percé.

Lithofacies were recognized on the basis of sedimentary structures and grain size, based on the code of Miall (1978). The following lithofacies were recognized: Se (sandstone with erosional scours), Gm (massive to crudely

horizontally stratified conglomerate), St (trough cross-stratified sandstone), Sr (ripple cross-laminated sandstone), Sh and Sl (horizontal and slightly dipping ((under 10 degree)) sandstone), Fl and Fm (laminated and massive mudstone), C (carbonaceous mudstone and coal), and Fr (rooted mudstone and very fine-grained sandstone). A new ^{termed} facies code, Sm, is proposed for massive sandstone deposits.

The section measured south of False Bay is characterized by a Sandstone Facies Association of Gm-Se-St-Sh/l-Sr, with under 15% mudstone. In the other sections an Alternating Sandstone-Mudstone Facies Association is present, with the mudstone comprising half or more of the sections. The facies sequence is commonly Se-St-Sh/l-Sr-Fl/m-C. Markov Chain Analysis of the vertical facies transitions in each of the measured sections revealed non-random transitions. The above-random transition probabilities between facies Sr and Fl/m increased upward in the stratigraphic sequence, showing the increased influence of these transitions. This is attributed to progressively developing floodplains upward in the sections.

Lithologically, the rocks in the study area are grouped as sublithic, lithic and subarkosic modified from Dott's (1964) classification. In the section south of False Bay subarkoses are common. In the other sections the subarkoses become less important, and none were present above the Coalbrook seam. The amount of metamorphic rock fragments and polycrystalline quartz increases upward in the section.

The presence of coals, paleosols (including in-situ rooted horizons), upright tree trunks with intact roots, and freshwater ostracods (Carbonita fabulina and mollusks (Anthracomya) indicate that the Lonchopteris and Linopteris obliqua strata in the study area were deposited in a terrestrial environment. There is no evidence for marine incursion: marine fossils and thick, coarsening upward deltaic sequences are absent.

The section measured south of False Bay is interpreted as a sandy distal braidplain deposit (Type S[iii] of Rust, 1978) on the basis of lateral continuity, paleocurrents, lithofacies sequence, and the amount of sandstone in the section. The Alternating Facies Association in the other sections is interpreted as a meandering river deposit. Lateral accretion surfaces are present within channel sandstone beds as gently dipping planes that cross the entire unit. These channel sandstones are interpreted as point bar deposits. Abandoned channels filled with fine-grained material indicate chute cutoff, neck cutoff or avulsion. Tabular sandstone bodies with non-erosional bases that frequently preserve upright trees are interpreted as splay deposits. Levee deposits occur as interbedded sandstone-mudstone units laterally transitional between channel sandstone deposits and overbank mudstones.

The two facies associations indicate deposition on an alluvial plain. As the basin filled distal braidplain

deposition gave way to deposition on a wide meandering river floodplain. The braidplain probably supported a fair amount of vegetation, especially in the transitional stages to meandering channel patterns. However, most of the peat and mud was not preserved in place.

✓ The facies sequence of the Sandstone Facies Assemblage most closely resembles the South Saskatchewan River model of Cant and Walker (1979). One important difference is that facies Sp is relatively unimportant in the study area. This is probably a function of deeper channels in which trough cross-beds formed. Shallow-water sand flats which may generate planar cross-beds were developed more rarely.

Paleocurrent data indicate that drainage was from the south or southwest throughout deposition of the measured sequence. The lower part contains enough feldspar (mostly potassium-rich) to produce subarkosic rocks (Dott, 1964). Feldspar content drops off quickly above the Tracy Seam, and no subarkoses were found above the Coalbrook seam. The percentage of polycrystalline quartz and metamorphic rock fragments increases above the Tracy, and most sandstones are classified as sublithic or lithic above that horizon. More sampling is necessary to trace these trends across the basin. Petrography indicates that during Lonchopteris time an igneous plutonic source area was being actively eroded. Later, this source became unimportant, and evidence of a metamorphic source became more abundant.

The transition from a Type S[iii] distal braidplain to a meandering system indicates a gradual decrease in regional slope as the basin filled. Rivers became more sinuous and mud was preserved on a relatively large area of the floodplain. As the amount of mud increased, compaction became important, and caused water tables to rise. Swamps formed in low areas and were preserved as coal seams. The thickness and lateral extent of the coal seams generally increase upward in the section.

Integration of this study area with other parts of the Sydney Basin awaits completion of work in those areas. One aspect in need of attention is the facies change from east to west across the basin. With respect to time markers (represented by coal seams) deposition is coarser in the western part of the basin (e.g. Victoria Mines) than at Cape Morien. Meandering river deposition commenced earlier in the east than in the west.

A small syncline was observed offshore of the Cape Morien Headland. This indicates that an anticline is present between this syncline and the Morien Syncline. It is proposed that the newly observed syncline and inferred anticline be called the South Head Syncline and Anticline. These structures and other new and old seismic and field data were incorporated into a new structural interpretation of this offshore area. It is believed that a swing in the axis of the Morien Syncline towards the south would account

60 9

for an observed 253 m anomaly in Borehole H-3 from Morien Bay.

Appendix I
STRATIGRAPHIC SECTIONS

| | PAGE |
|---|---------|
| Key | 158 |
| South False Bay Section - Measured from the first outcrop north of the Ferguson property to the south shore of False Bay... | 159-161 |
| Cape Morien (east half) - Measured from the first outcrop north of False Bay to just north of Noneck Point, where beach ends. | 162-169 |
| Cape Morien (west half) - Measured from Campbell Pond north to Emery seam..... | 170-173 |
| Cape Percé Section - Measured from north end of Long Beach to Emery seam east of Donkin..... | 174-177 |

APPENDIX I KEY



MDST



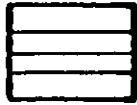
ROOTS



St



INTRACLASTS



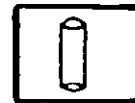
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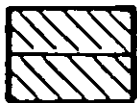
MUD CRACKS



Sr



BURROWS



Sp



WOOD FRAGMENTS



COAL



FI/m



IN-SITU TREE

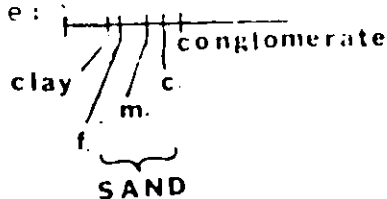
Vertical scale in metres.

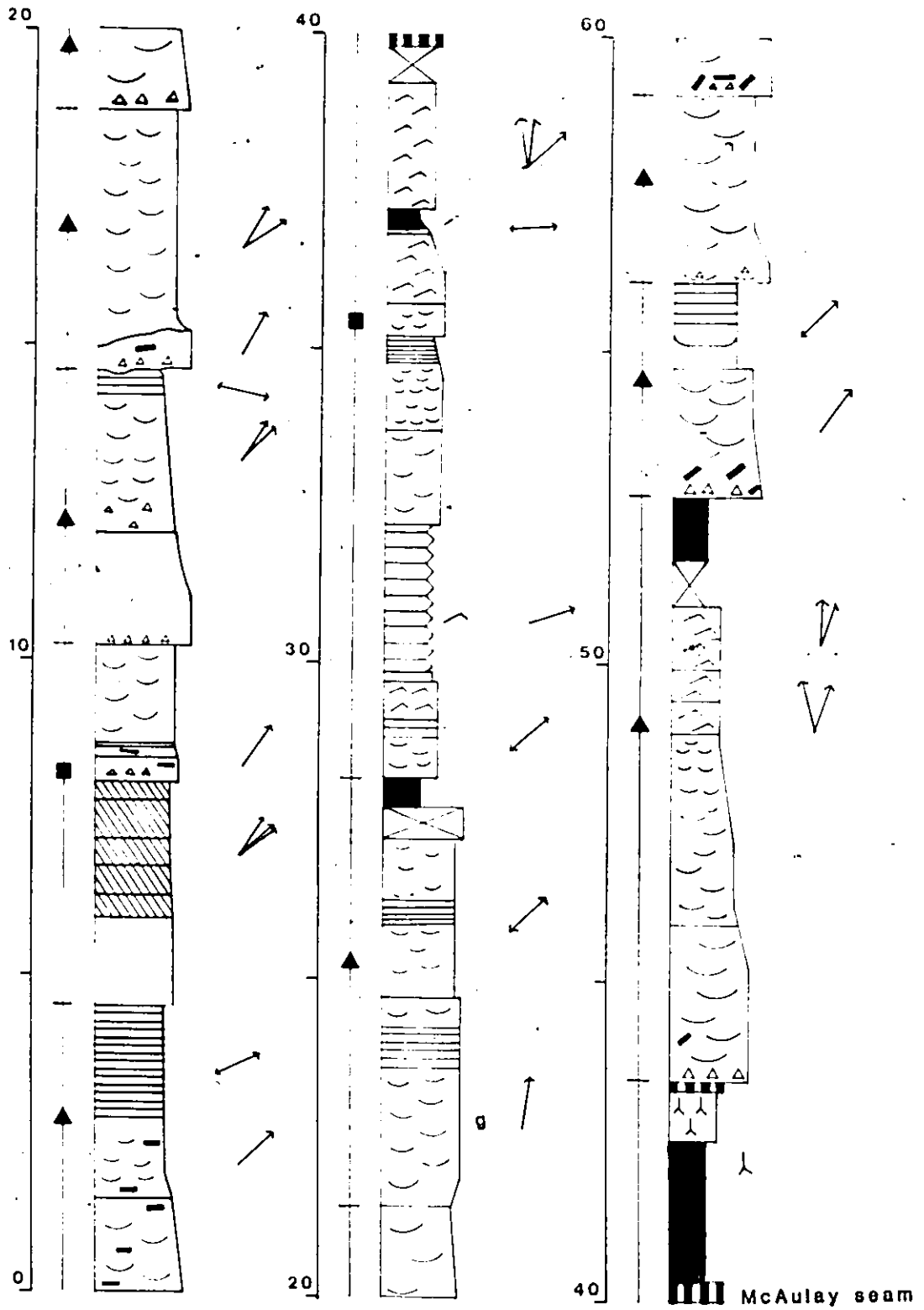
Arrows indicate paleocurrent direction.

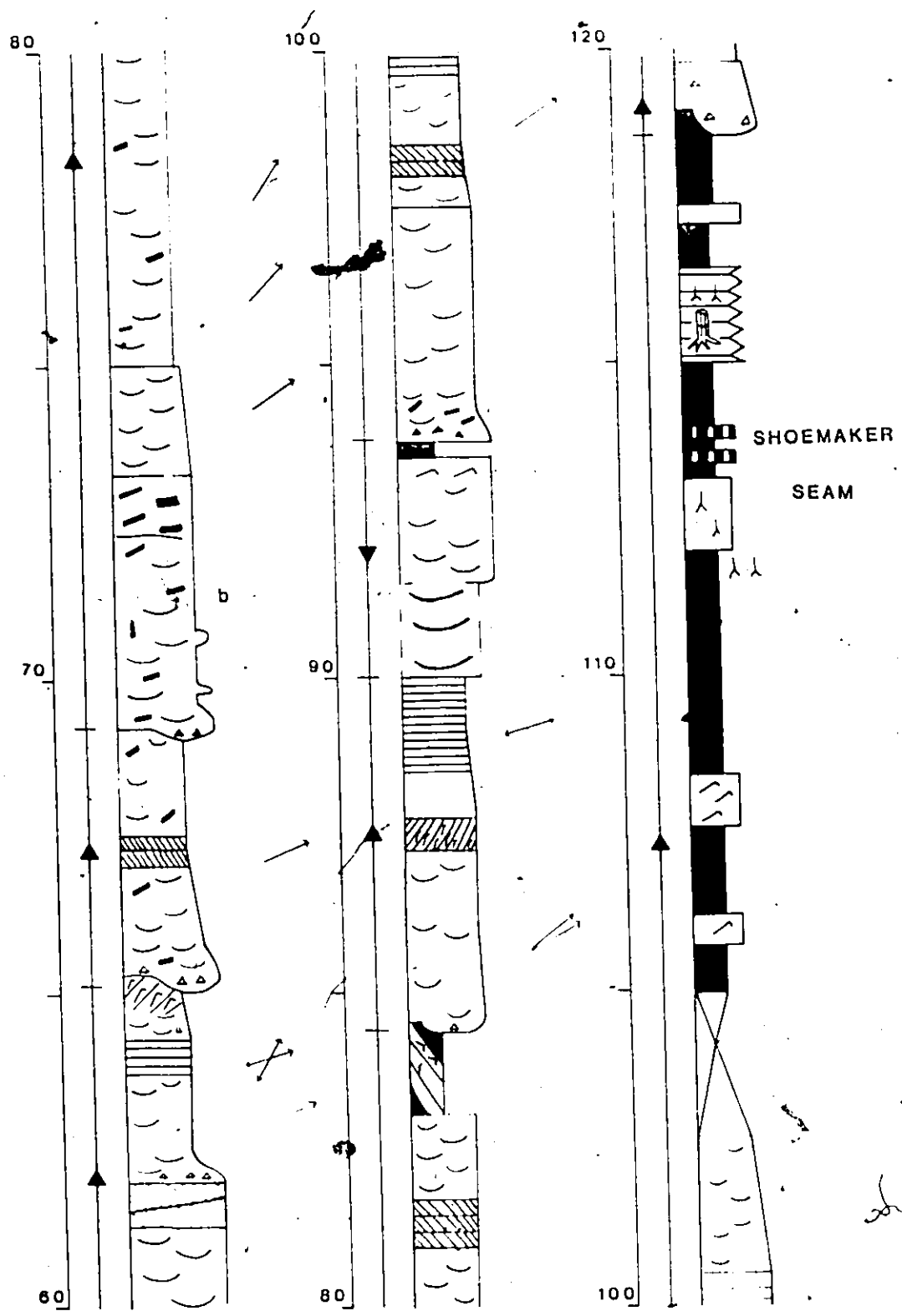
Blank space represents massive sandstone.

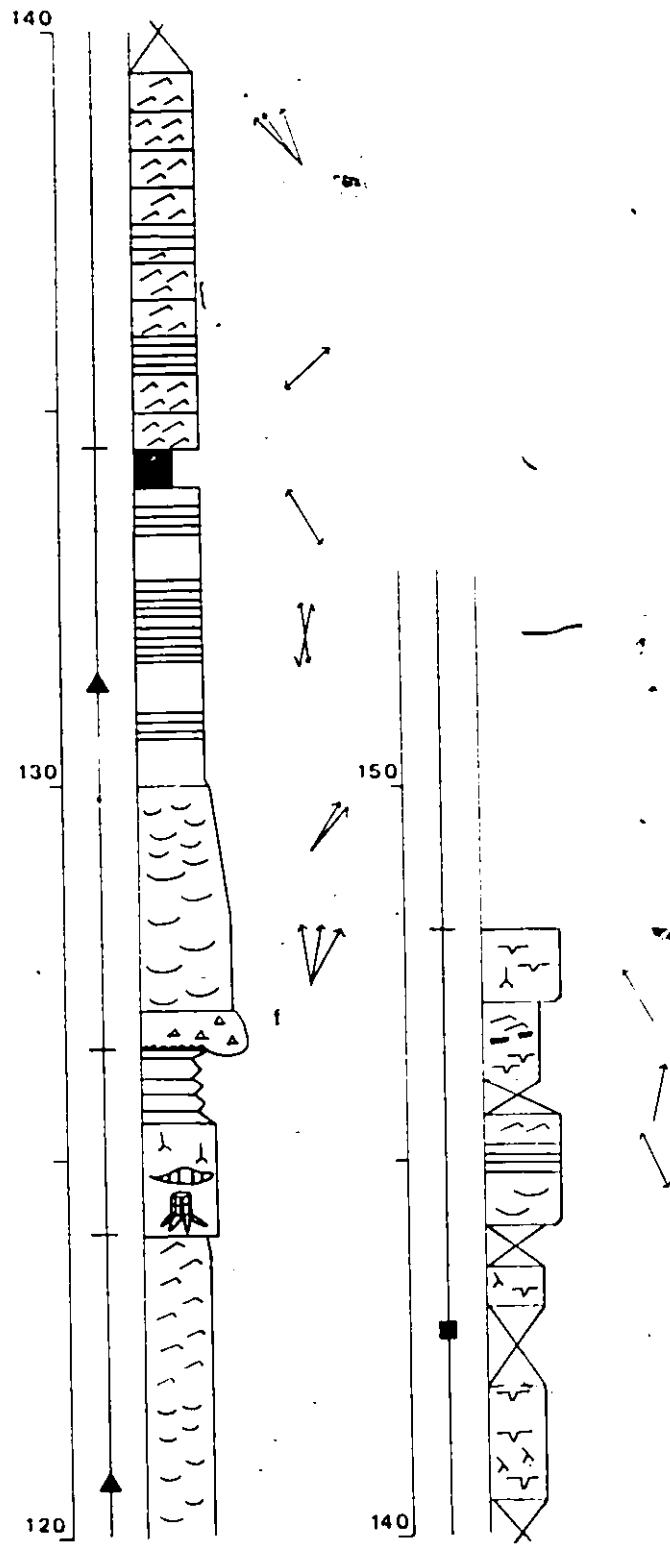
▲ = Fining up; ▼ = Coarsening up; ■ = Alternating beds.

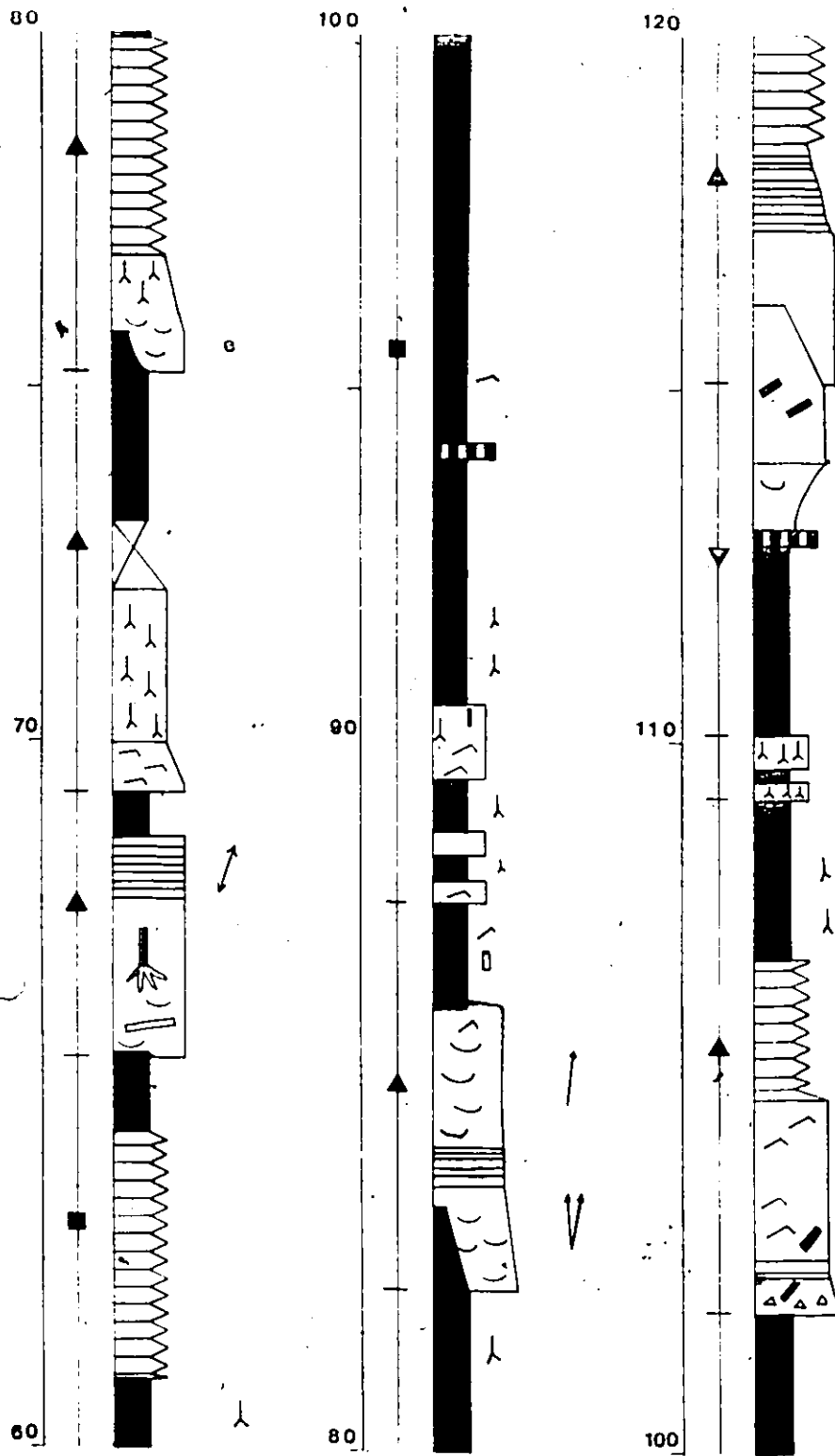
Horizontal scale:



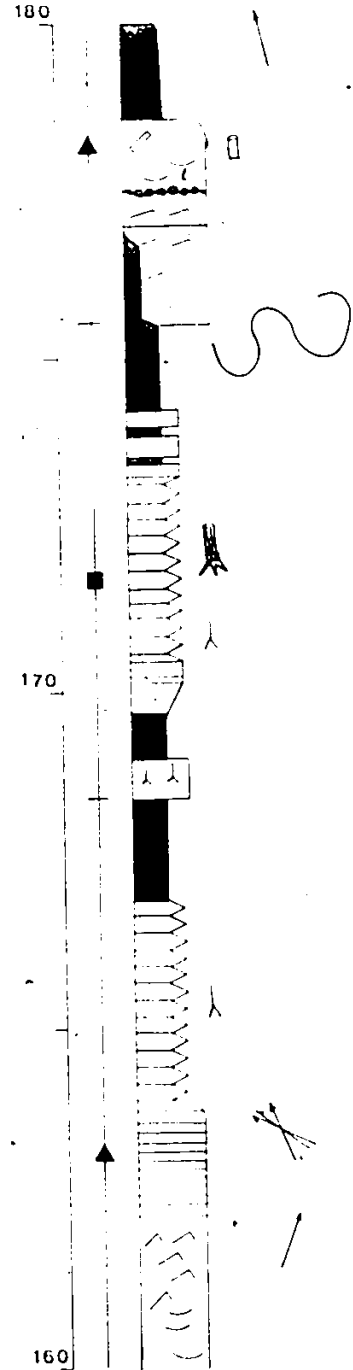
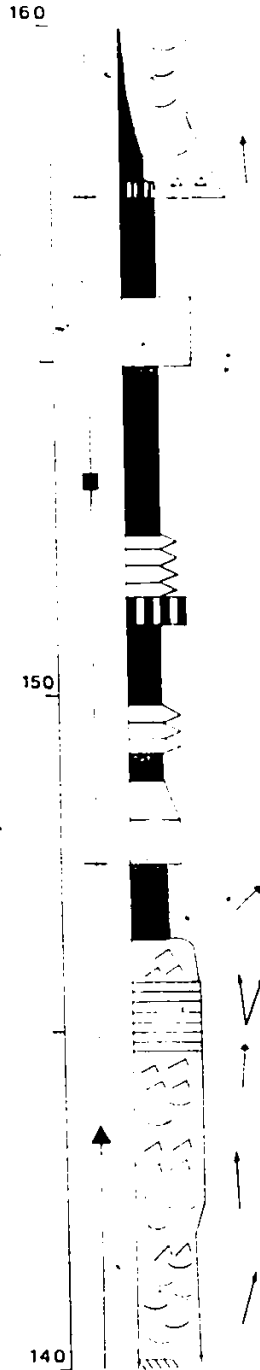
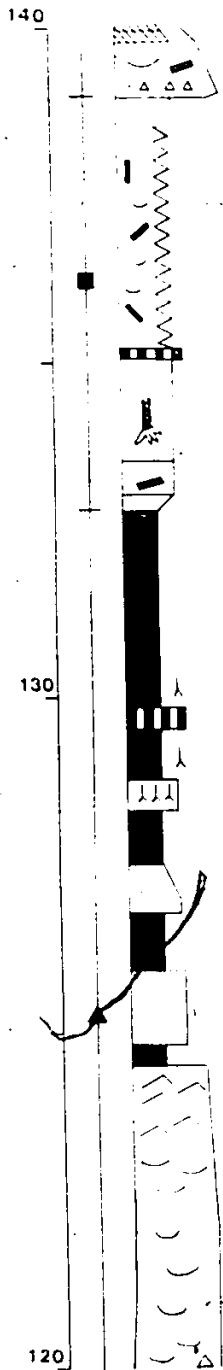


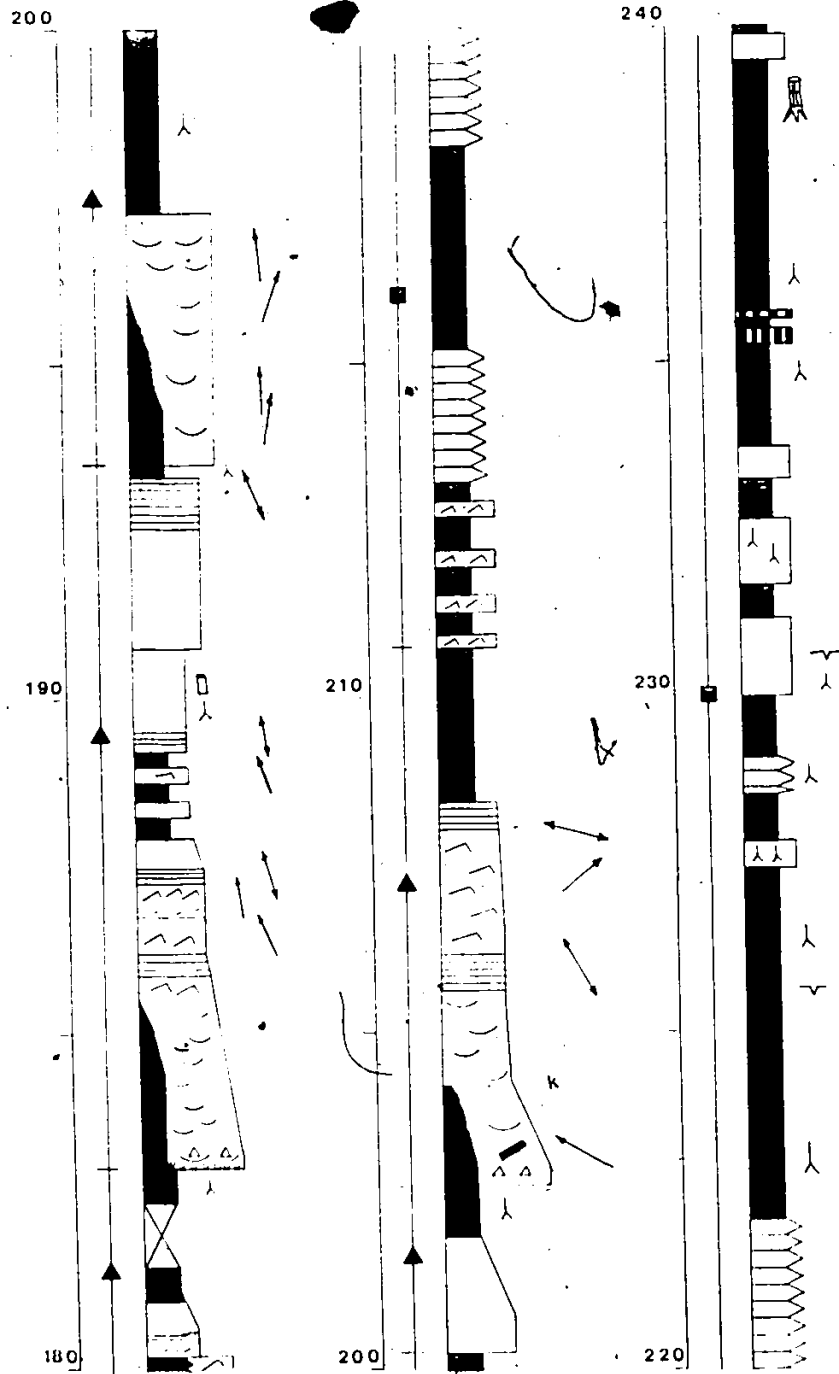


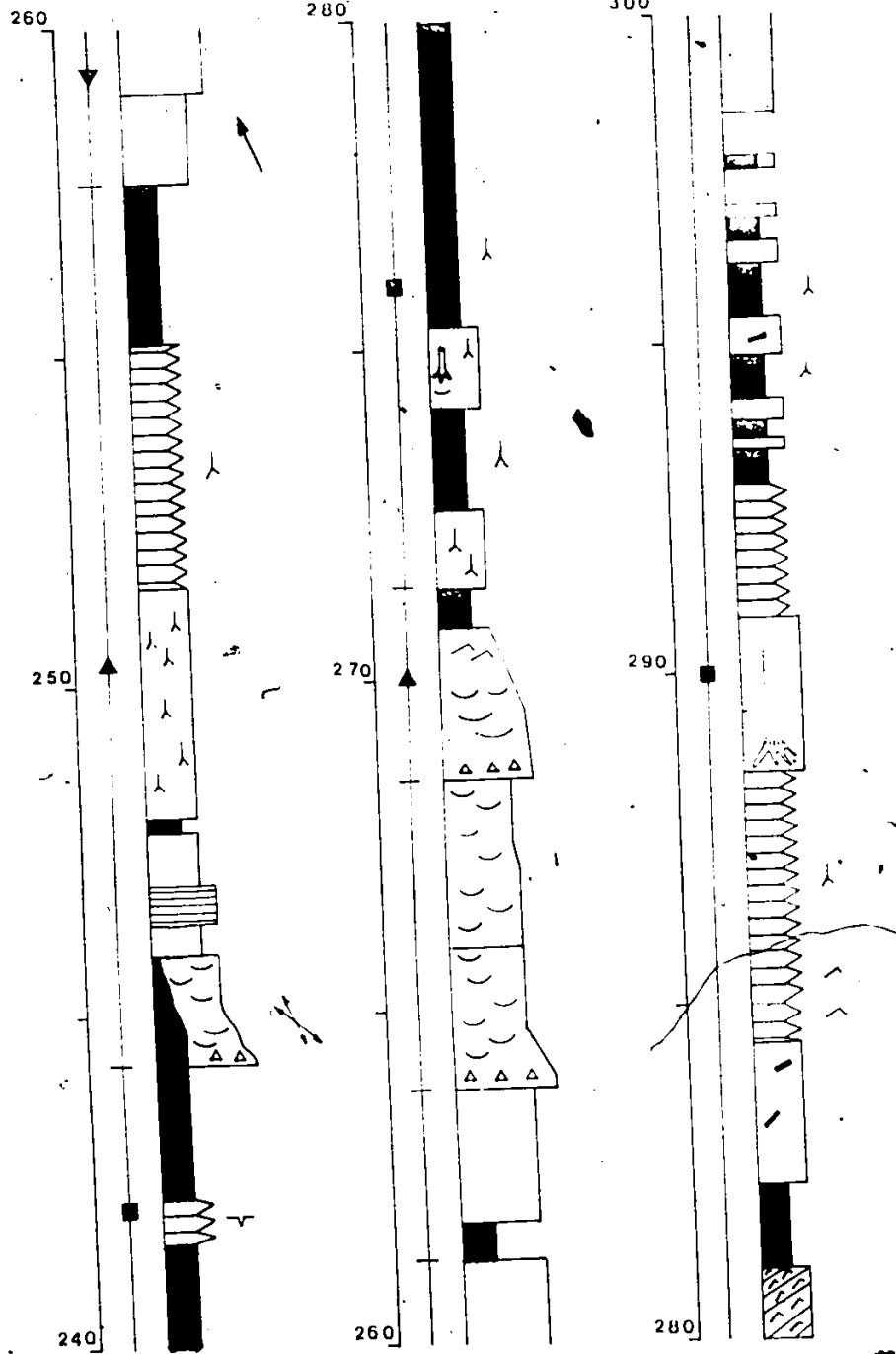


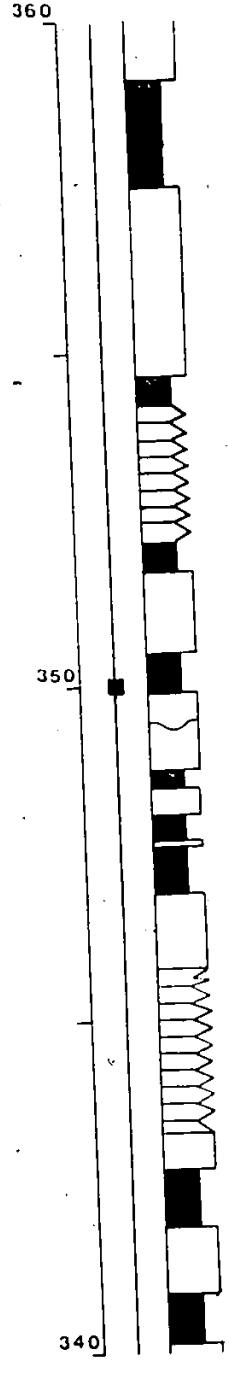
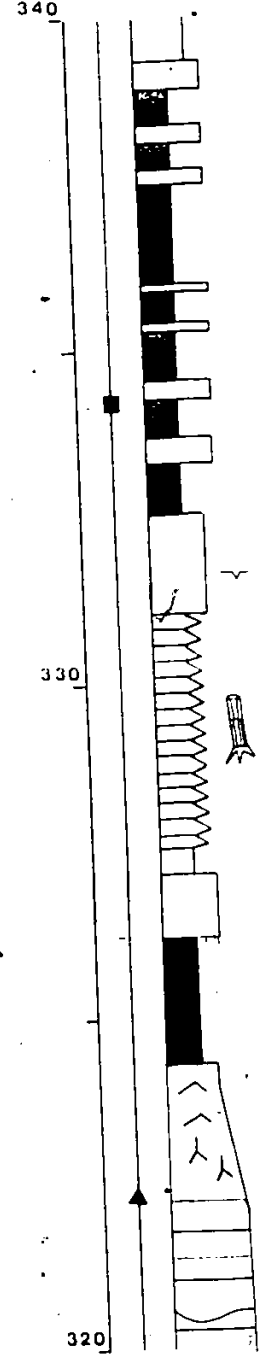
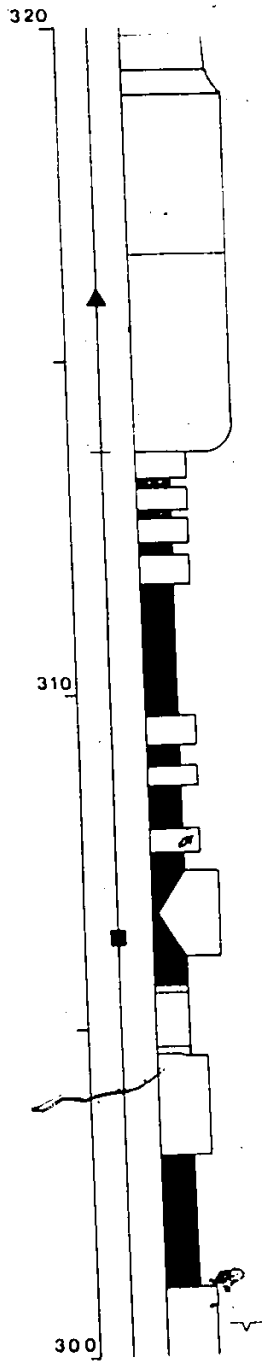


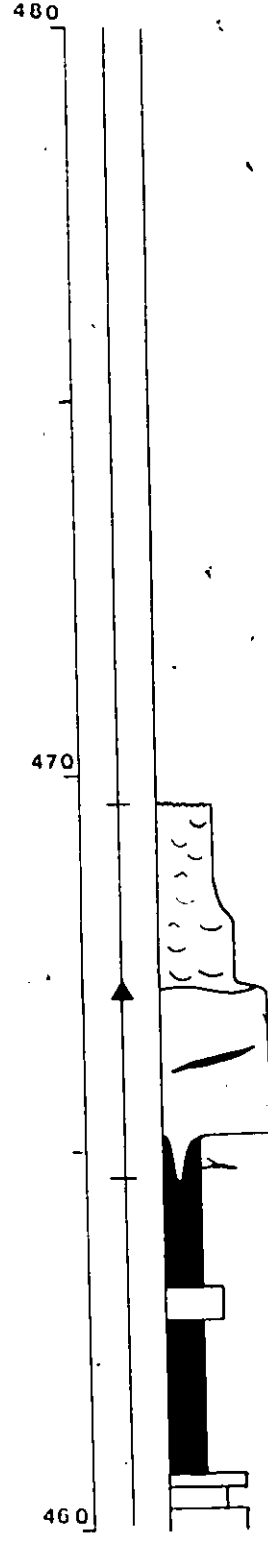
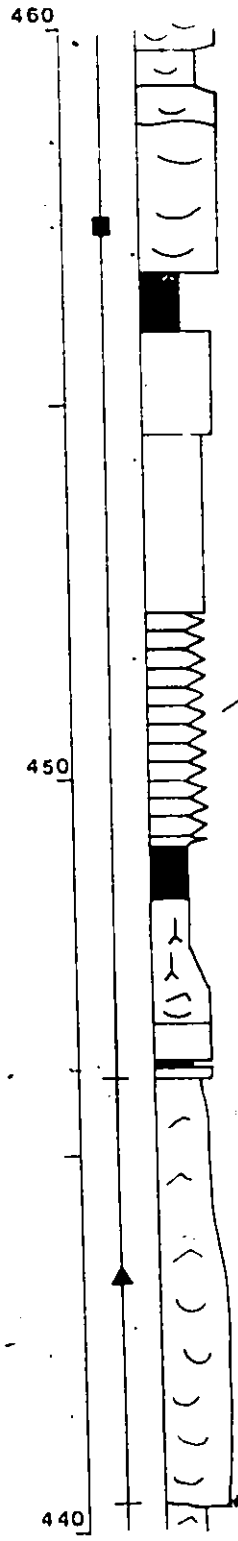
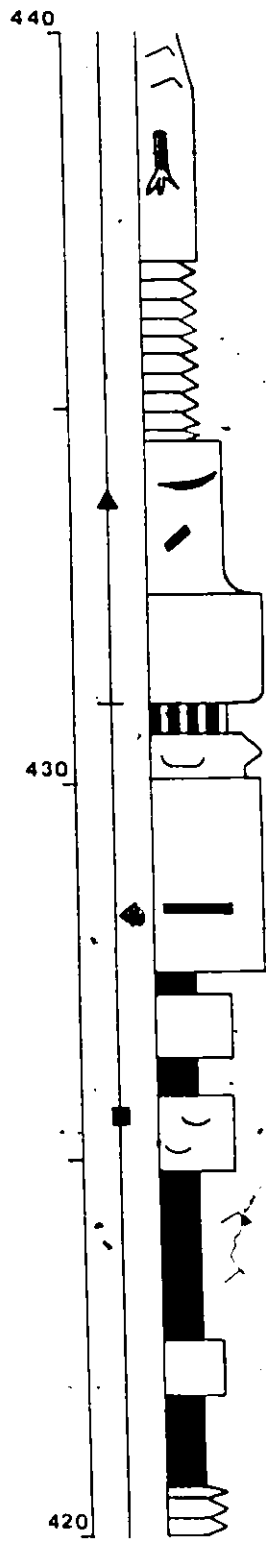
l B

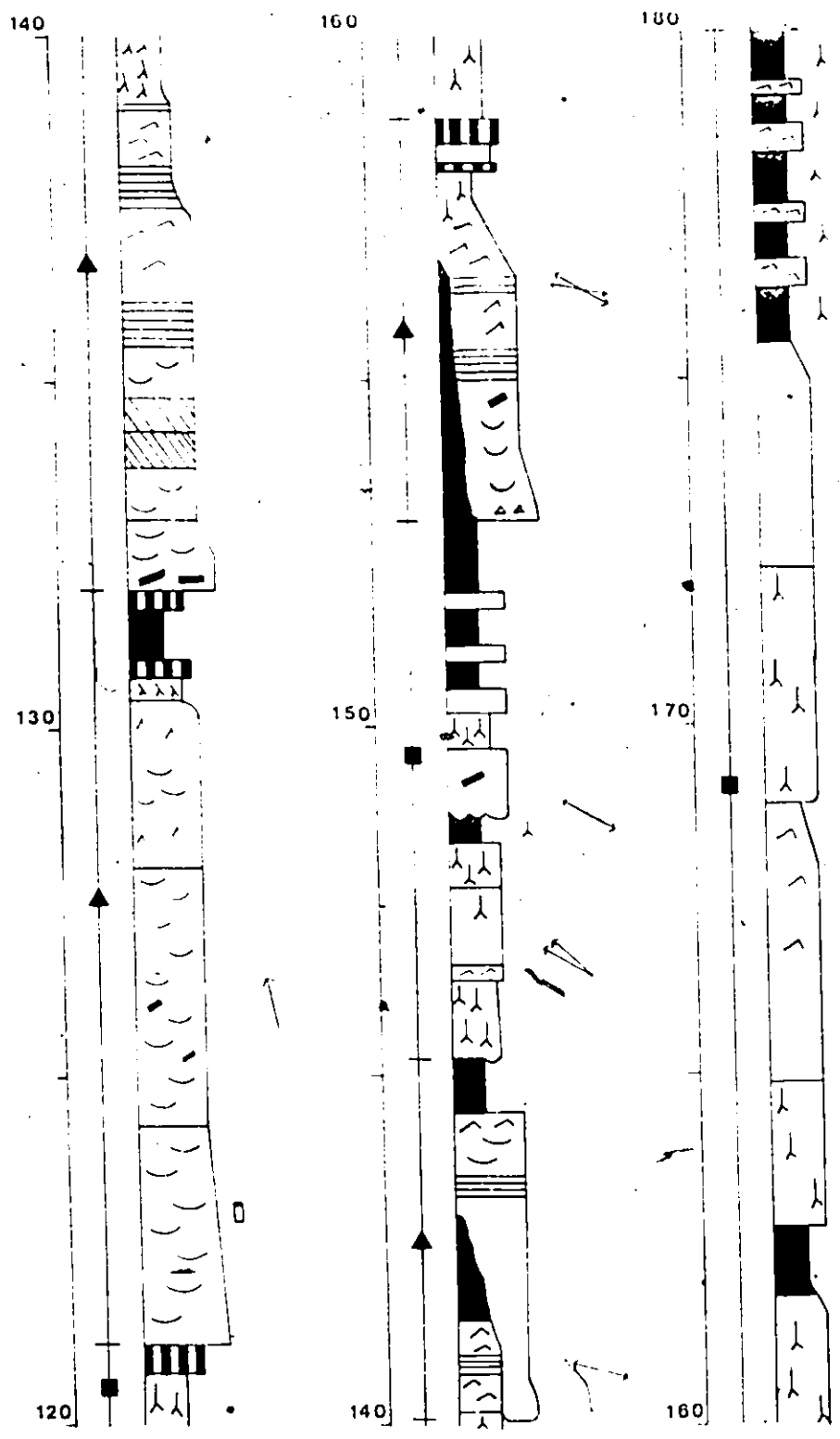


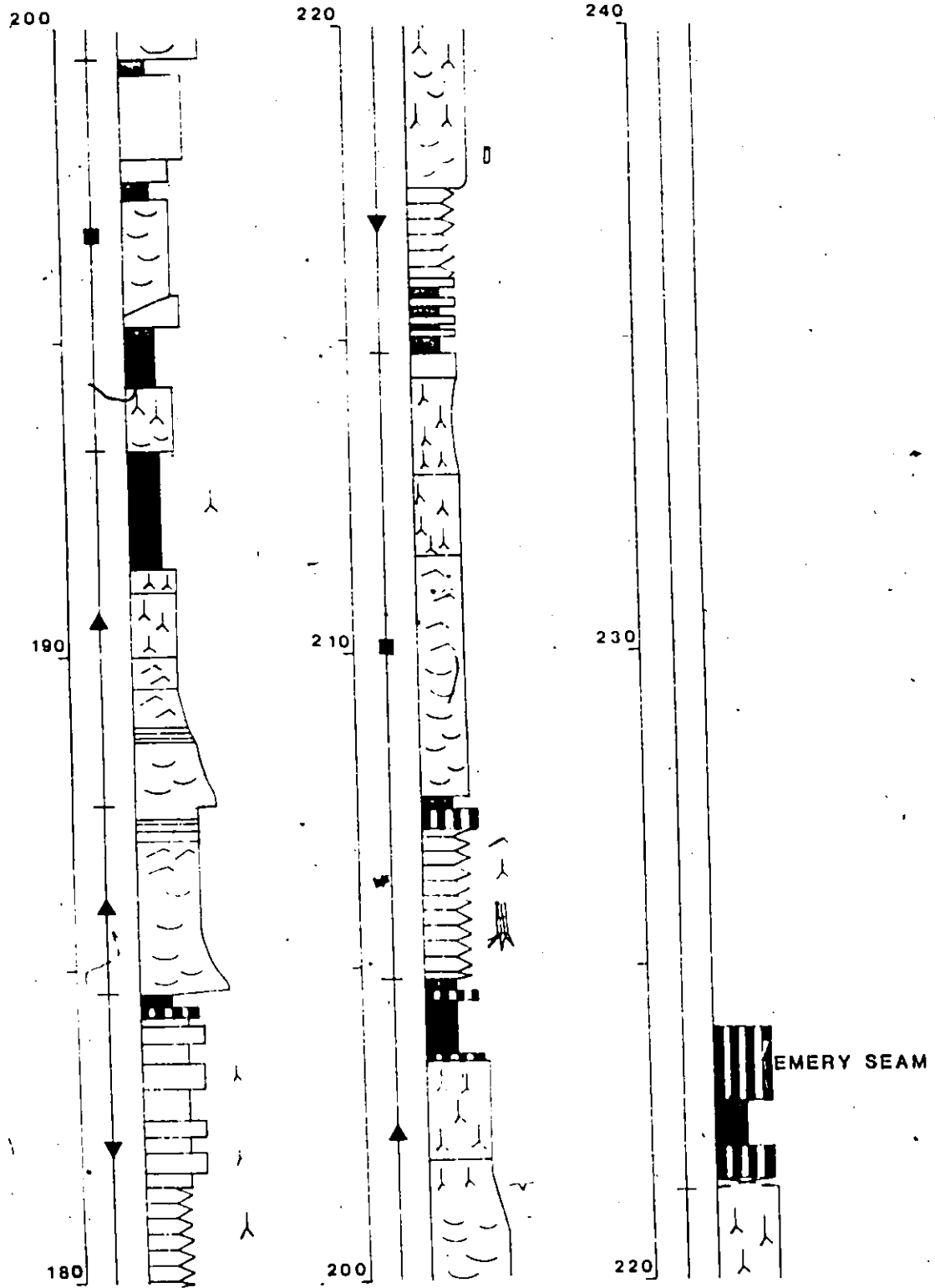


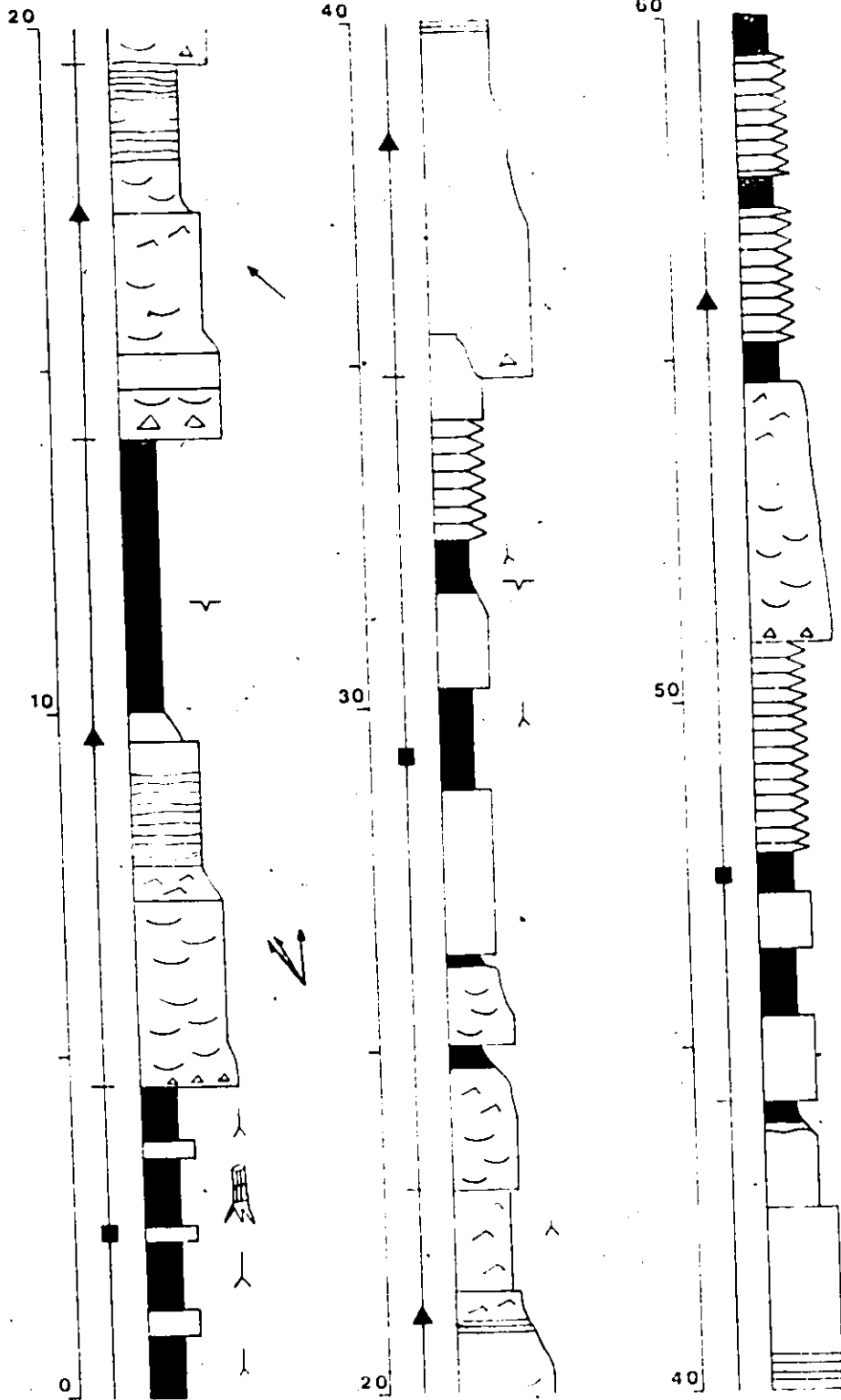


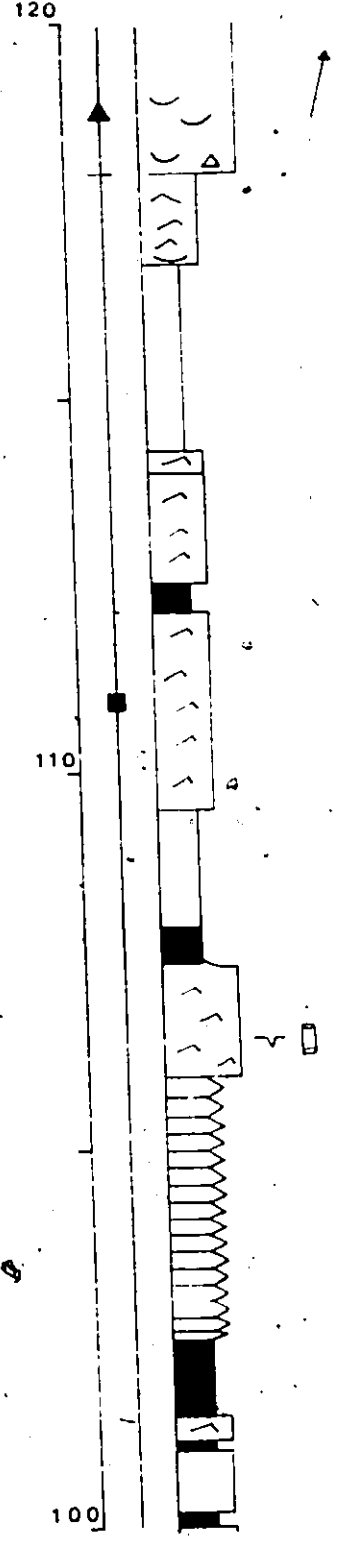
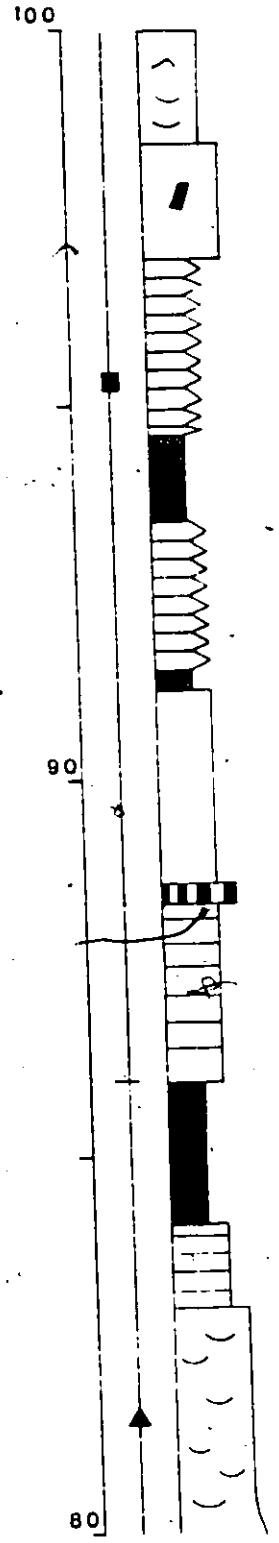
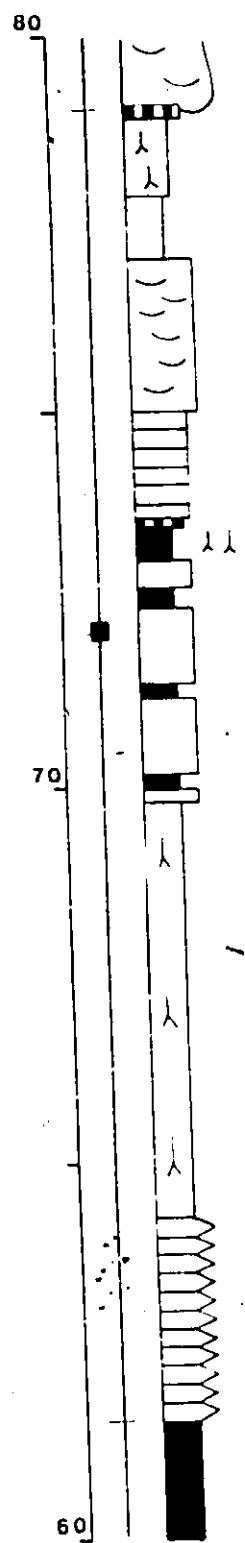


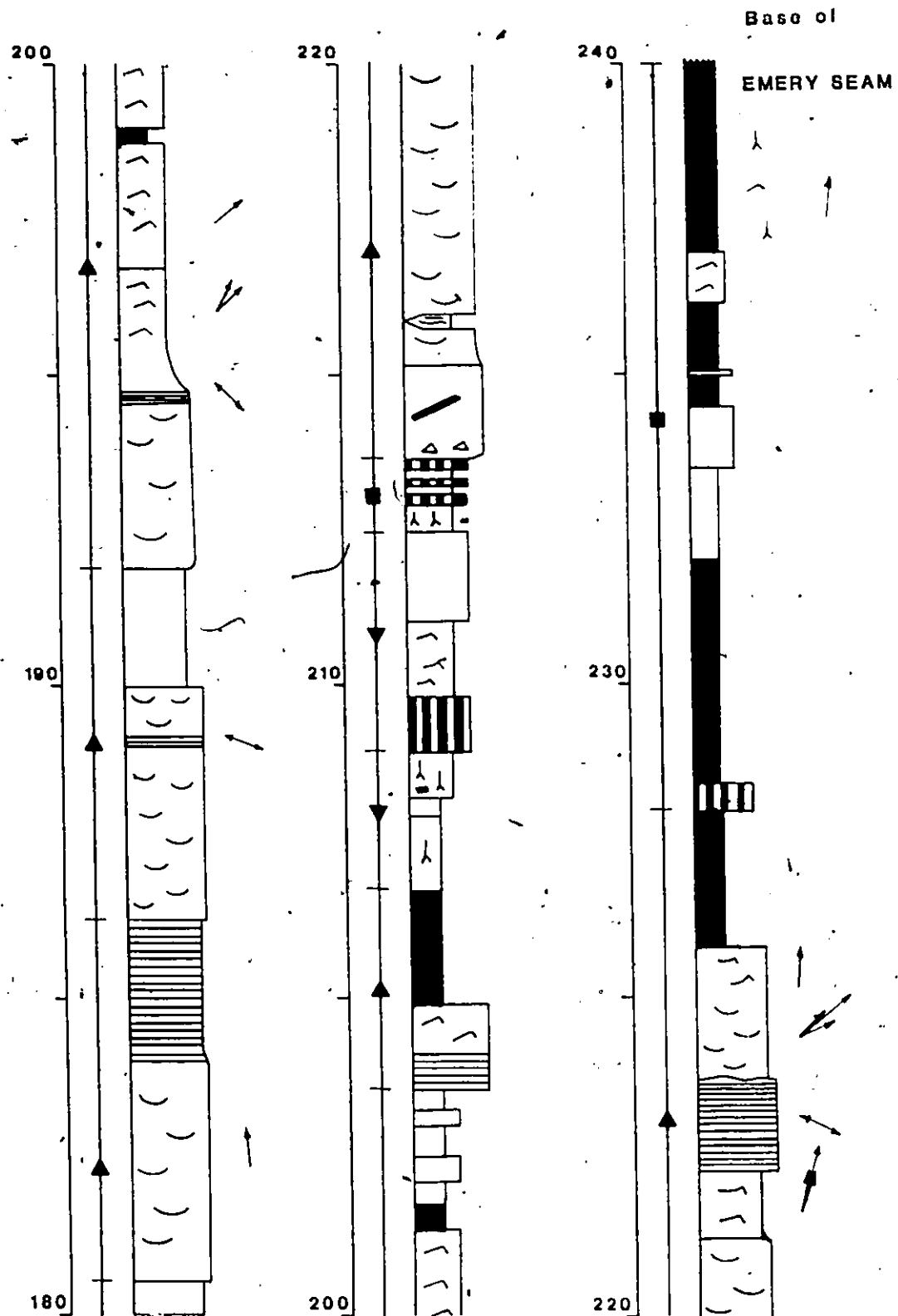












Appendix II

PREVIOUSLY DESCRIBED FLORA FROM THE STUDY AREA

McAuley Seam:

Family Calamariaceae

Asterophyllites equisetiformis (Schlotheim) Brongniart

Calamites waldenburgensis Kidston

Family Alethopterides

Alethopteris davreauxi (Brongniart) Goepfert

Family Neuropterides

Neuropteris aculeate Bell = N. pseudogigantes H. Potonié

Neuropteris heterophylla (Brongniart) Sternberg

Family Sphenopterides

Sphenophyllum cuneifolium (Sternberg) Zeiller

Sphenophyllum cf. trichomatosum Stur

Shoemaker Seam:

Family Sphenophyllaceae

Sphenophyllum sp. indet.

Family Lepidodendraceae

Lepidodendron dawsoni Bell

Lepidodendron sp. (twig)

From Bell (1966) and Zodrow and McCandish (1980)

Family Alethopterides

Alethopteris davreauxi (Brongniart) GoepfertAlethopteris valida, BoulayLonchopteris eschweilleriana Andrae

Family Neuropterides

Linopteris muensteri (Eichwald) H. PotoniéNeuropteris rarinervia BunburyNeuropteris sp. indet.Neuropteris tenuifolia (Schlotheim) Brongniart

Family Pecopterides

Odontopteris subcuneata Bunbury

Family Sphenopterides

Sphenopteris cf. striata GothanSphenopteris (Diplotmema) Bell

Tracy Seam:

Family Neuropterides

Linopteris neuropterides (Gutbier) H. PotoniéNeuropteris tenuifolia (Schlotheim) Brongniart

Family Paleopterides

Eremopteris artemisiaefolia (Sternberg) Schimper

Family Sphenopterides

Sphenopteris cf. striata Gothan

APPENDIX III
PETROGRAPHIC DATA

TABLE III-A
POINT COUNT DATA (300 Points)

| SECTION | %Qm | %Q Pxl | %F | %I.R.F. | %S.M.R.F | MATRIX | MEAN GRAIN SIZE |
|---------|-----|--------|----|---------|----------|--------|--------------------|
| SFB-39 | 54 | 7.5 | 6 | 1 | 20 | 12 | C. SAND |
| SFB-7 | 58 | 5 | 3 | 1 | 11 | 22 | P. BEARING C.S. |
| A-397 | 59 | 3 | 5 | 1 | 32 | 1 | P. BEARING C.S. |
| SFB-4B | 62 | 8 | 6 | 0 | 5 | 19 | P. BEARING C.S. |
| NCP-17 | 60 | 17 | 5 | 1 | 11 | 5 | P. BEARING C.S. |
| NCP-28 | 56 | 13 | 1 | 0 | 13 | 15 | P. BEARING C.S. |
| SFB-45 | 57 | 3 | 7 | 1 | 27 | 4 | P. BEARING C.S. |
| SFB-47 | 43 | 22 | 0 | 0 | 29 | 6 | P. BEARING C.S. |
| A-B1-2 | 48 | 22 | 7 | 3 | 15 | 5 | P. BEARING C.S. |
| NCP-C9 | 36 | 22 | 1 | 0 | 28 | 13 | P. BEARING C.S. |
| A-19 | 60 | 20 | 4 | 0 | 12 | 4 | P. BEARING C.S. |
| A-13 | 59 | 14 | 2 | 0 | 10 | 15 | COARSE SAND |
| NNP-12 | 30 | 33 | 1 | 0 | 23 | 13 | CONGLOMERATE |
| CPE-95 | 26 | 46 | 1 | 0 | 18 | 9 | CONGLOMERATE |

SFB = SOUTH FALSE BAY; A = CORE A-45; NCP = NORTH CAMPBELL POND;
NNP = NORTH NONECK POINT; CPE = CAPE PERCE (See Fig. 1-1).

TABLE III-B
THIN-SECTION AND HAND SAMPLE DATA

| SAMPLE | COMPOSITION | | | | | GRAIN SIZE | | | | | |
|--------|-------------|-------|-------|-----|-------|------------|----|------|------|---------|--------|
| | % Q | % F | % R | F | OTHER | CLAY | FS | M.S. | C.S. | GRANULE | PEBBLE |
| 311-AH | 70 | 8-10 | 20 | -- | -- | -- | 20 | 52 | 15 | 3 | 10 |
| 47-SH | 80 | 8-10 | 10-12 | -- | -- | -- | 0 | 10 | 65 | 20 | 5 |
| 300-AH | 75 | 10-14 | 7-10 | 5 | -- | -- | 45 | 30 | 15 | 3 | 7 |
| 371-AH | 80 | 8-10 | 3-5 | 3-5 | -- | -- | -- | 32 | 60 | 8 | -- |
| 318-AH | 80 | 10-15 | 5 | -- | -- | -- | 30 | 60 | 10 | -- | -- |
| 281-AH | 75-80 | 10-12 | 10-12 | -- | -- | -- | 50 | 30 | 18 | -- | -- |
| 39-SH | 65-70 | 7-9 | 5 | 15 | 15 | 15 | 20 | 50 | 10 | -- | -- |
| 365-AH | 70-75 | 10-15 | 10-15 | -- | -- | -- | 30 | 65 | 5 | -- | -- |
| 20-SH | 70-75 | 10-15 | 10 | -- | -- | -- | 85 | 15 | -- | -- | -- |
| 351-AH | 80 | 10 | 5 | 5 | -- | -- | 5 | 40 | 15 | 25 | 15 |
| 45-SH | 80 | 10-12 | 8-10 | -- | -- | -- | -- | 10 | 25 | 55 | 10 |
| 294-AH | 80 | 10-12 | 8 | -- | -- | -- | -- | 15 | 75 | 5 | 5 |
| 1-SH | 80 | 12 | 3 | 5 | -- | -- | -- | 7 | 85 | 5 | 3 |
| 298-AH | 83 | 10-12 | 3-5 | -- | -- | -- | 0 | 25 | 65 | 10 | -- |
| 7-SH | 80 | 7-10 | 10 | -- | -- | -- | 10 | 45 | 30 | 10 | 5 |
| 17-NH | 75 | 1-2 | 24 | -- | -- | 12 | 20 | 51 | 12 | -- | -- |
| 28-NH | 74 | 5-7 | 24 | -- | -- | -- | 25 | 65 | 8 | 2 | -- |
| 232-AH | 78 | 3 | 4 | 14 | 20 | 75 | 5 | -- | -- | -- | -- |

AH = CORE A-45, SH = S.F.B SECTION, NH = CAPE PERCE SECTION

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