'Detailed Stratigraphy of Part of the Upper Morien Group, (Upper Carboniferous), North Sydney, Cape Breton Island, Nova Scotia.'

by

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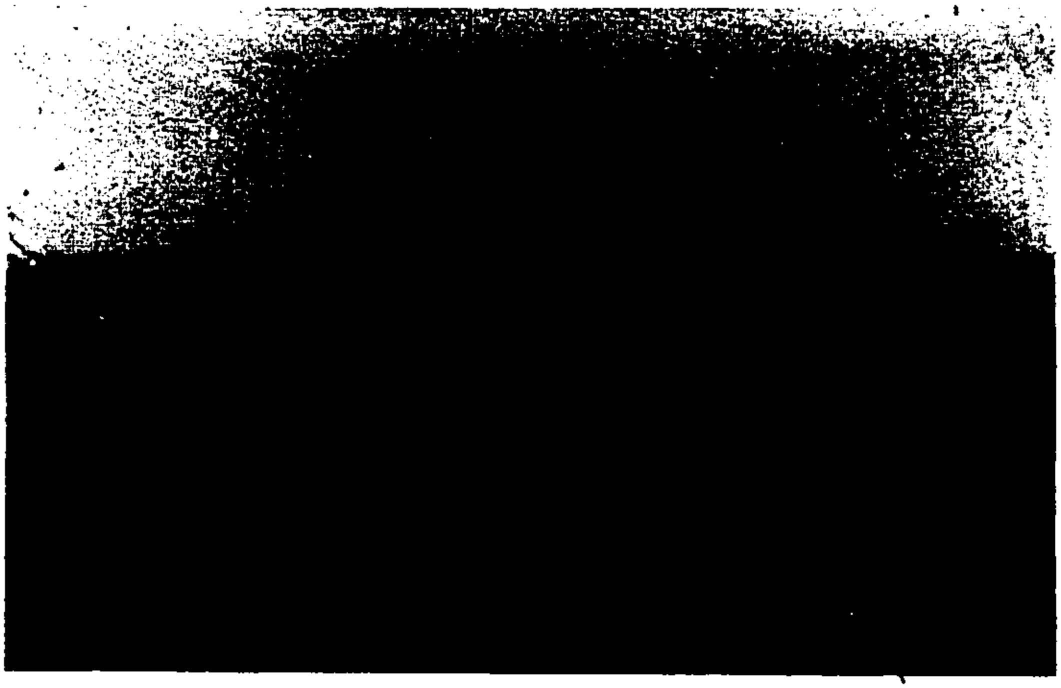
Frontispiece: Cranberry Head, Cape Breton Island.

"..many rivers go down to the sea,
and the sea goes on forever, forever."
(Chris de Burgh)



ABSTRACT

The Sydney Basin, Nova Scotia contains Carboniferous rocks ranging from Visean to Stephanian in age, of which the Morien Group is the youngest part of the succession. Lack of marine fossils and marine sequences, the presence of non-marine fauna, abundant organic material (including <u>in situ</u> trees), paleosols and a fluvial association indicate a terrestrial environment of deposition for the Morien Group.

The upper Morien Group is interpreted as a meandering fluvial sequence deposited on a broad flood plain. It consists of three major facies assemblages : a sandstone assemblage, an alternating assemblage and a mudstone assemblage.

The sandstone facies assemblage comprises fining upward sequences dominated by trough cross-stratified sandstones, ripple cross-stratified and horizontally stratified sandstones and siltstones. Lateral accretion units are recognized and attributed to point bar deposition. Sinuosity of the system was calculated from widths and depths obtained from the lateral accretion units. The result (mean sinuosity = 1.87) indicates a highly sinuous system. Lateral correlations of drill cores and cliff sections show great lateral extent for the sandstones. The high sinuosity and

great lateral extent are attributed to a very migratory system, which traversed a broad flood plain.

The alternating facies assemblage consists of alternating beds of sandstone, siltstone, mudstone and coal. The sandstone and siltstone are typically rippled and grade into each other; less commonly, they grade into mudstone and coal. Fossil rich black shales and limestone are less common, and contain non-marine fossils. These lithofacies fine and coarsen upward into each other. They are only occasionally marked by erosional surfaces. These units are attributed to upper point bar surfaces, lake deltas, levee, crevasse splay, flood plain and lacustrine deposits.

The mudstone facies assemblage consists of thick sequences of red and grey mudstones and minor siltstone and sandstone beds. These units are laterally continuous for great extents (up to a few kilometres). This assemblage is attributed to distal flood plain and flood basin deposition. Both the alternating facies assemblage and the mudstone facies assemblage contain various paleosols. These include calcretes and non-calcareous paleosols. Crystallaria and ped structures are observable in thin sections of the calcretes.

Paleocurrent analysis of the upper Morien Group shows an overall northeasterly trend. Within the group, there is an orthogonal relationship between the overbank deposits and the channel sandstones.

The upper Morien Group was deposited on a broad flood plain located in the southwestern part of a larger, east-west elongated basin. Sedimentological data and the structural framework of the area indicate that the Sydney Basin is a marginal strike-slip basin. It formed part of the Fundy Basin System, which developed early in the Devonian Acadian orogeny and experienced continual faulting, folding and subsidence into the Carboniferous. These internal faults and folds created local uplifted blocks and sub-basins. Deformation included the final stages of the Acadian orogeny and deformation associated with the Alleghenian orogeny, which formed integral stages in the development of the Appalachian Structural Province.

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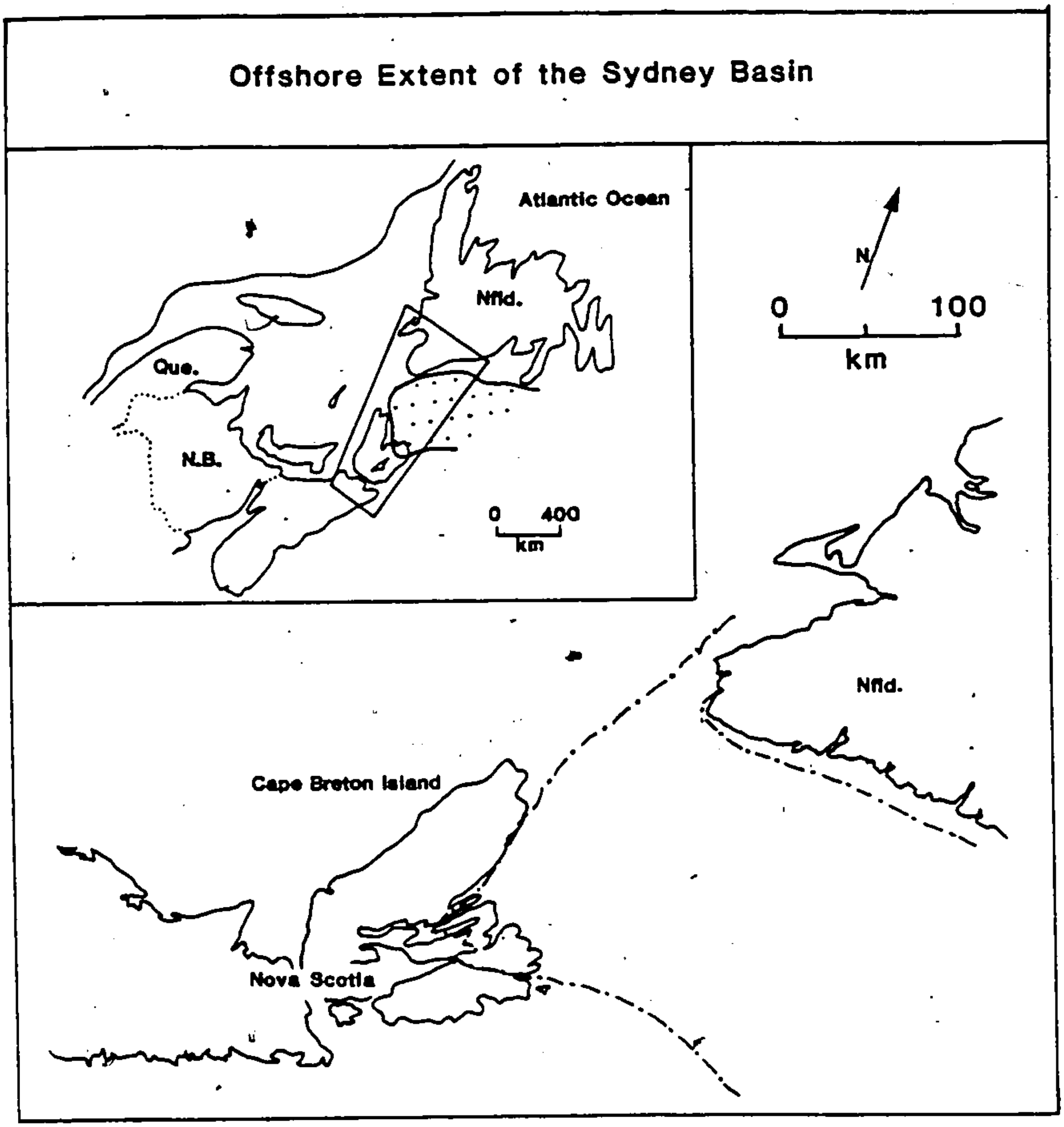
Chapter I

INTRODUCTION

The onland part of the Sydney Basin occupies the north-eastern part of the lowlands of Cape Breton Island, Nova Scotia. It is the south-western extremity of a much larger basin, which extends north-eastward under the Atlantic Ocean (figure 1). On land, the Sydney Basin covers approximately 360 km^2, bounded on three sides by the Atlantic Ocean and to the south-west by lower Carboniferous rocks (figure 1).

The Sydney Basin consists of Carboniferous rocks ranging from Visean to Stephanian in age. In ascending stratigraphic order, the succession consists of the Grantmire Formation, the Windsor Group, the Point Edward and Cape Dauphin Formations and the Morien Group (figures 2 and 3). More detailed descriptions of the lower parts of the succession can be found in Bell,(1938), Weeks (1954), Boehner (1983), Dilles and Rust (1983), Giles and Boehner (1982), Giles (1983), Rust and Masson (1981) and Rust et al. (1983).


Offshore Extent of the Sydney Basin
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Nova Scotia

Figure 1

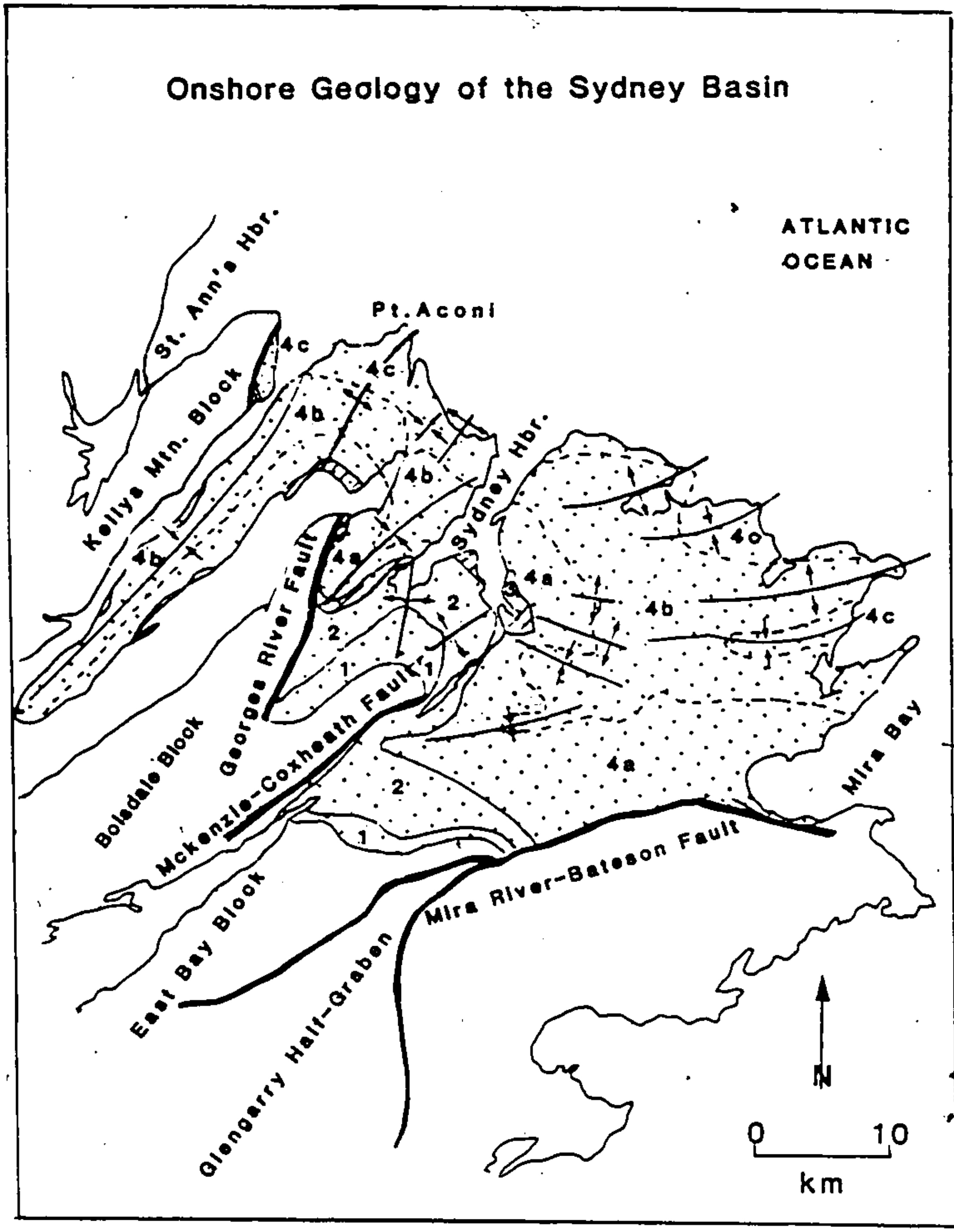


Figure 2 (legend see figure 2b)

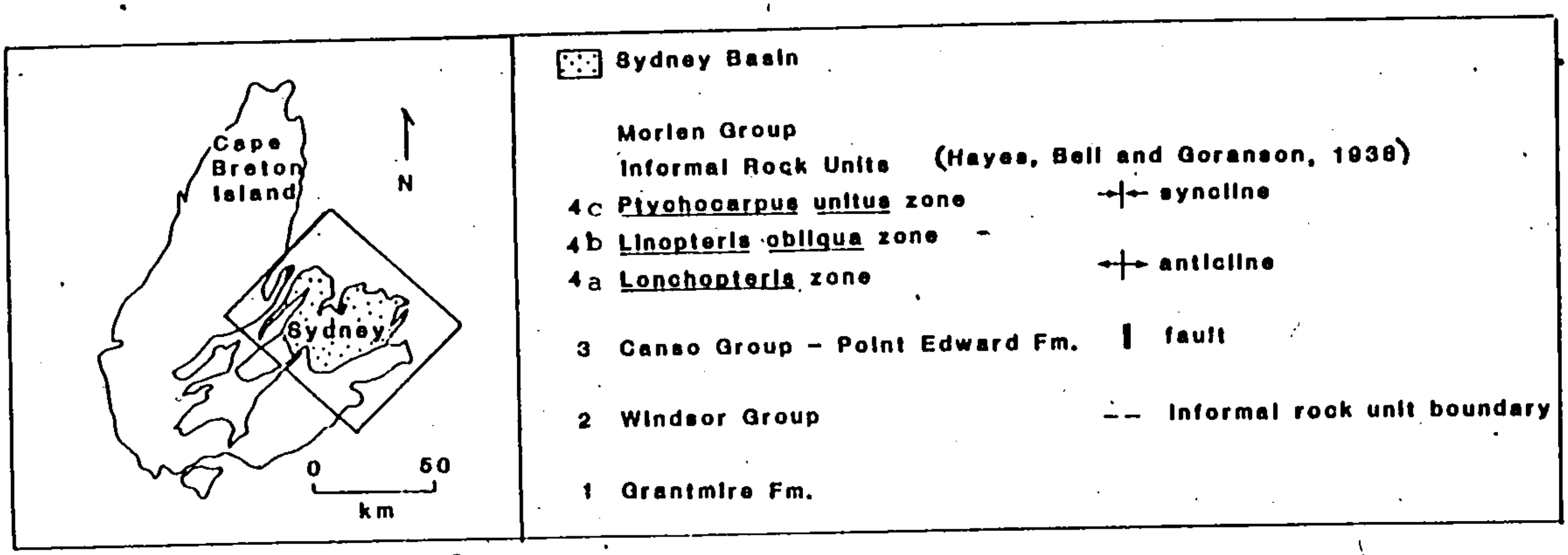
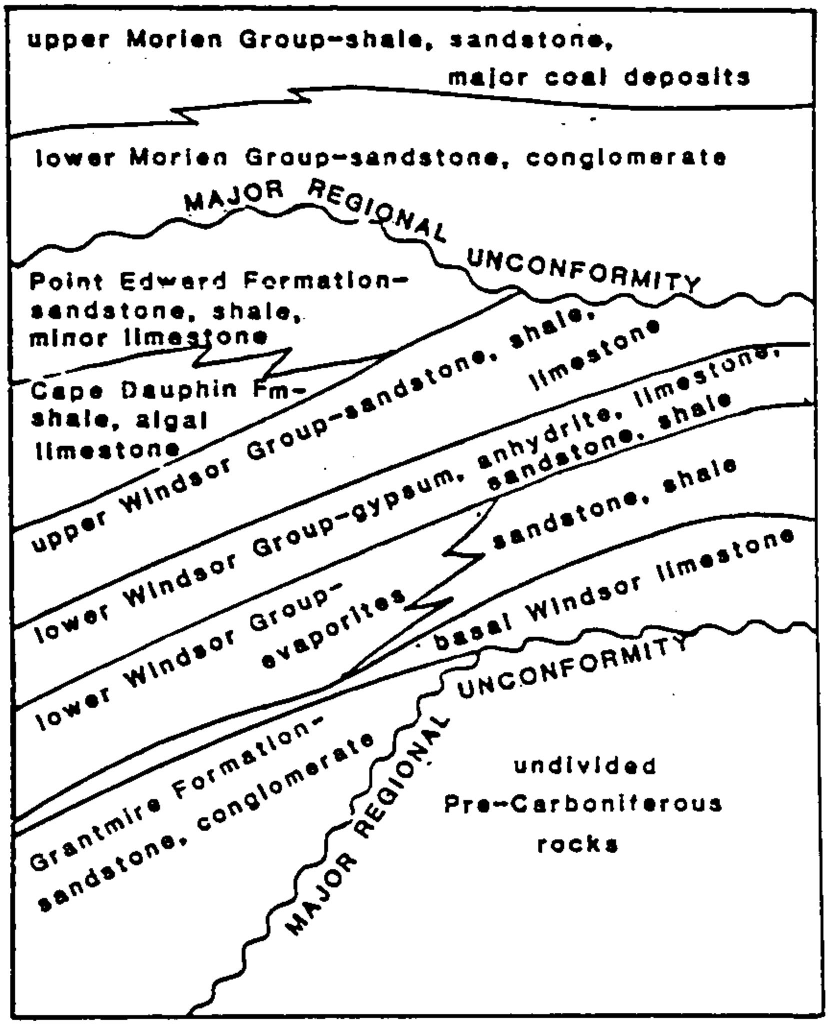


Figure 2b: Legend for figure 2.



(after Giles, 1983)

Figure 3: Sydney Basin stratigraphy.

1.1 PREVIOUS WORK

The Sydney Basin has been studied geologically since the mid-1800's (Lyell, 1842). Geological investigations during the 1800's and early 1900's were concerned with general mapping of the basin, coal potential and detailed descriptions of the megaflora (Dawson, 1855, 1891; Lesley, 1863; Brown, 1871; Robb, 1874, 1875, 1876; Hyde, 1913; Young, 1913; Dowling, 1915; Bell, 1938).

More recently, Hacquebard and Donaldson (1969) and Hacquebard (1983) have continued investigations into the economic aspects of the basin and the chemical and microscopic characteristics of the coal. The present Carboniferous stratigraphy in the Sydney Basin was developed from work by Hayes, Bell and Goranson (1938a, b & c); Weeks (1954); Barss and Hacquebard (1967); Hacquebard and Donaldson (1969); Zodrow and McCandlish (1978 & 1980); Boehner (1981) and Giles (1981). The presently accepted stratigraphy for the Sydney Basin is shown in table 1 and figure 3.

The Morien Group was subdivided into three megafloral biostratigraphic zones, defined by Hayes, Bell and Goranson (1938) as : a lower <u>Lonchopteris</u> zone; a middle <u>Linopteris obliqua</u> zone and an upper <u>Ptychocarpus unitus</u> zone, later equated with three spore assemblages by Barss and Hacquebard (1967), (table 2). The boundaries of the megafloral zones were mapped across the Sydney Basin by Hayes et al. (1938a, b & c).

Table 1: Sydney Basin Stratigraphy

Age	
Stephanian Westphalian D Westphalian C	upper Morien Group lower Morien Group
Westphalian B Westphalian A Namurian	Regional Unconformity
Visean	Point Edward/ Cape Dauphin Formations Windsor Group Grantmire Formation

Table 2: Stratigraphic units within the Morien Group.

	Age	Robb (1876)	Hayes, Bell and Goranson (1938)	Barss and Hacquebard (1967)	Zodrow and McCandlish (1978, 1980)	this study (informal)
UPPER CARBONIFEROUS	Westphalian D	Productive Coal Measures	<u>Ptychocarpus unitus</u> zone	<u>Thymospora</u> zone C	<u>Linopteris obliqua</u> zone	upper Morien Group
	Westphalian C	Millstone Grit	<u>Linopteris obliqua</u> zone	<u>Torispora</u> zone B		lower Morien Group
			<u>Lonchopteris</u> zone	<u>Vestispora</u> zone A	<u>Lonchopteris eschweileriana</u> zone	

The boundary between the upper *Ptychocarpus unitus* zone and the middle *Linopteris obliqua* zone was placed at the Stony coal seam (also known as the Lingan or Emery seam). The boundary between the middle zone and the lower *Lonchopteris* zone was placed at the Tracy coal seam on the east side of the basin, but was arbitrarily marked on the basin's west side. The Morien Group was previously informally divided into upper and lower subdivisions: Productive Coal Measures and Millstone Grit, respectively (Robb, 1876), based on the presence of economic coal measures in the upper division. The upper subdivision of Robb (1876) coincides with the upper biostratigraphic zone of Bell (1938) and Barss and Hacquebard (1967). Robb's (1876) lower subdivision encompasses the lower two biostratigraphic zones (table 2). Subsequent work on the basin's megaflora by Zodrow and McCandlish (1978 & 1980) has revised the biostratigraphy (table 2). These authors reported an extension of the *Lonchopteris* zone upward into the *Linopteris obliqua* zone and an extension of the *Linopteris obliqua* zone upward into the *Ptychocarpus unitus* zone. Zodrow and McCandlish have thus divided the Morien Group into two parts consisting of Bell's *Lonchopteris* and *Linopteris obliqua* zones. Zodrow and McCandlish have abandoned the *Ptychocarpus unitus* zone and have placed the Westphalian C-D boundary at the roof of the Tracy coal seam (formerly Bell's *Linopteris obliqua* - *Lonchopteris* boundary).

The Morien Group has been correlated with the Pictou Group of mainland Nova Scotia and New Brunswick by Van de Poll (1972) and Barss and Hacquebard (1967).

Previous workers have agreed that the deposits of the Upper Morien Group are largely continental, due to the presence of abundant flora and <u>in situ</u> trees, (Dawson, 1855, 1891; Robb, 1874, 1875, 1876; Hayes, Bell and Goranson, 1938). The environment of deposition is presently described as a braided to meandering fluvial system on a broad flood plain (Rust et al., 1983).

In 1981, the Nova Scotia Department of Mines and Energy began a three year project on the Sydney Basin, jointly funded by Nova Scotia and the federal government. This involved redefinition of stratigraphic and structural relations and proposals for depositional environments within the basin. In conjunction with the Nova Scotia Department of Mines and Energy, Dr. B.R. Rust of the University of Ottawa, Dr. M.R. Gibling of Dalhousie University and University of Ottawa graduate students G. Masson, S. Dilles and the author, are completing detailed studies on parts of the Morien Group.

1.2 LOCATION, ACCESS, METHODS AND AIMS

The study area is located in the north-western part of the Sydney Basin, along the west side of Sydney Harbour, near the towns of North Sydney, Sydney Mines and Florence (figure 4). Cliff sections of the upper Morien Group were examined between Stubbert Point and Merritt Point (figure 5). The cliffs are moderate in height (10-30 m) and are accessible at low tide.

Seven sections were measured, sampled, described and photographed between North Sydney and Merritt Point. The low dip and continuous cliff exposure, almost parallel to the dip between Stubbert Point and Cranberry Head, allowed a complete sequence to be examined from the informal upper - lower boundary within the group, to the Aconi Seam - approximately 450 metres thick. The base of the upper Morien was defined by Giles (1983) as the first appearance of thick laterally persistent shales within the succession. Other sections, to the north of Cranberry Head, varied from 5 to 120 metres thick and occur stratigraphically below the Aconi Seam. Sedimentary facies were identified, and their spatial arrangement was observed . Facies assemblages were developed and applied to depositional models. Paleocurrent data were obtained wherever possible, with a multitude of values being taken on exposed shelves. In addition, drill core logs obtained from Nova Scotia Department of Mines and Energy, Devco and Robertson and Associates Engineering, were incorporated into the study.

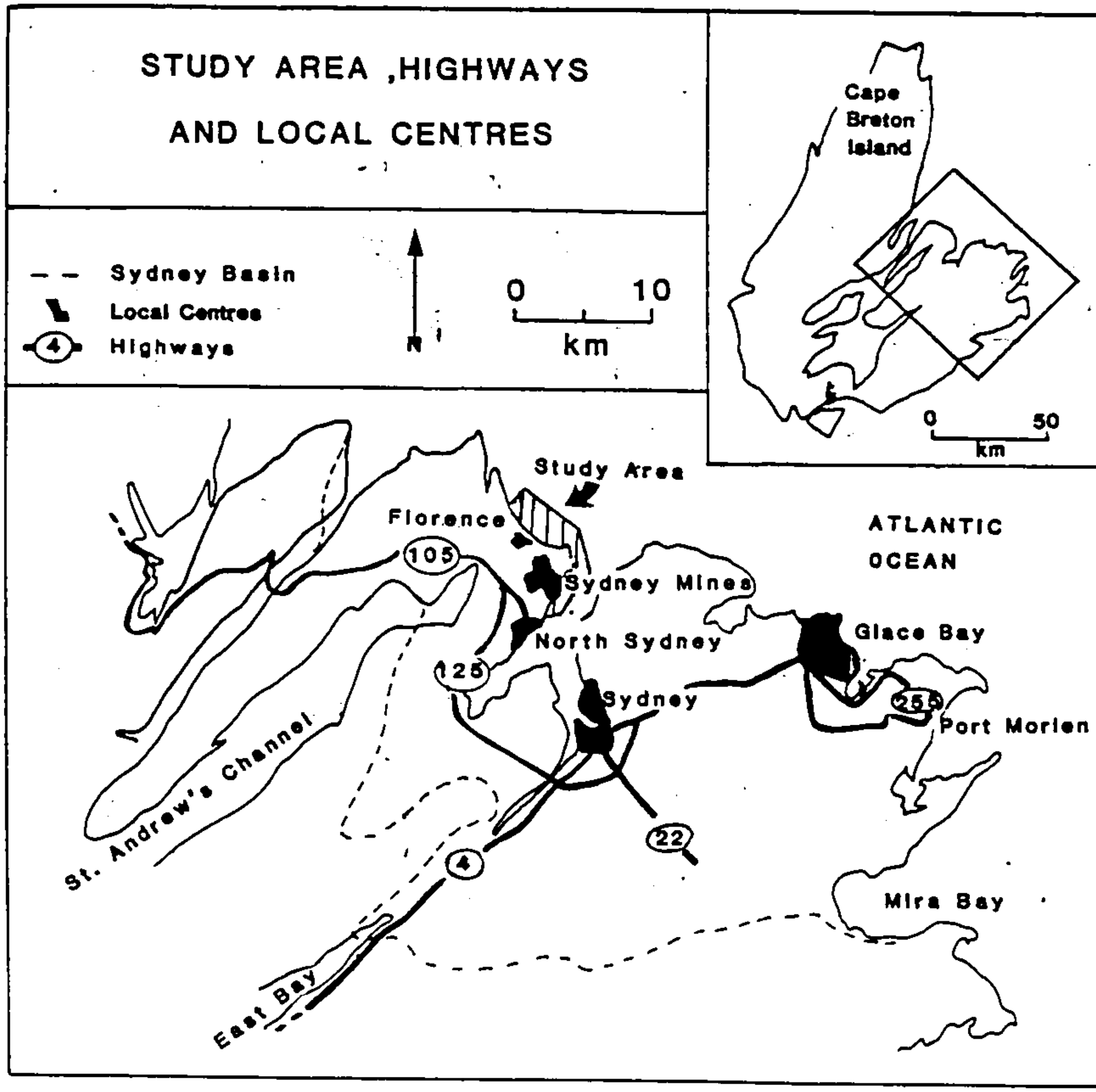

STUDY AREA ,HIGHWAYS
AND LOCAL CENTRES
Sydney Basin
Local Centres
Highways
N
0
10
km
Cape
Breton
Island
0
50
km
Study Area
Florence
105
Sydney Mines
North Sydney
125
Sydney
ATLANTIC
OCEAN
Glace Bay
255
Port Morien
22
4
St. Andrew's Channel
Mira Bay
East Bay

Figure 4

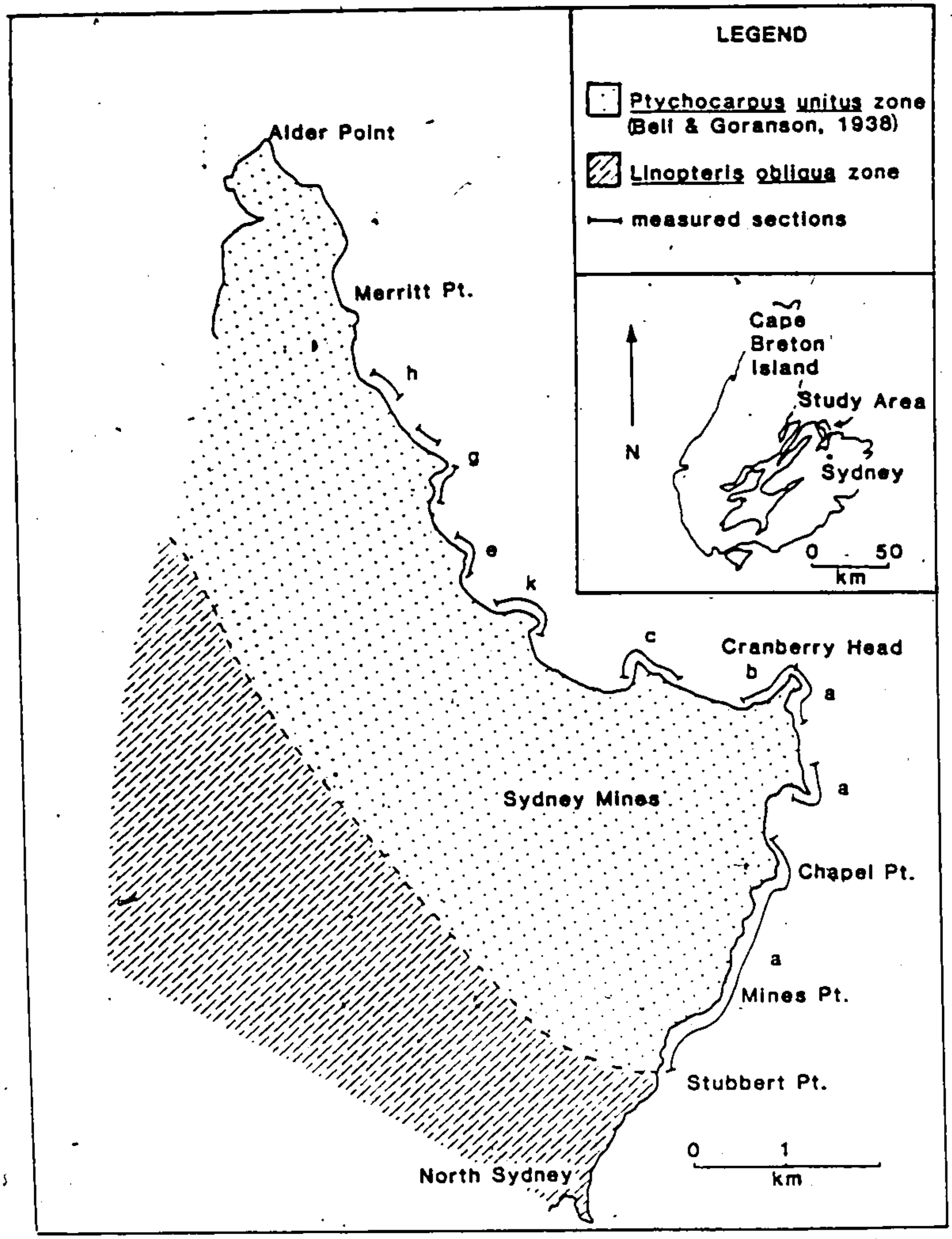


Figure 5: Location of the measured sections.

The logs were correlated with the cliff sections to obtain some idea of the lateral extent of the major facies. Since data varied greatly from log to log, the lateral correlations are based on very generalized lithologies.

From field data, facies interpretations were aided by petrographic examination, paleocurrent analysis and Markov Chain Analysis. These data were used to reconstruct the paleoenvironment and depositional constraints.

1.3 TECTONIC FRAMEWORK

The Sydney Basin is part of the Appalachian Structural Province of eastern Canada (Williams et al., 1972; Poole, 1967) and lies in William's (1979) Avalon Zone. The Appalachian Structural Province extends northeasterly along the Atlantic coast (figure 6). Kennedy (1979) and others suggested that the Appalachians were once continuous with the Caledonian Mountain Belt in Ireland, Britain and elsewhere . The Appalachian Structural Province is a zone of Paleozoic rocks which has undergone several phases of igneous activity and tectonism. The province is flanked to the northwest by the Grenville Province of the PreCambrian shield and by the Atlantic Ocean to the southeast. The Appalachian Structural Province has undergone four major orogenies: the Avalonian orogeny of late Precambrian age; the Taconic orogeny of the Ordovician ; the Acadian orogeny of Devonian age and

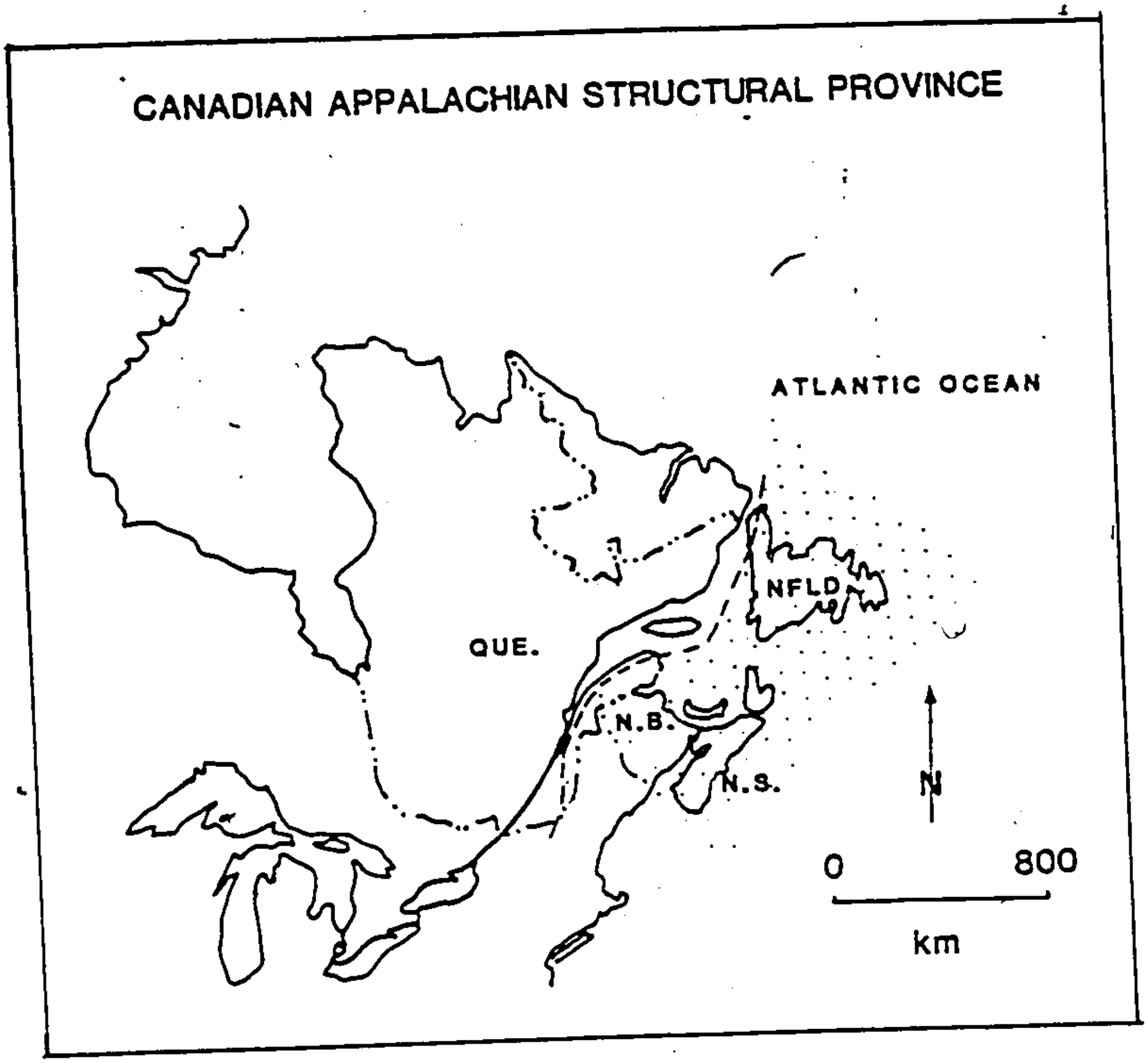


Figure 6

- - - Canadian Shield - Appalachian Structural Province boundary the last major orogeny of late Paleozoic age, the Allegheni- an. These orogenies were marked by intense folding and re- folding of strata, uplift, faulting, volcanism and intrusion (Poole, 1967; Williams, 1979).

The Carboniferous Period includes the final stages of de- formation of the Acadian orogeny and the deformation associ- ated with the Alleghenian orogeny. The Acadian and Alleghe- nian orogenies marked the development of various upland and shelf areas within the structural province (figure 7). These orogenies set the controls and limits for Carboniferous sed- imentation.

It was during the Acadian orogeny that the Fundy Basin System became fully developed (Belt, 1968; Poole, 1967). Initiation of the Fundy Basin System began with two deeply subsiding, northeasterly trending basins (the Fundy Basin System in the southeast and the northwestern Matapedia ba- sin). These basins were separated by the Miramichi geanti- cline (figure 7). Sedimentation in the smaller basin (to the northwest) terminated during mid-Devonian times; this area was then uplifted after the Acadian orogeny. Meanwhile, the larger basin, to the south, developed northeasterly trending faults and the central region of this basin experienced con- tinued subsidence.

This larger basin is made up of a series of sub-basins, separated by locally uplifted areas (figure 8). The central part of this large basin fits the Fundy Rift Basin of Belt (1968) and the Fundy

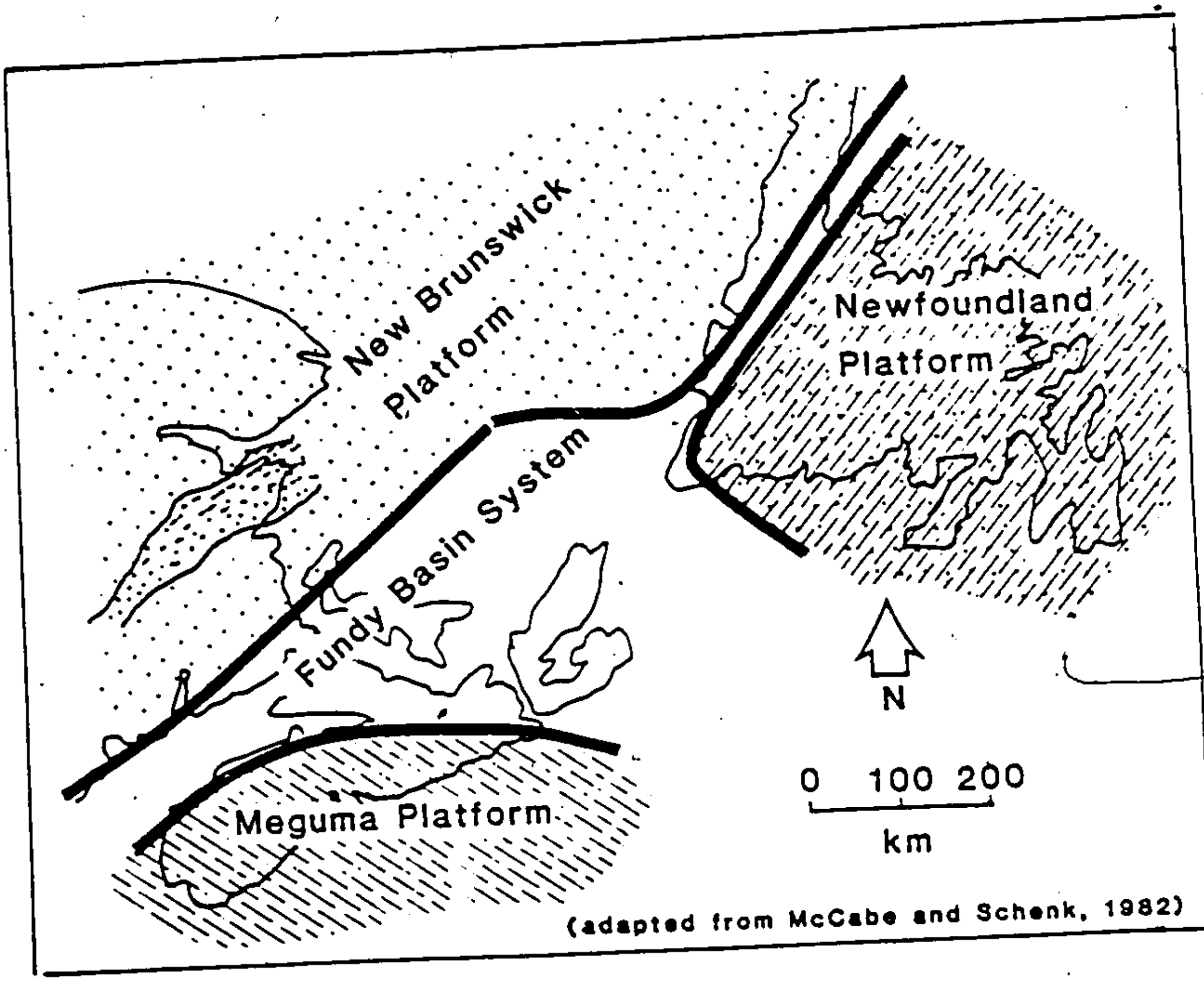
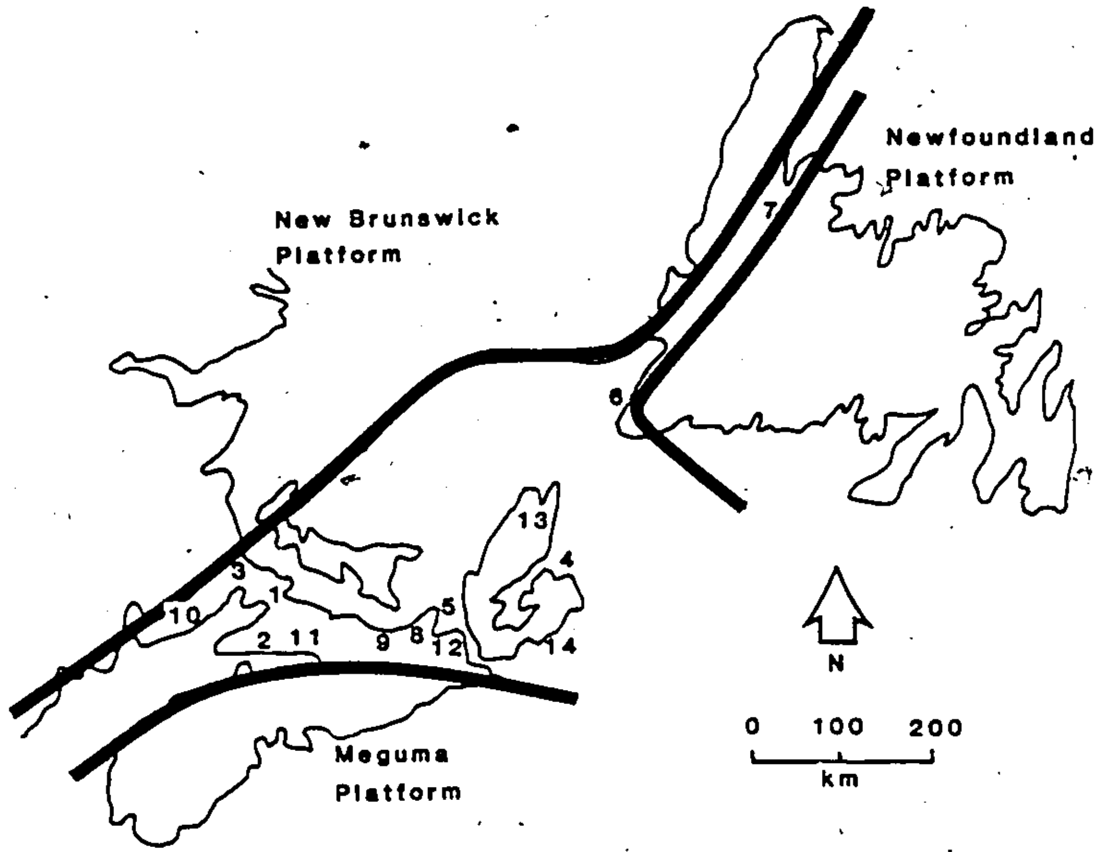


Figure 7: Shelf areas in the Maritime section of the Appalachian Structural Province.

Pre-Carboniferous Miramichi geanticline

(Ruitenberg et al, 1977)



FUNDY BASIN SYSTEM

Basins: 1) Cumberland; 2) Minas; 3) Moncton; 4) Sydney; 5) Antigonish; 6) Southwestern; 7) North-central;

Structural Sub-Basins; 8) Merigomish; 9) Stellarton;

Massifs: 10) Caledonia; 11) Cobequid; 12) Browns Mtn.; 13) Cape Breton Highlands; 14) Louisbourg;

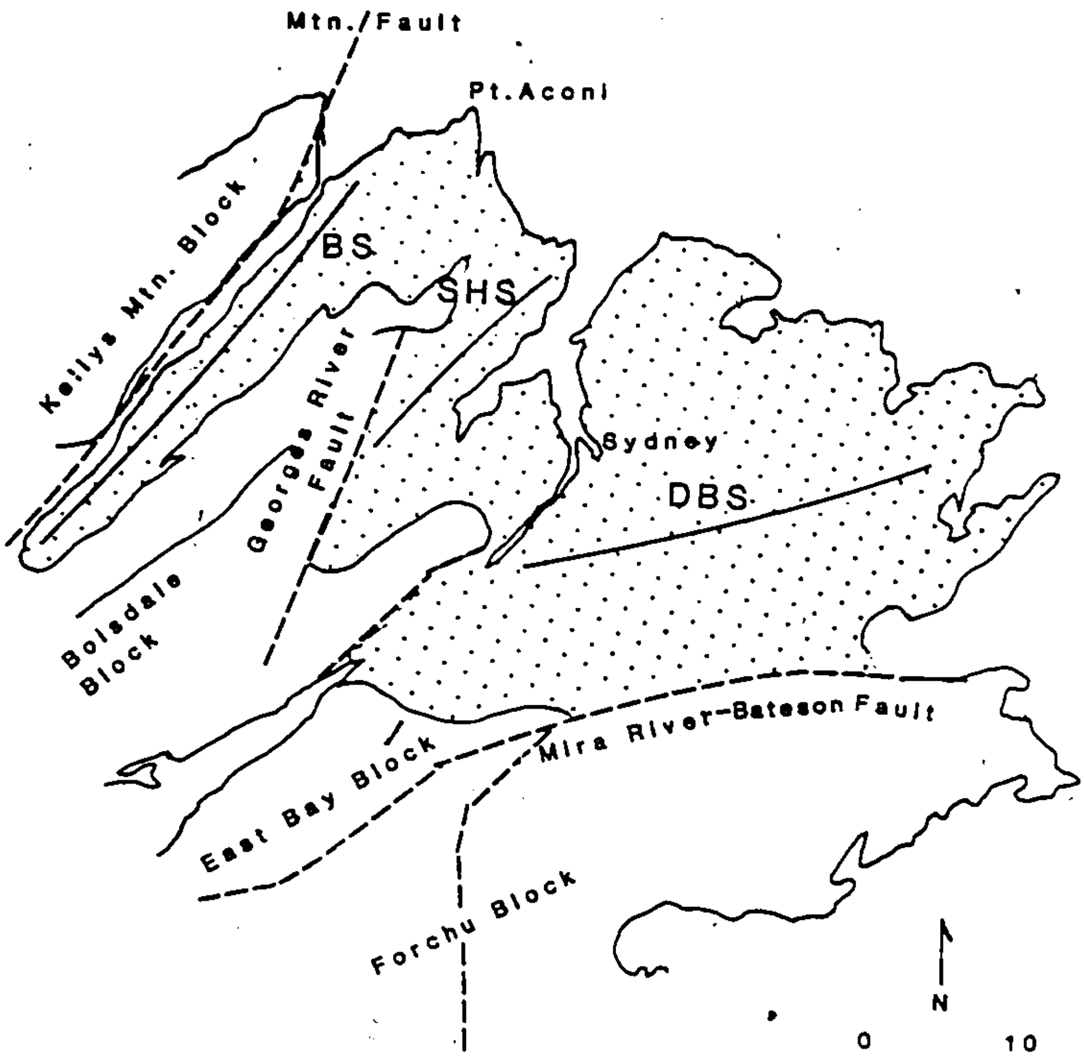
(McCabe and Schenk, 1982).

Figure 8

Geosyncline of Poole (1967). The basin is most likely the result of various differential movements, regional and local tectonism and progressive onlapping of the basin strata on to adjacent platformal areas.

The Sydney Basin is part of the Fundy Rift System. It is bounded to the south by the East Bay and Forchu Blocks and to the northwest by the Kellys Mountain Block; these are major fault boundaries (Keppie, 1979) (figure 9). Internally, the Sydney Basin contains a series of northeasterly trending gentle folds (Hayes, Bell and Goranson, 1938a, b & c) which die out seaward. Major faults bounding the basin and minor in basin faults also trend to the northeast. Folding and faulting within the basin strongly influenced and disturbed pre-Morien rocks (Giles, 1983). The major folds are not easily extended into the younger Morien strata, although smaller scale folds are present. Giles (1983) has suggested that this represents final infill of the pre-existing terrain by the youngest Carboniferous strata.

Major faulting affects strata only in the lower Morien Group ; the upper Morien Group appears to be affected only by the Mountain fault. This suggests that last movements pre-date deposition of the upper Morien Group (Giles, 1983), or that the other major faults do not cut the upper Morien strata, because they do not occur the same areas. Thus, by the time the Morien Group was being deposited tectonic activity was limited. Since then, General Structural Features of the Sydney Basin



Boulardarie Syncline: BS ——
Sydney Harbour Syncline: SHS ——
Dutch Brook Syncline: DBS ——

Sydney Basin, ...
fault ———

(after Giles, 1983)

Figure 9

little other tectonism has affected the basin, leaving the Morien Group in essentially its attitude of deposition.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my thesis advisor, Dr. B.R. Rust, for suggesting the topic and for his assistance and encouragement during this study. I would also like to thank Drs. F.W. Chandler and O.A. Dixon for their helpful suggestions, enlightening discussions and assistance. Dr. G. Narbonne kindly identified trace fossils and W.G. Parkins and Dr. G. Nowlan provided fossil identification and SEM photographs.

This study was supported in part by the Nova Scotia Department of Mines and Energy. The author enjoyed the discussions and advice in the field of R. Boehner and P. Giles of the provinicial survey. Excellent field assistance was provided by Diane Webber and together with the 1983 Sydney Basin crew and Cape Bretoners, provided an enjoyable summer.

I would also like to thank my father, who assisted in photographic work as well as both my parents who gave their continual support and encouragement.

My sincere thanks for support, encouragement and laughter is extended to all my fellow students, past and present, and to the support staff, all of whom helped to make all of my time here pleasant.

A. Thuswaldner helped with the drafting.

Chapter II
LITHOFACIES

2.1 INTRODUCTION

The most common usage of the term facies is based on the original definition of the term by De Raaf et al (1965). They defined the term facies as subdivisions of a sequence based on lithological, structural and organic aspects observed in the field. Facies may be given general informal designations, such as: sandstone facies, or brief descripttive designations, such as: rippled sandstone facies. When describing facies, it is understood that environmental interpretations will be made, but this is normally done on the basis of facies assemblages. That is, facies assemblages are based on spatial relations between different facies and total features of a sequence which characterize the sediment as having been deposited in a specific environment.

The upper Morien Group is described here according to facies associations subdivided into lithofacies, which are adapted from Miall's (1978) classification (table 3). Descriptions of the lithofacies follow.

Table 3: Lithofacies observed in the upper Morien Group. (modified after Miall, 1978)

D - limestone

C - coal and carbonaceous shale

Fm - massive and thickly bedded mudstone

Fl - inter-stratified sandstone, siltstone, mudstone and shale

Sr - ripple cross-stratified sandstone and siltstone

Sh - horizontally stratified sandstone and siltstone

St - trough cross-stratified sandstone

Sp - planar cross-stratified sandstone

E - erosional surface treated as a lithofacies for purposes of Markov chain analysis

2.2 FACIES ST

Lithofacies St consists of very coarse to medium- grained trough cross-stratified sandstone. Trough sets range from 50 cm wide x 10 cm deep to 15 x 5 cm, commonly decreasing in size upward within the coset (photo 1). Cosets of lithofacies St average 7 m in thickness. Trough bases are marked by local accumulations of logs, pebbles and fine to very coarse plant debris (photos 2 and 3). Coal blocks (photo 5) (originally peat mats) occur at the bases and within the bases of some of these sets. Organic lags contain logs varying in size from <1 cm up to 40 cm. Clasts are mostly < 2 cm and are predominantly composed of quartz grains, sedimentary and metamorphic rock fragments.

Lower contacts are either erosional or non-erosional. Erosional bases are characterized by local scouring, intraformational mud clasts (photo 4) and coal blocks. Non-erosional bases overly coal seams without cutting into them (photo 6), presumably due to the resistant nature of the original peat. Upwards, St grades to smaller troughs and finer lithofacies (Sh and Sr), which may further grade into the interlaminated lithofacies Fl and mudstone (Fm) (figure 11, section a, 20 to 40 m). In places, compaction of underlying coals and muds has caused distortion of the trough sets.

Figure 10: Legend for graphic logs, figures 11 to 17.

md	mudstone
sdst	sandstone
vf	very fine
f	fine
m	medium
c	coarse
vc	very coarse
	limestone
	shale
	coal

lenticular interbeds

	mudstone
	sandstone
r	red
⊥	calcareous
:::	interbeds of mudstone and coal

stratification

- horizontal
- ripple
- trough
- planar
- deformed

structures

- rooting
- mud cracks
- flute casts
- cone-in-cone
- channel edge
- lateral accretion
- unit, extent
- covered interval
- erosional contact
- sharp contact

	coal mats
	logs
P	plant debris
	in situ trees
o	pebbles
▲	mudstone clasts
0	concretion/nodule
c	coprolite
	pelecypod

coal seams

AS	Aconi Seam
LCS	Lloyd Cove Seam
LCPS	Lower Chapel Point Seam
UCPS	Upper Chapel Point Seam
SMS	Sydney Main Seam
MS	Millpond Seam
ICS	Indian Cove Seam
SS	Stony Seam

paleocurrent data

5	number of measurements
	trough cross-stratified units
	ripple cross-stratified units
	flute casts
	primary current lineation

(mean azimuth directions)

Figure 11: section a, figure 5: refer to figure 10 for legend.

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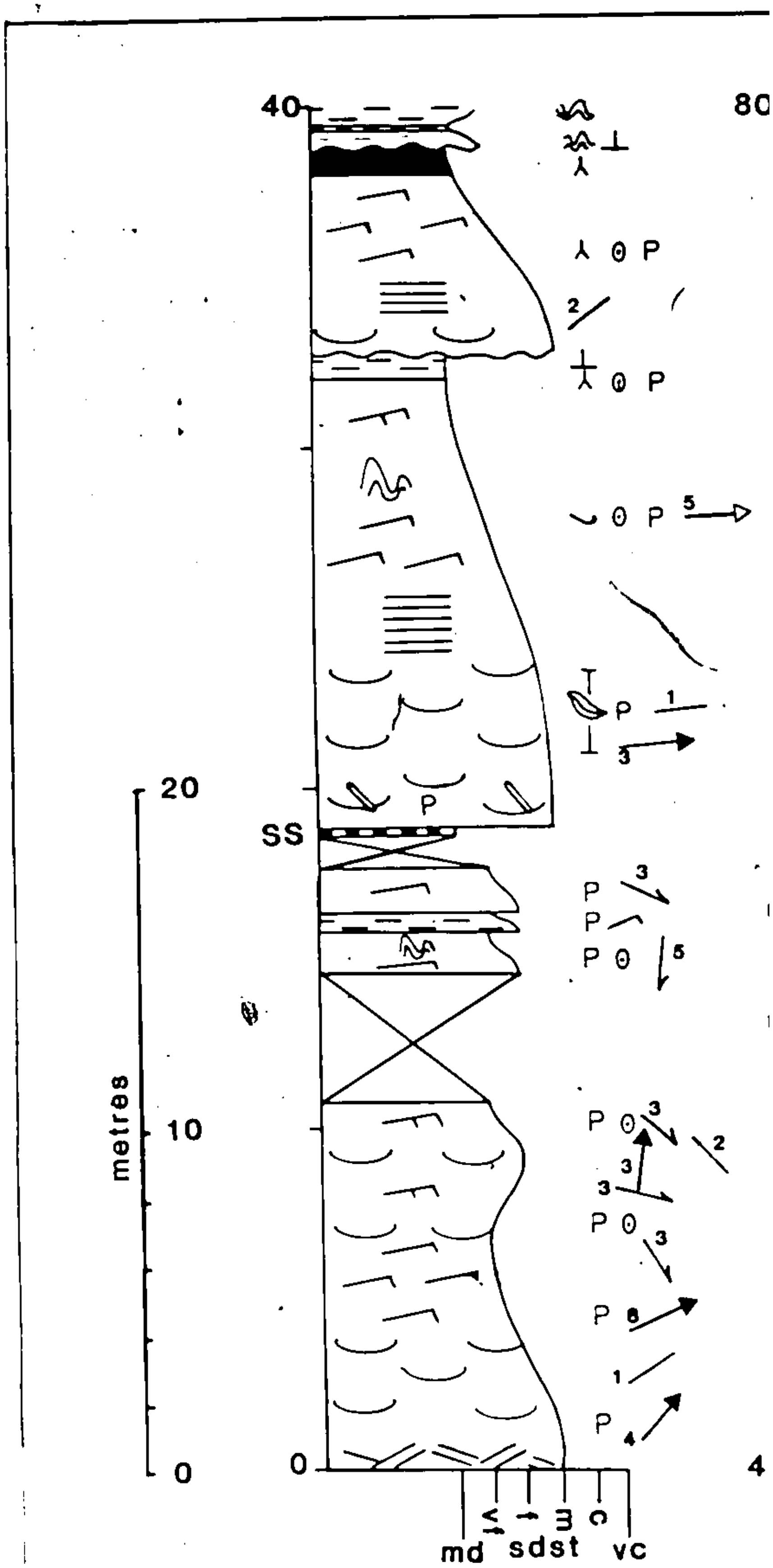

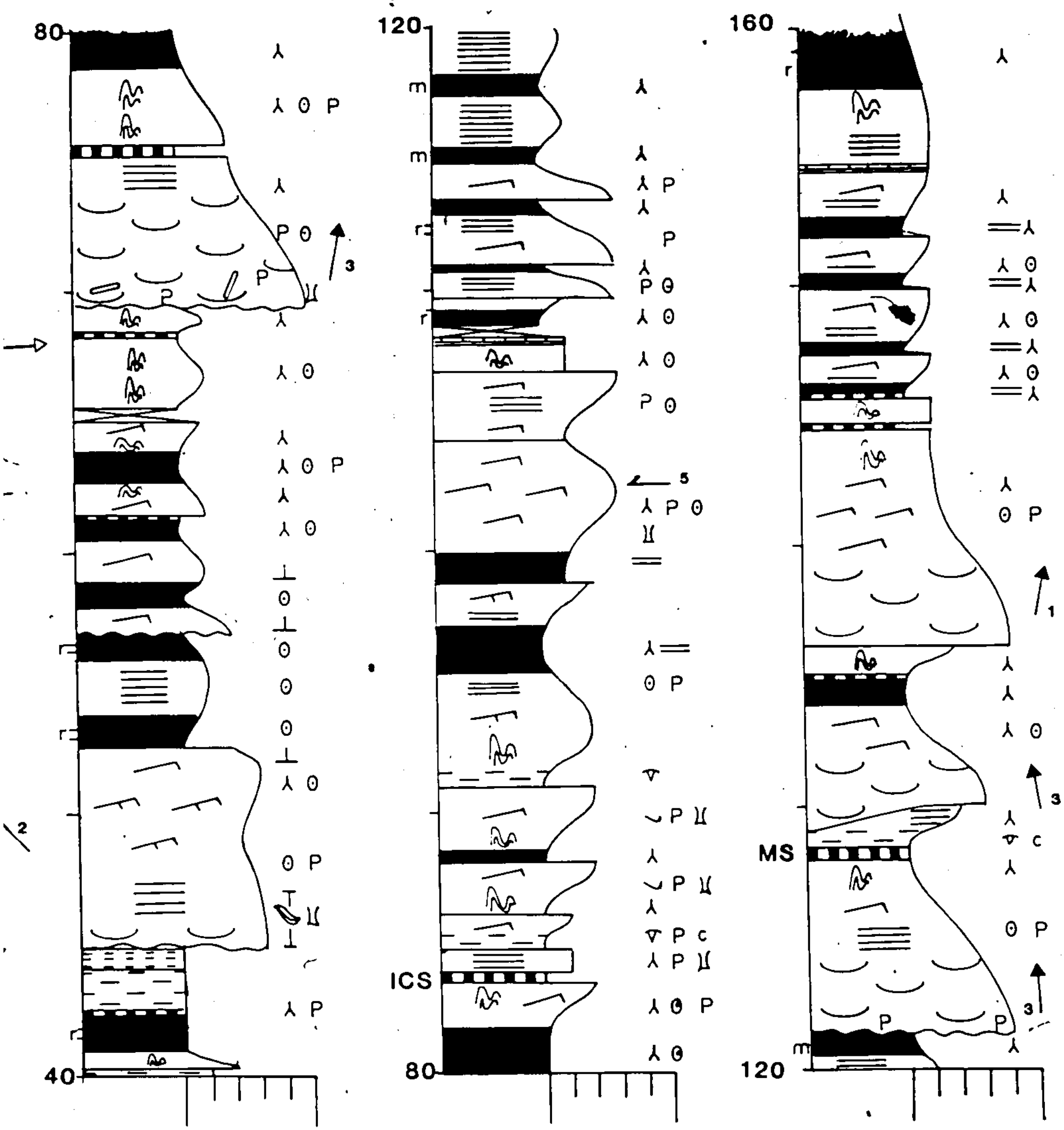
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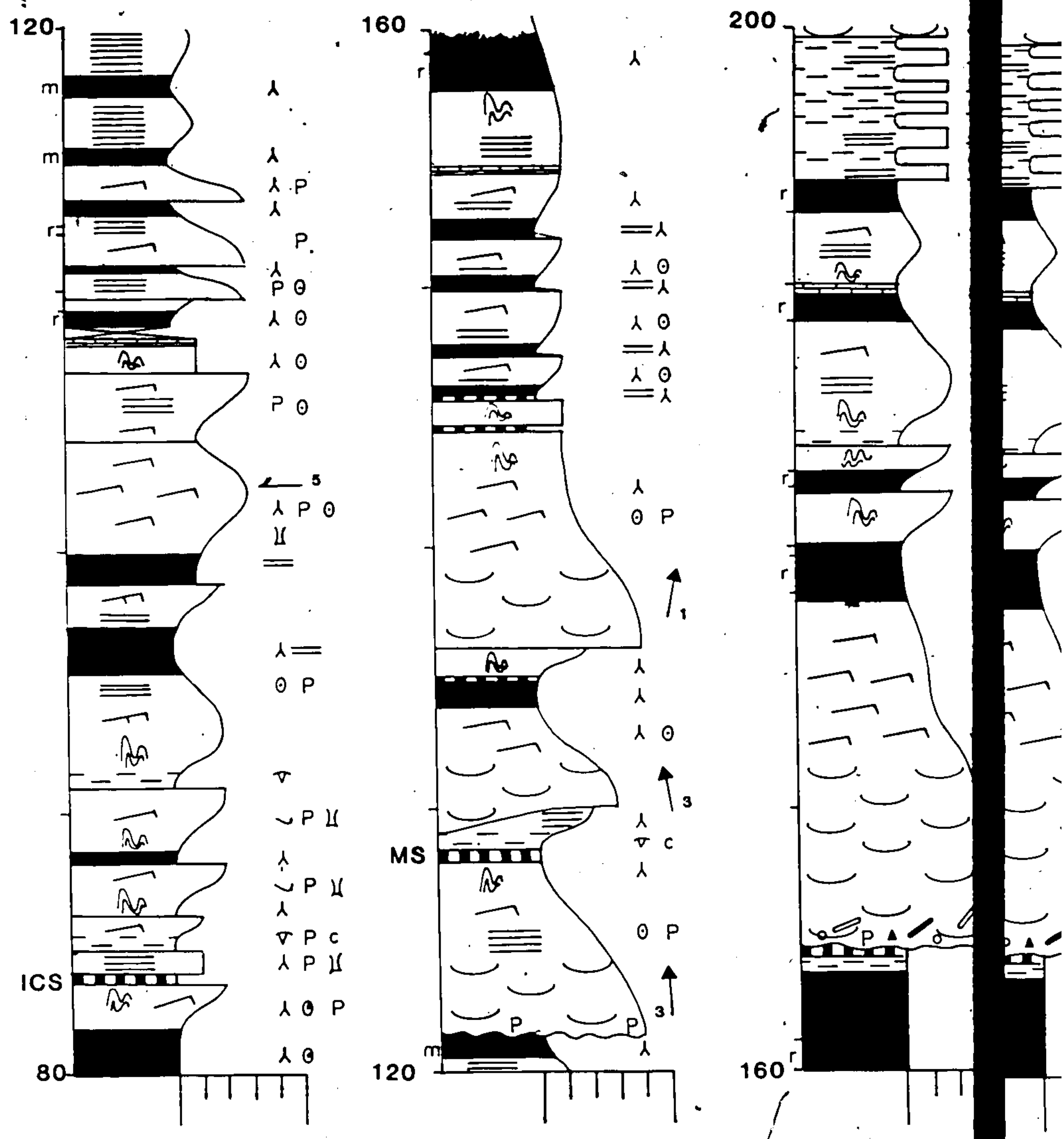

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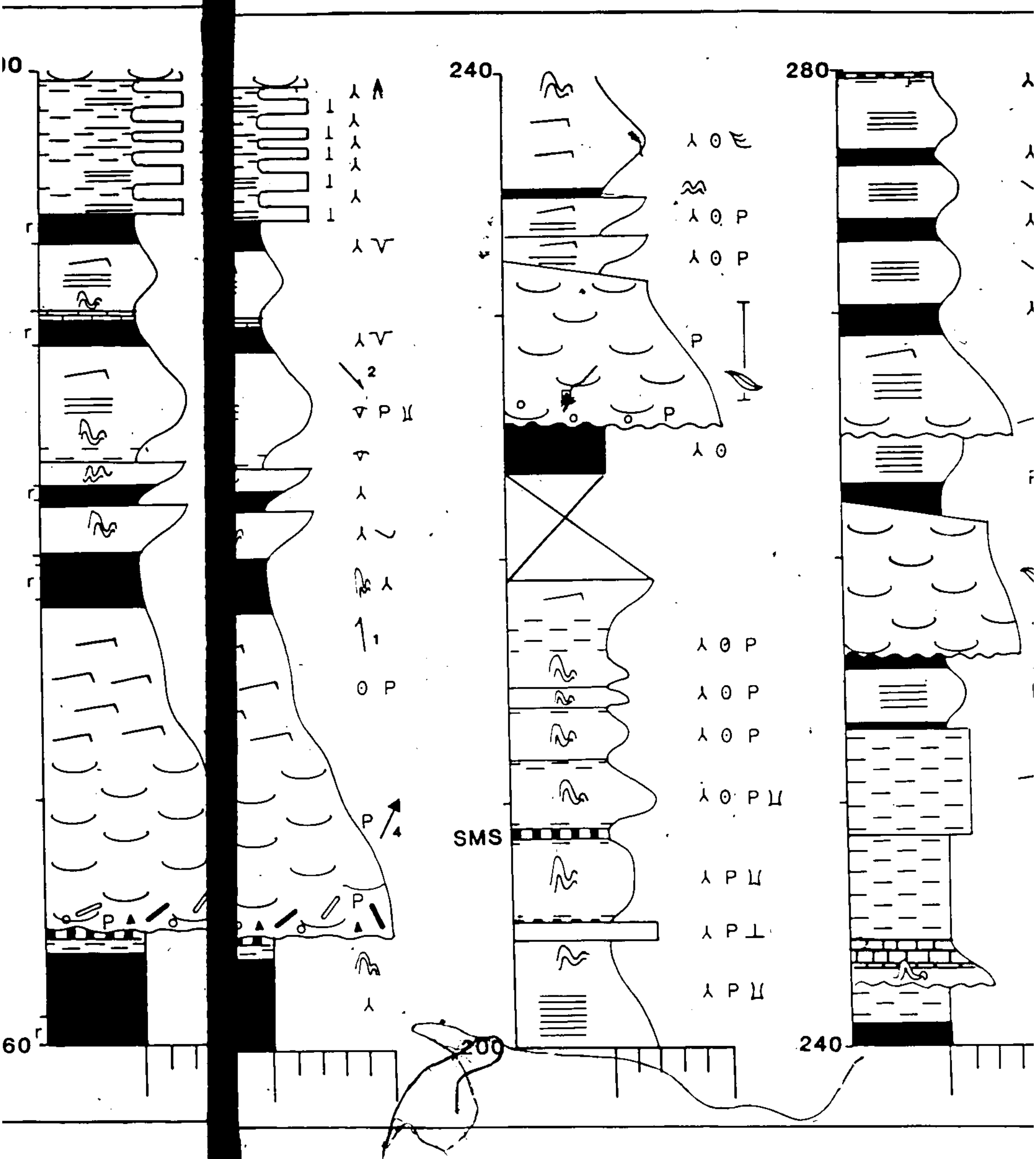

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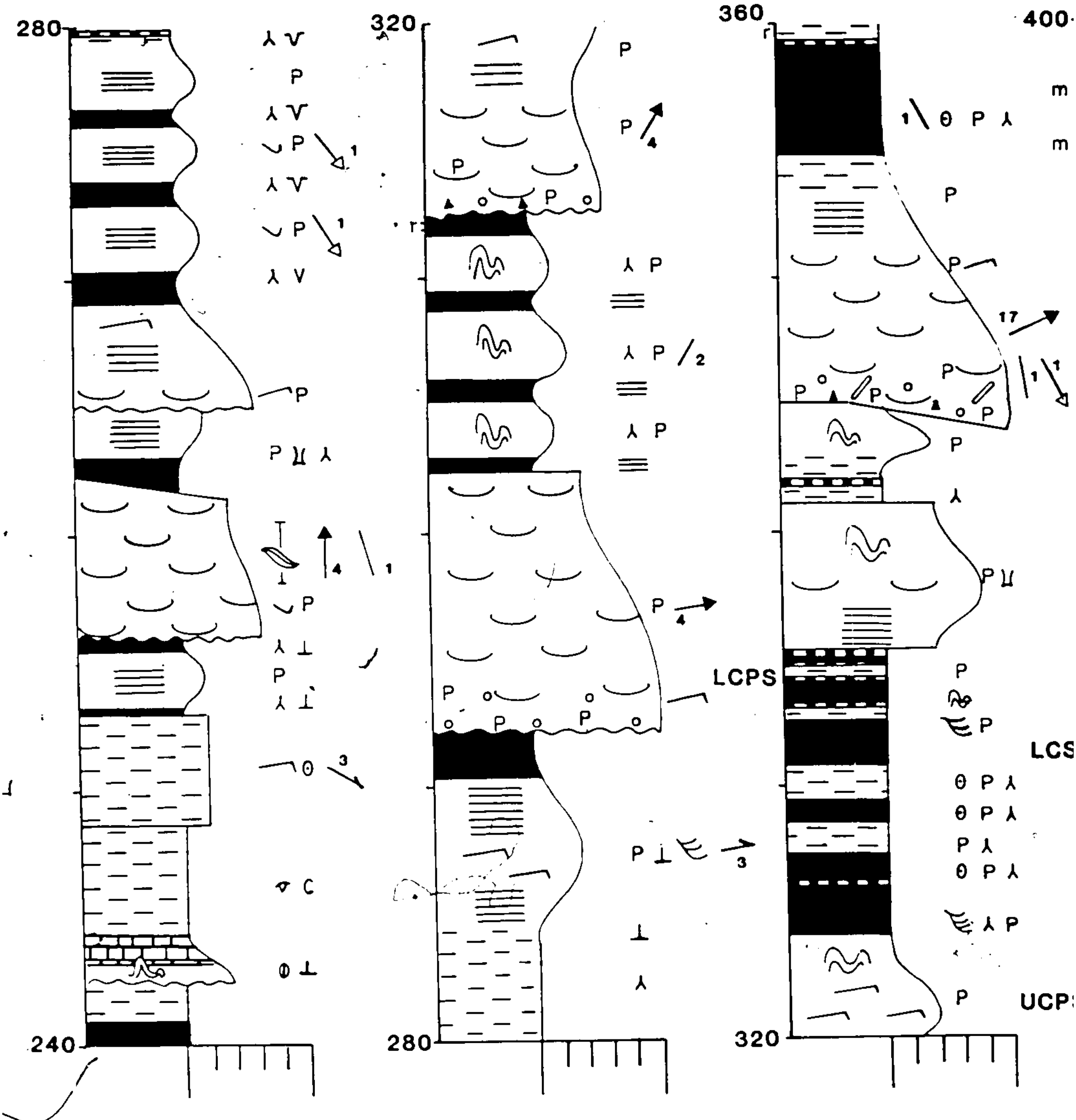
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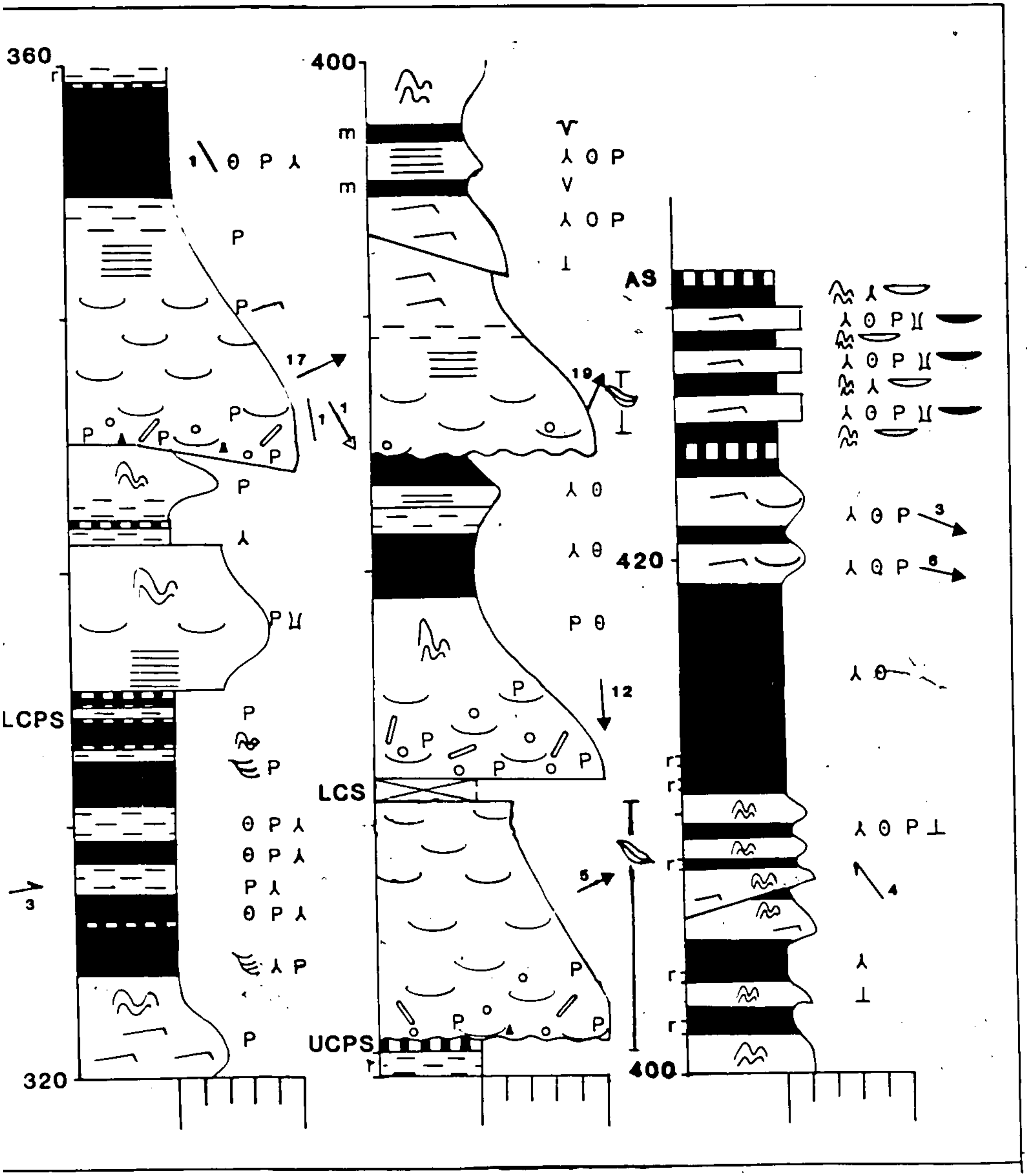


2.3 FACIES SP

Planar cross-bedded sandstones are extremely rare in this part of the upper Morien Group. They occur as isolated (30 to 60 cm thick) units below the lithofacies St and have a gradational contact with this facies. Sp consists of medium to fine-grained sandstones. They were observed at the contact of the upper and lower parts of the Morien Group, near Stubbert Point (figure 11, section a, lower 2 m).

2.4 FACIES SH

Lithofacies Sh consists of fine to very fine-grained sandstone . Set thicknesses are up to 50 cm, with internal stratification ranging from 3 cm to less than 0.3 mm (thinly laminated) which results in extreme fissility. Horizontally stratified sandstones and siltstones are transitional into facies of rippled sandstones (Sr) (photo 8) and siltstones (Fl). They are also transitional upward into shales (Fl(c)) and mudstones (Fm) and downward into St. Lithofacies Sh may also grade laterally to Sr and Fl. Leaf and plant materials are present in some cases. Horizontal laminations are marked by dark organic accumulations.

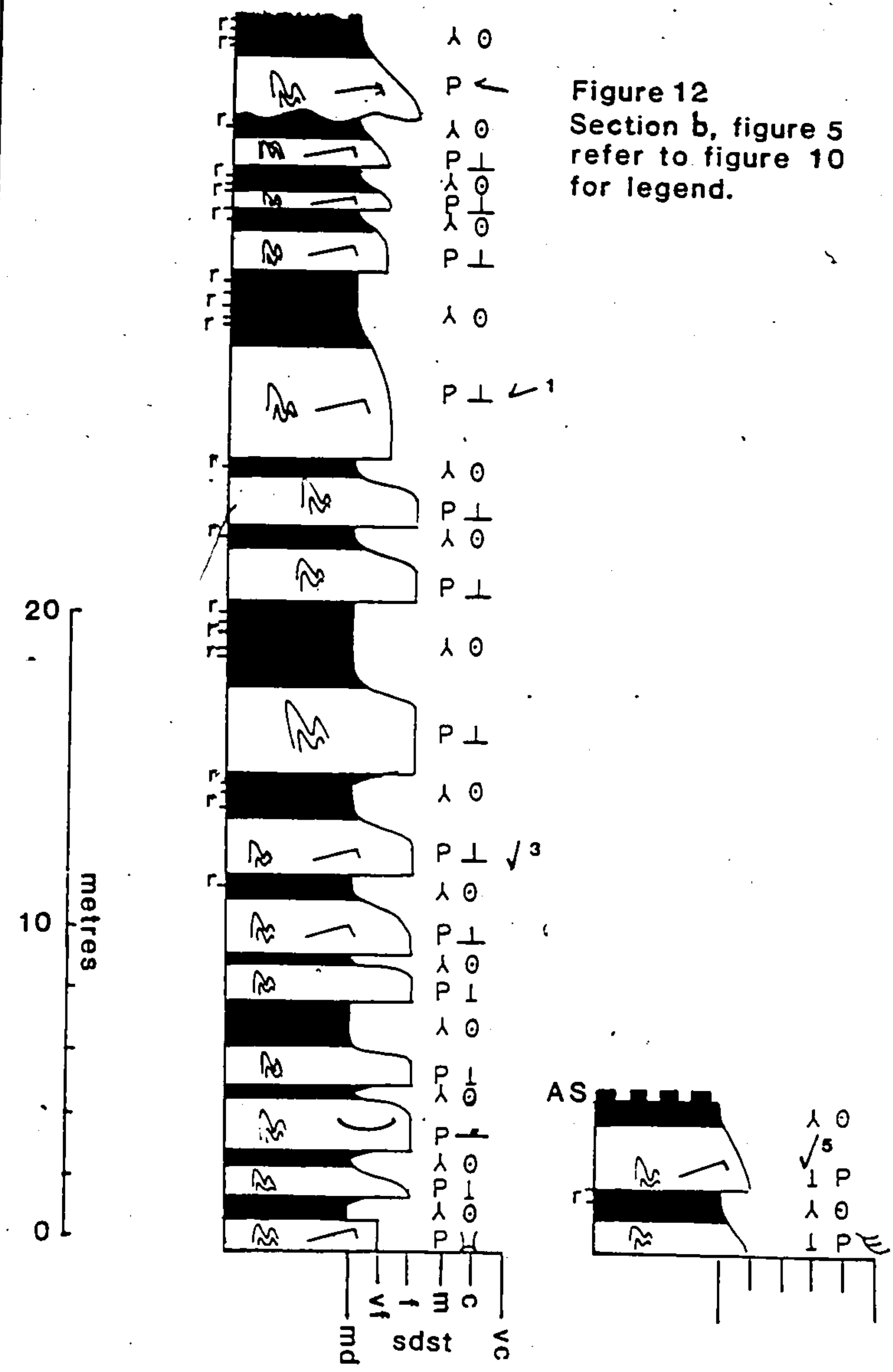
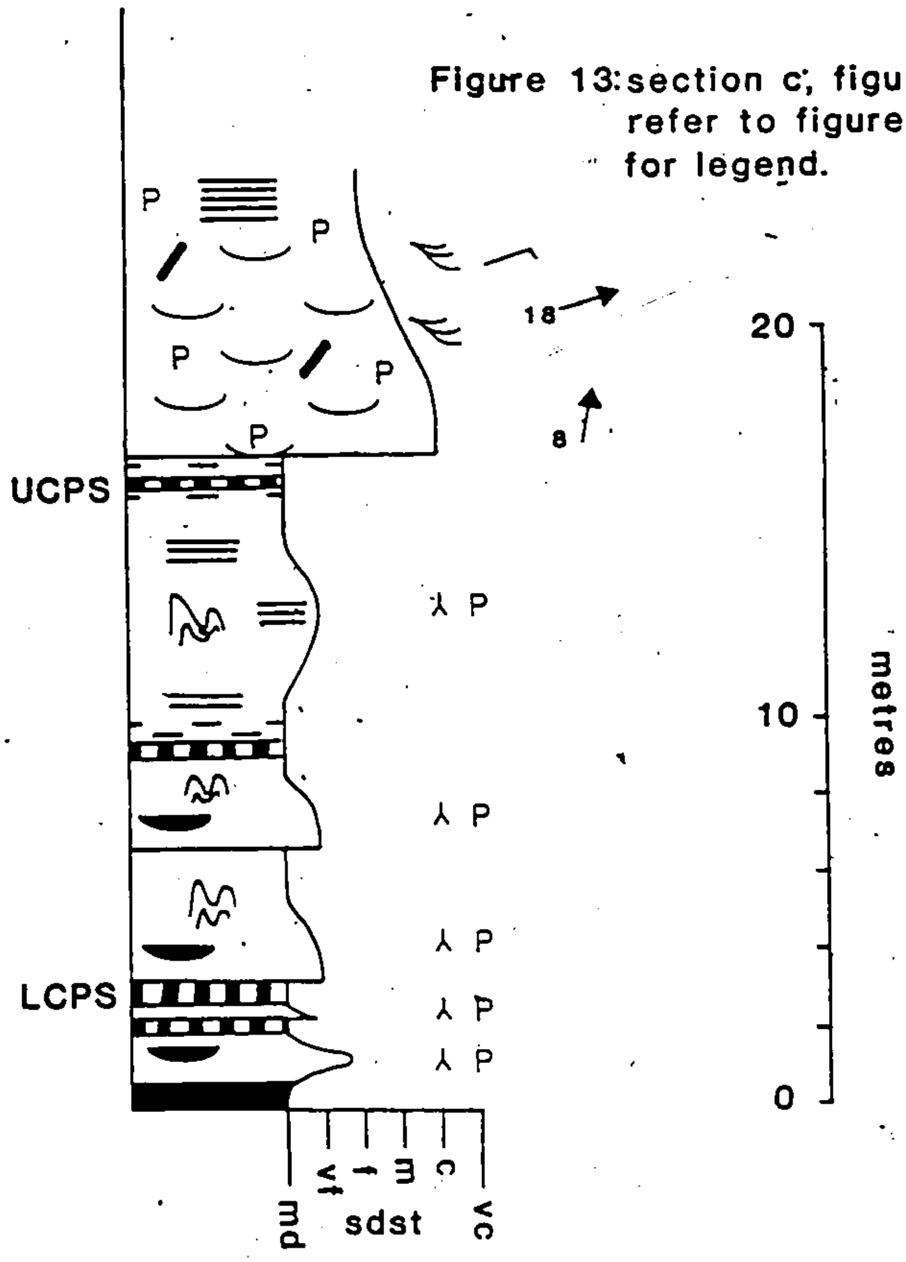


Figure 12
Section b, figure 5
refer to figure 10
for legend.

Figure 13: section c, figure 5 refer to figure 10 for legend.



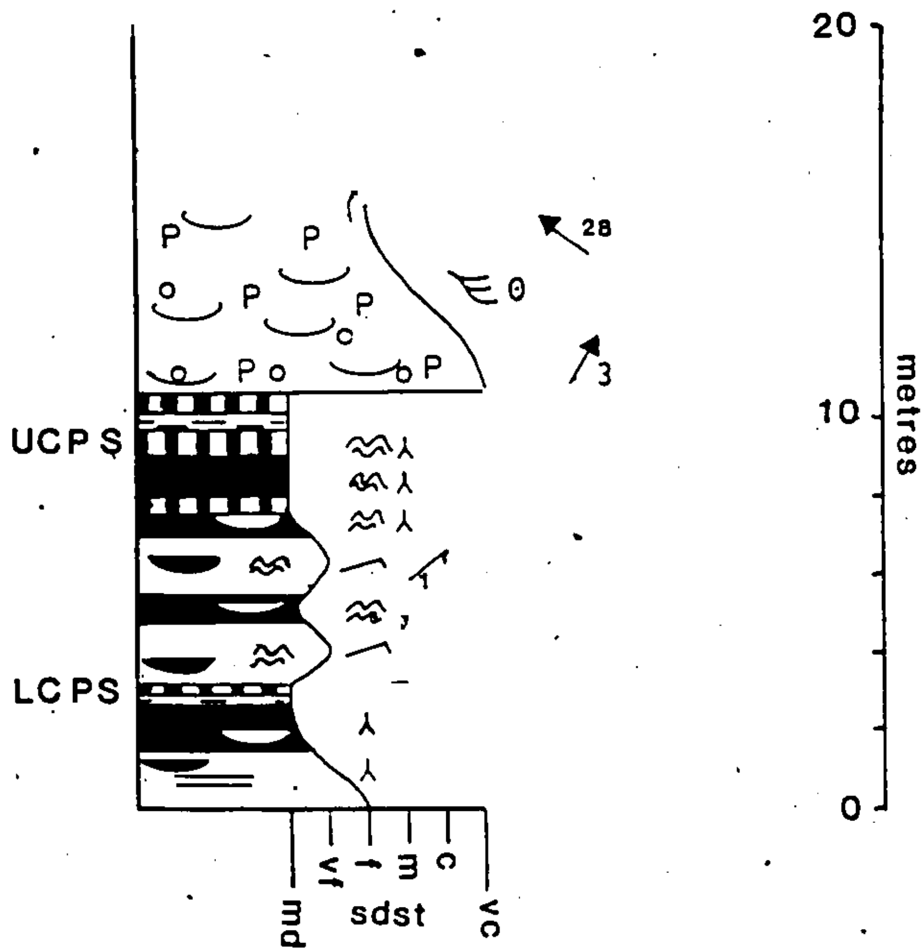
2.5 FACIES SR

Ripple cross-stratified sandstones, mudstone (Fm) and laminated fine-grained facies (Fl) are the dominant facies types in the upper Morien Group. Grain size in this facies ranges from medium sandstone to very fine-grained sandstone. Cosets of lithofacies Sr range from 1/2 to 3 m thick, with an average thickness of 1 m. The units are commonly very fissile and show abundant organic material on lamination planes (photo 9). In situ trees are also commonly observed (photo 10) in association with Sr. The ripple forms are unidirectional current forms with low (< 1/4 to 1/2 cm) amplitudes; climbing ripple forms are present but are not common (photo 11). Sr commonly fines upward into flatter ripple forms and finer grained sediments. Lithofacies Sr is gradational upward from St and Sh and into Sh, Fm and Fl (parts of figures 11, 13, 14 and 15). It is also found as thin (2 to 30 cm thick) cosets within St unit. Laterally, lithofacies Sr may grade into Sh, Fm or Fl and occasionally lithofacies St.

Due to extensive bioturbation, stratification is commonly disrupted or obscured. Compaction has also caused deformation of internal structures.

Some of the sandstones and siltstones are calcareous, in which case they are closely associated with red mudstones and calcretes.

Figure 14: Section k, figure 5, refer to figure 10 for legend.



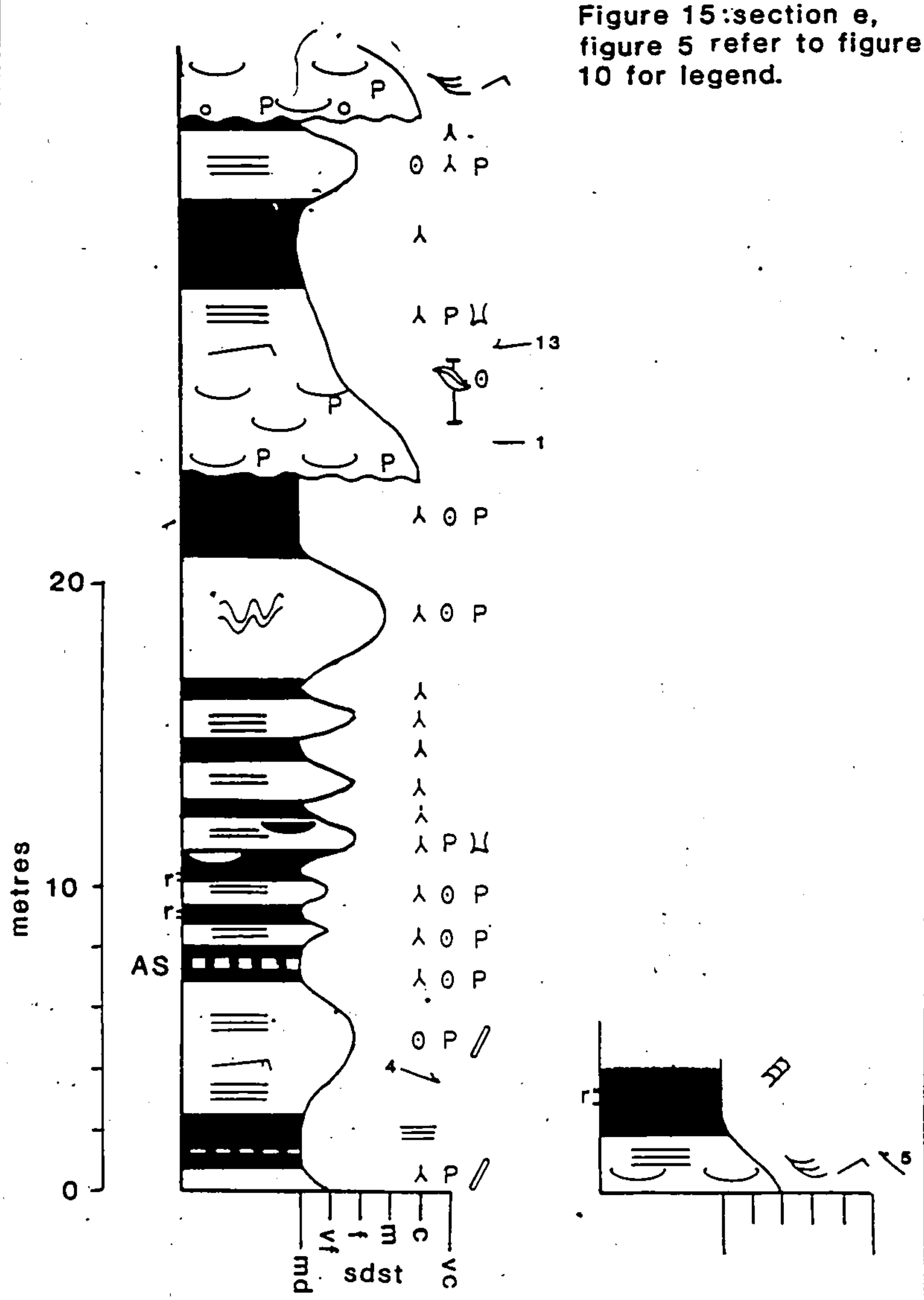


Figure 15:section e, figure 5 refer to figure 10 for legend.

2.6 FACIES FL

Interlaminated shale, siltstone, sandstone and mudstone units are common, with the individual rock types grading upward, downward and laterally into each other. This facies is gradational into lithofacies Sr, Fm and C. Stratification is highly variable from rippled to horizontally stratified units; thicknesses range from <0.3 to 3cm. Units tend to be very fissile, with abundant organic material concentrated on the lamination planes;these concentrations commonly accentuate internal structures such as ripple forms (photo 9). Ripples are asymmetric unidirectional current forms, of low amplitude (average of 5 mm). Bioturbation and compaction commonly obscure and distort much of the internal structure, leaving only a hint of the original stratification. Organic debris, rootlets, in situ trees and pedogenic nodules are common in this facies.

Trace fossils were observed on boulders attributed to this lithofacies near Cranberry Head and Oxford Point (figure 5, photos 12 and 13). They have been identified by Dr. G. Narbonne (pers. comm.) as *Diplichnites* sp. and *Beaconites* sp.; non-marine to marginal marine environments are most probable for these two traces (Briggs et al., 1979; Allen and Williams, 1981).

Figure 16:
Section g, figure 5
refer to figure 10
for legend.

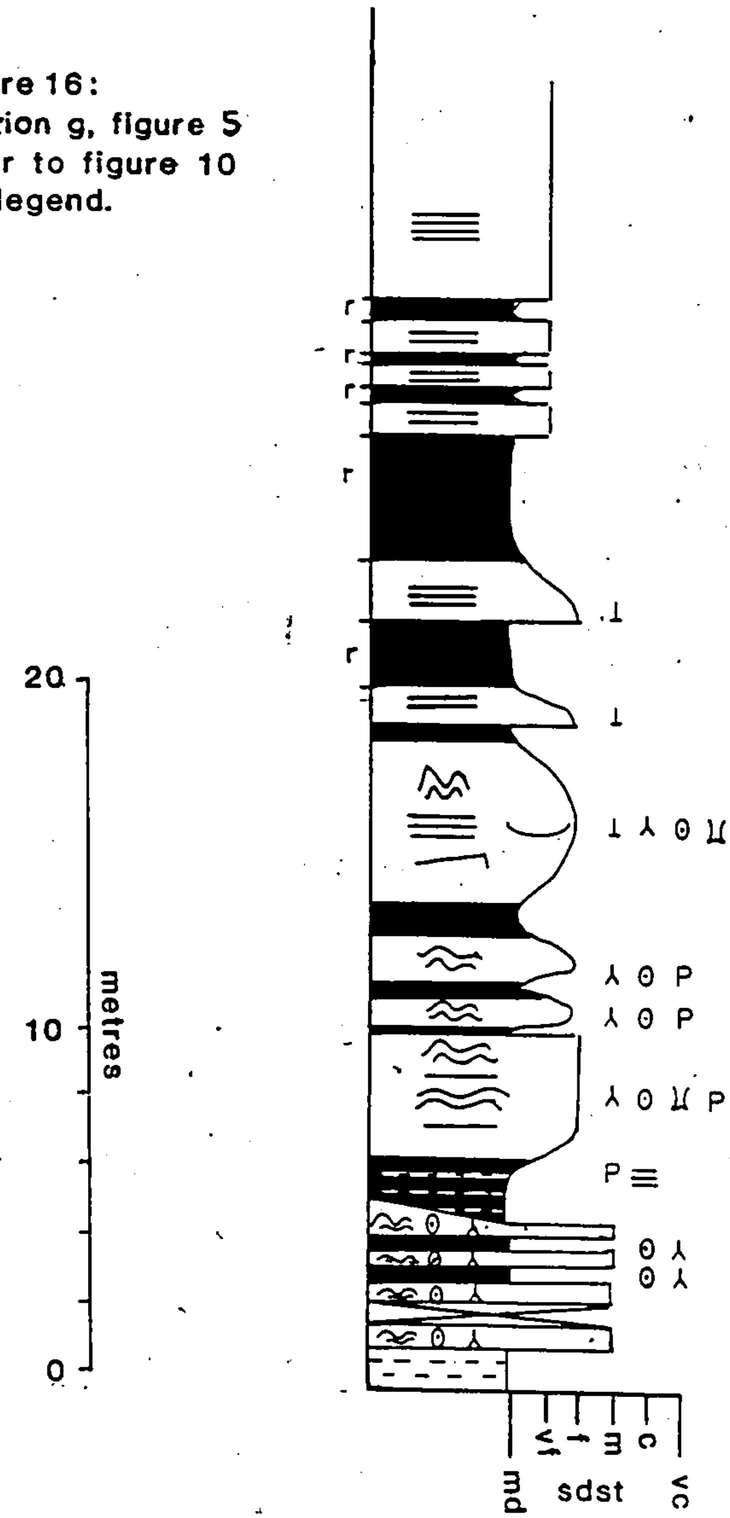
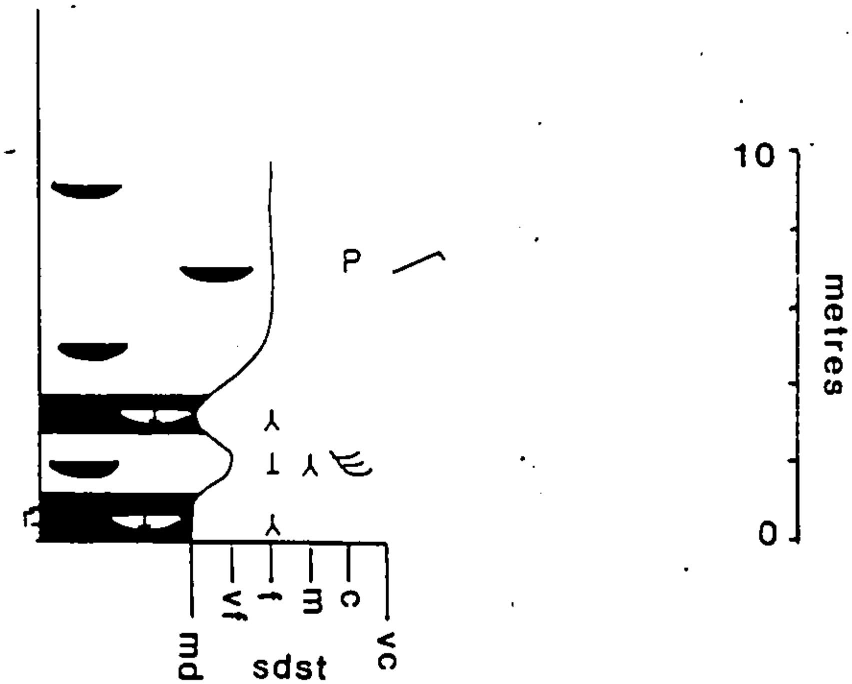


Figure 17: Section h, figure 5
refer to figure 10
for legend.



2.7 FACIES FL(C)

Black to brown shale beds not directly associated with coal seams are not common. The black shales are usually closely associated with limestone beds (facies D). These units are 1/2 to 4 m in thickness. The black shales contain abundant pelecypods, coprolites, ostracods, fish bones scales and teeth. Teeth of the fresh water pleuracanth sharks have been reported by Masson and Rust (1983) from equivalent strata east of Sydney Harbour. The ostracods are non-marine and are probably the species *Carbonita inflata* and *C. scalpellus* identified by Copeland (1975). The lighter or brown coloured shales contain abundant plant material. These units occur most commonly with the lithofacies Fm, Sr and Sh; in some cases they pass laterally into lithofacies Fm or Sh.

2.8 FACIES FM

Massive to thickly bedded (3 to 10 cm) mudstones are commonly intergradational with facies Fl, Sr and Sh. The mudstones are red or grey in colour. The red mudstones are interbedded with grey mudstones, bedding being 2 to 10 cm; this results in 30 to 80 cm units of alternating red and grey beds. Both mudstones weather very rubbly. The red mudstones are also commonly associated with calcareous sandstones and siltstones. They are mudcracked in places and do not show extensive bioturbation. The red mudstones exclusively display convex up fracture systems (photo 14). The grey mudstones are generallly heavily bioturbated and commonly contain abundant roots and plant material. Leaf material was described in detail by Bell (1966); identifications by the author include: Lepidodendron sp.; Calamites sp.; Sphenopteris sp.; Calamites undulatus ; Linopteris sp.; and stigmaria roots (photo 15). The grey mudstones are more abundant than the red mudstones by approximately 3:1.

2.9 FACIES D

This lithofacies varies from calcareous sandstone and siltstone to limestones which vary in thickness from 5 to 30 cm. Stratification in the calcareous units is very thin bedded to thinly laminated (2 to <0.3 cm) but the true limestone units are massive. The calcareous sandstones and siltstones are gradational upward and downward into non-calcareous sandstones and siltstones (lithofacies Sr, Sh and Fl). As well, these units may also grade upward into nodular limestone (photo 16). These nodular limestones are 4 to 15 cm thick and are discontinuous; in some parts, they may be conglomeratic (8 cm thick unit), with <2 cm intraclasts of limestone. There are also units of limestone which laterally pinch and swell. These occur below some coal seams (photo 17). Other nodular limestone units are closely associated with the black shales and red mudstones. The nodular limestones contain various non-marine fauna. One bone fragment has been identified as a basisphenoid bone from the skull of a crossopterygian lung fish (photos 18 and 19) (W.G. Parkins, pers. comm.). This fish is attributed to non-marine to marginal -marine environments. No algal stromatolites have positively been identified, but bedding plane structures have been observed (photo 20) which are similar to horizontal sections through stromatolite columns described by Collinson and Thompson (1982). Possible algal filaments in thin section (photo 21) also indicate stromatolitic units. Positive identification of stromatolitic units from equivalent strata east of Sydney Harbour have been made by Masson and Rust (1983).

2.10 FACIES C_1

Coal and carbonaceous shale are present in the upper Morien Group, some of the coal parts being important economic units. The carbonaceous shales occur as thin (<1/2 to 5 cm) units above and below coal seams. These shales also occur as thin (1/2 to 1 cm) discontinuous wisps within lithofacies Fl. The coal seams vary in thickness from 1 to 80 cm as exposed along the coast, greater thicknesses are reported from mine records. Laterally, the coal seams split , rejoin and thicken to economic proportions, as observed in vertical correlations of sections and drill logs (figures 18 and 19) and as described by Hacquebard and Donaldson (1969).

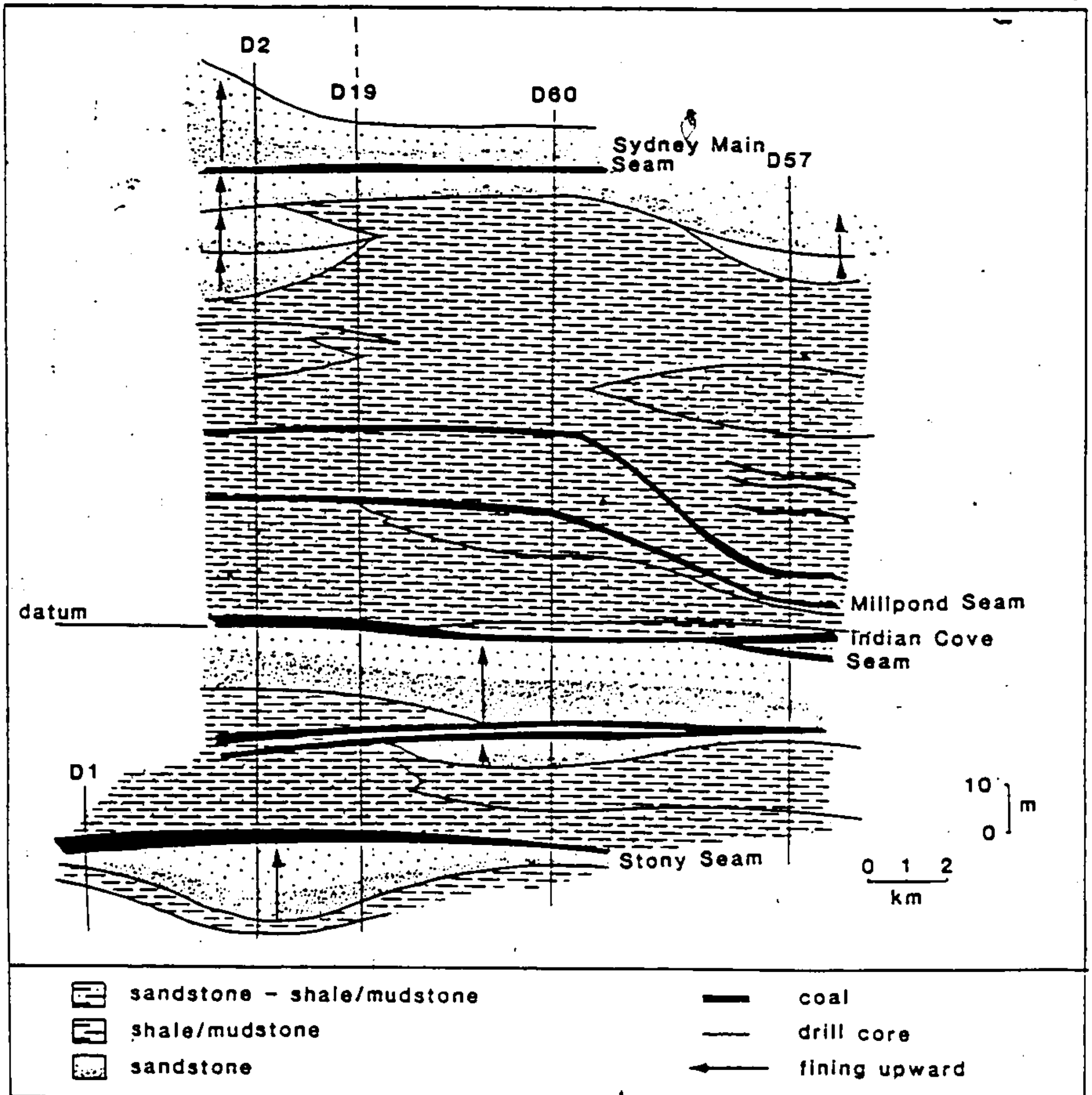


Figure 18: Drill log correlations. Locations of drill holes are shown on figure 18b.

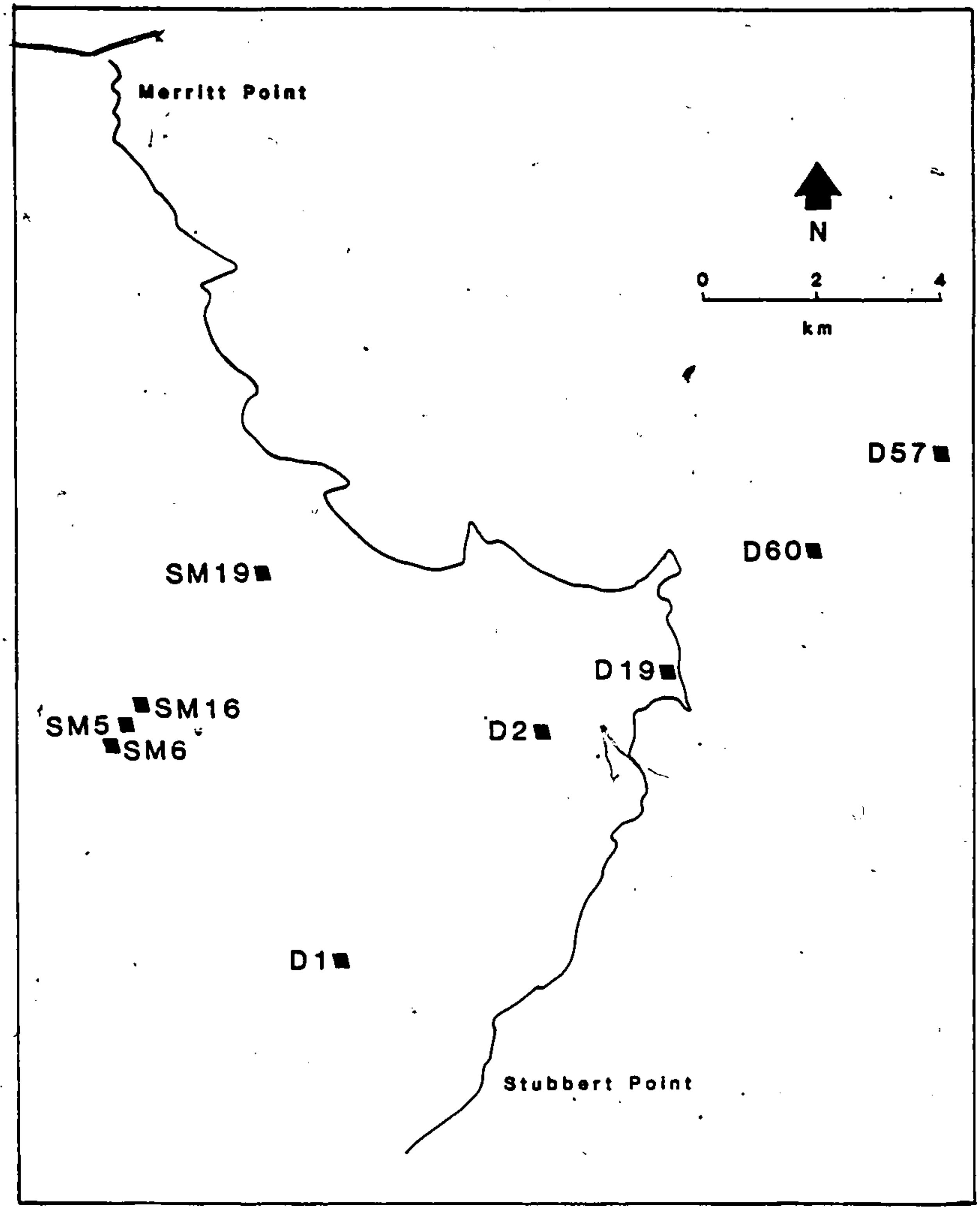


Figure 18b: Location of the drill holes shown in figures 18 and 19.

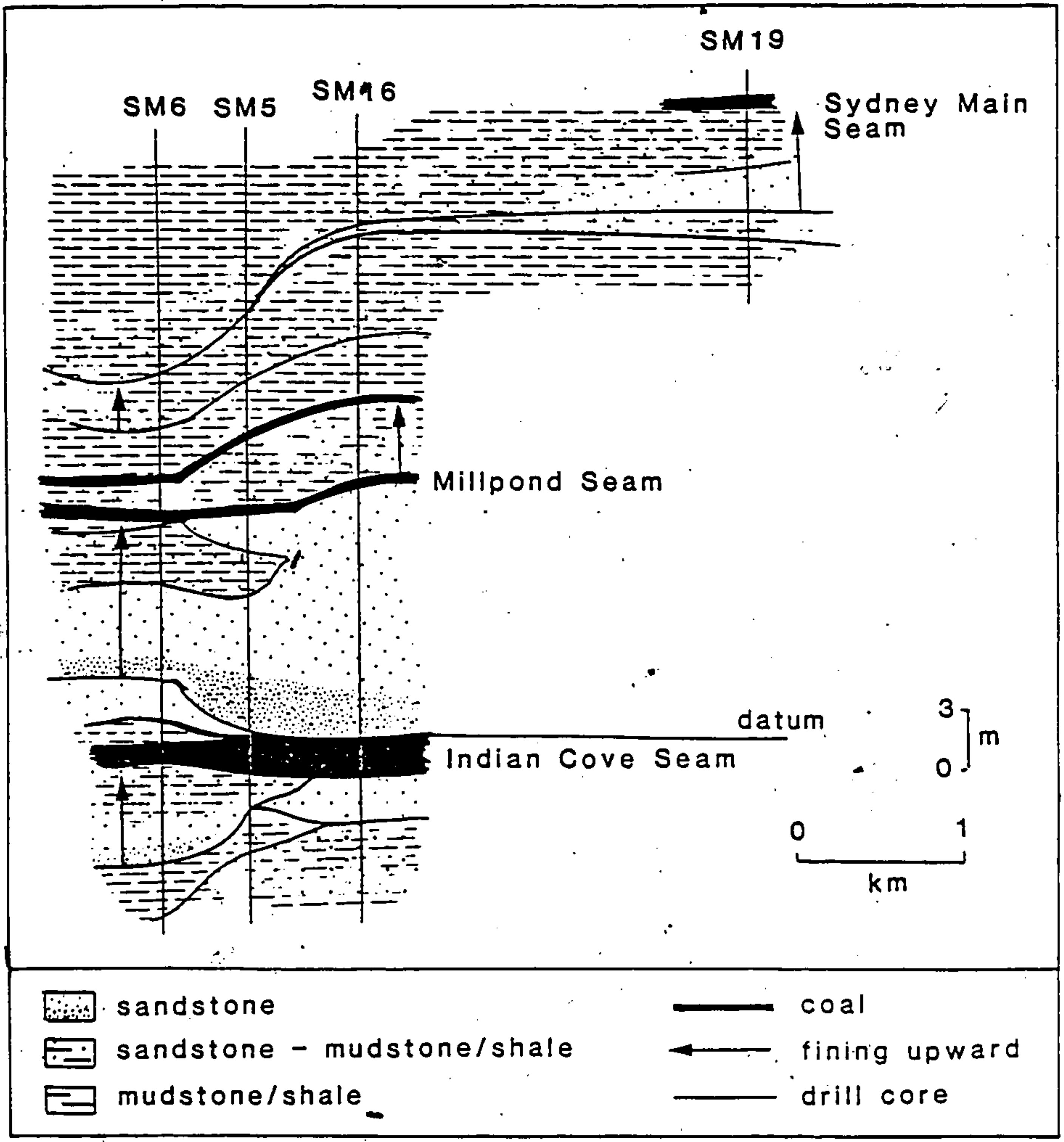


Figure 19: Drill log correlation. Locations of drill holes are shown on figure 18b.

Coal also occurs as the preserved bark of trees (photo 22), which in some cases have coalified bark extending downward into an underlying coal seam. The coals are underlain by carbonaceous shale, whereas the presence or absence of a capping shale is dependent on the nature of the overlying sediments (the capping shale is not present when the overlying lithofacies is St).

2.11 FACIES P

Sideritic nodules are common throughout the fine-grained facies (Sr, Sh, Fl and Fm). They probably formed diagenetically in waterlogged sediments. Septarian nodules have also been observed (photo 23). Calcitic nodules are less common and are often concentrated along bedding planes, along roots, as individuals within beds and as discontinuos layers.

The nodules vary in size from 1 to 25 cm in horizons that are laterally continuous up to 15m.

2.12 FACIES ASSEMBLAGES

Three facies assemblages have been identified in the upper Morien Group: a sandstone facies assemblage; an alternating facies assemblage and a mudstone facies assemblage.

The sandstone facies assemblage is dominated by trough cross-stratified sandstones, which fine upward into ripple cross-laminated and horizontally laminated sandstones and siltstones (figure 11, section a, 20 to 40 m).

The alternating facies assemblage consists of alternating beds of sandstone, siltstone, mudstone and coal. The sandstones and siltstones are typically rippled and grade into each other; less commonly, they grade into mudstone and coal (figure 16, section g, 0 to 20 m).

The mudstone facies assemblage consists of thick sequences of red and grey mudstones, siltstones and coal beds. The siltstones are generally rippled and the mudstones massive; units commonly grade into each other (figure 12, section b).

Chapter III

SANDSTONE FACIES ASSEMBLAGE

3.1 INTRODUCTION

The sandstone facies assemblage is present throughout the measured sections, but is most common in the lower parts and generally forms headlands along the coast. This assemblage comprises approximately 20% of the total succession. The sandstone assemblage is a distinct vertical and lateral arrangement of lithofacies indicating a meandering fluvial system of deposition. Channel-floor erosion, channel migration, avulsion and channel infilling were the main processes occurring. Lithofacies within this assemblage are predominantly St, Sr and Sh with minor amounts of Fl and Sp. The proportions and range of thicknesses for the major lithofacies are summarized in table 4. The assemblage occurs as fining upward sequences: the trough cross-stratified sandstone fines upward into horizontal or ripple cross-laminated sandstone and siltstone. In some cases, these lithofacies additionally fine upward into mudstone and coal (parts of figures 11, 13, 14 & 15). The finer (upper) parts of these sequences are heavily rooted and contain abundant plant debris and concretions.

Table 4

Sandstone Facies Assemblage				
Lithofacies	%	Unit Thickness metres		
		minimum	mean	maximum
St	56.8	0.5	4.0	10.0
Sr	23.2	0.5	2.3	6.0
Sh	12.5	1.0	1.8	2.5
Fl	6.8	1.0	1.9	3.0
Sp	0.7	1.0	1.0	1.0

The bases of the trough cross-bedded sandstones are either erosional or non-erosional, of which erosional bases constitute approximately 70 %.

3.2 VERTICAL DISTRIBUTION

The lithofacies were chosen to represent unique rock types formed under specific processes. It is the vertical succession of lithofacies which provides evidence for depositional environments and changing conditions.

Markov chain analysis deals with the relationship between a given bed and the preceding bed. In this study, a first-order embedded method is employed (see appendix A). Markov chain analysis deals with the principal cyclic relationships of a succession. The main problems encountered in this type of analysis include:

1. Simplification of lithofacies may cause omission of important hydrodynamic information (Reading, 1980).
2. Non-depositional periods are not considered.
3. Covered units are not considered.

Major path successions for the sandstone assemblage are represented in figure 20. For detailed explanation and analysis, see appendix A. Chi- square tests after Harbaugh and Bonham-Carter (1970) and Gingerich (1969) indicate that the vertical succession was derived by non-random variations in the depositional mechanism.

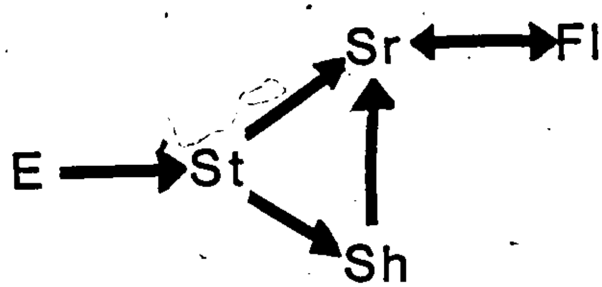


Figure 20: Sandstone facies assemblage preferred sequence.

For this assemblage, a fining upward cycle is distinguished and attributed to main channel deposition (Walker and Cant, 1979) (figure 21). The cycle begins with an erosional or sharp base, which is generally marked by local scouring, coarse pebbles, abundant organic debris and occasionally mud rip-up clasts (photos 2, 3 and 4). This was formed by scouring and re-working of underlying sediments by high peak flow. The scoured base is overlain by trough cross-stratified sandstones which represent preservation of dune forms on a point bar (Walker and Cant, 1979). The point bar is the main depositional site within a meandering channel; meandering of the channel is maintained by erosion of the outer bank and deposition on the inner bank, laterally building a point bar (Walker and Cant, 1979; Allen, 1970) (figure 22).

As flow decelerated, due to either channel migration or decreasing energy levels up the point bar (Allen, 1970) (figure 22), the dunes decreased in size, as represented by an upward decrease in trough size in the channel sandstone.

Lithofacies St grades upward to lithofacies Sh or Sr. This transition is related to decrease in stream power and grain size on higher parts of the point bar (Allen, 1970) (figures 22 and 23). The development of horizontally laminated sandstones is favoured by higher velocity and shallower depths (Walker and Cant, 1979) on the upper point bar surface (figure 24). This would also account for the common lateral transition between lithofacies Sh and Sr, which may occur as lateral migration of the point bar proceeded (figure 24) be due to fluctuations in flow conditions.

The vertical sequence continues fining upward to lithofacies Fl and Fm; representing the uppermost parts of the point bar and/or overbank deposits (Walker and Cant, 1979). These upper parts are well rooted and contained abundant *in situ* trees as vegetation migrated onto the depositional site.

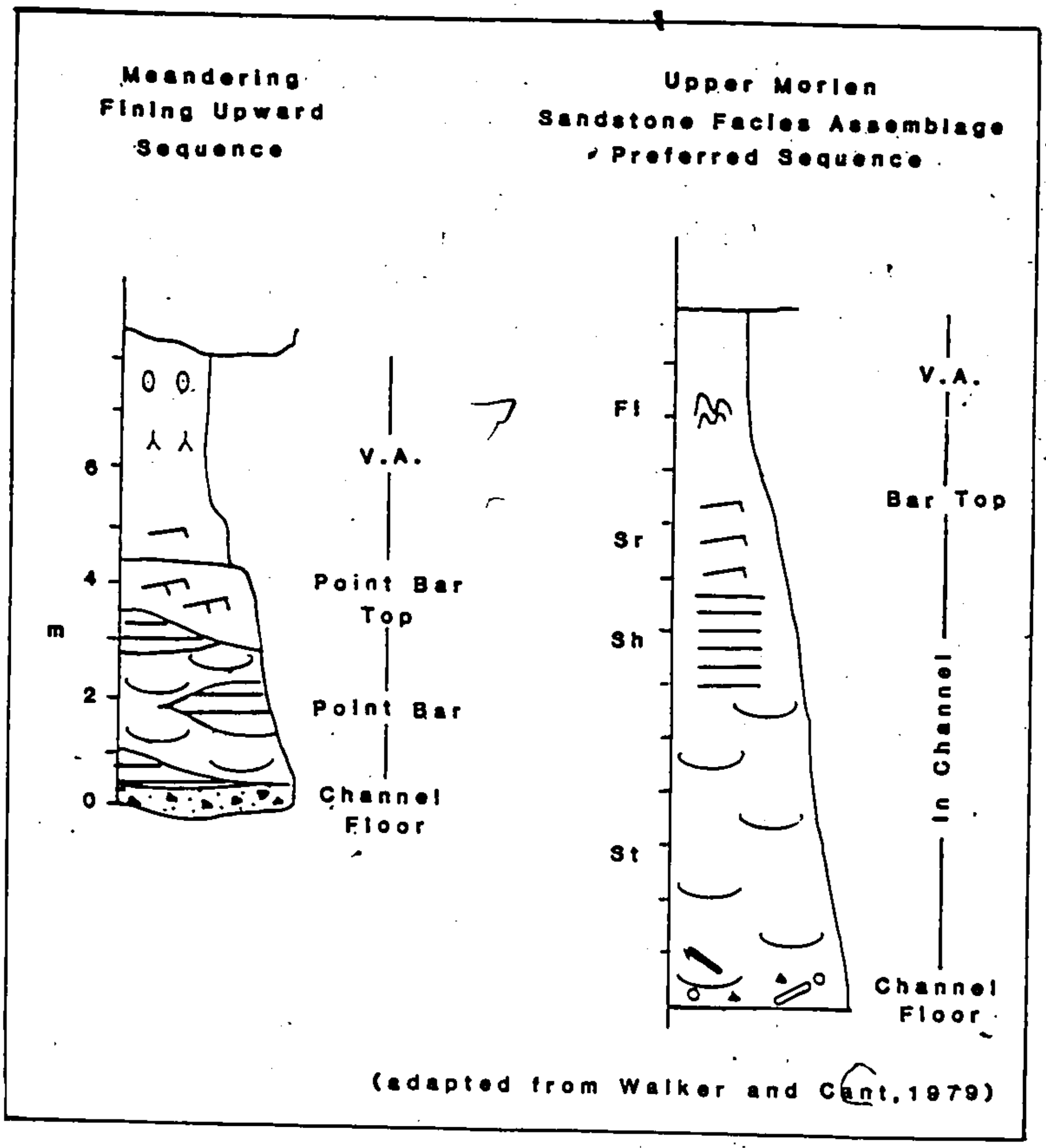


Figure 21: Comparison of the preferred sequence with the meandering river model. V.A. indicates vertical accretion. Letters correspond to lithofacies in this study. Symbols are described in figure 10.

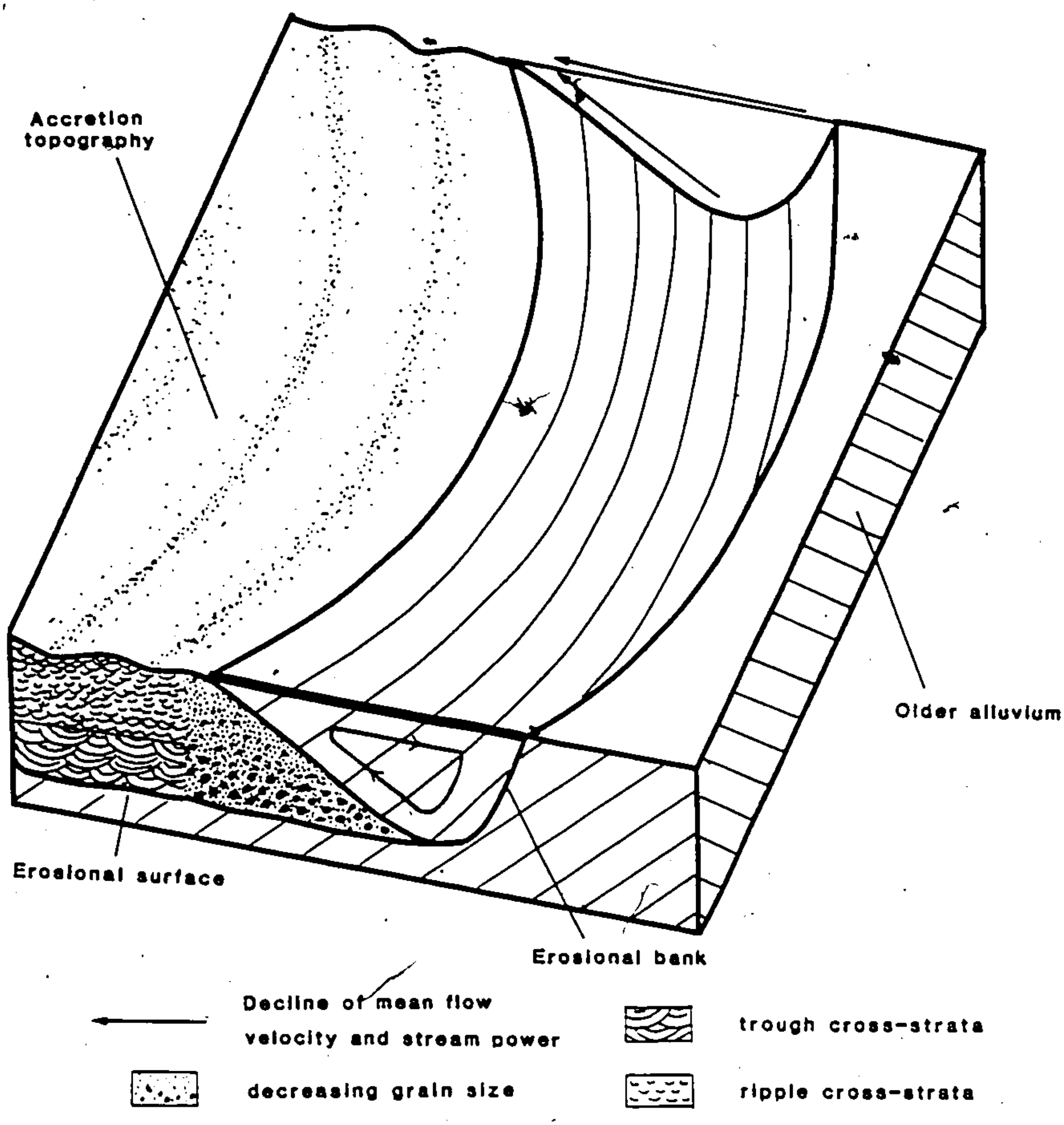
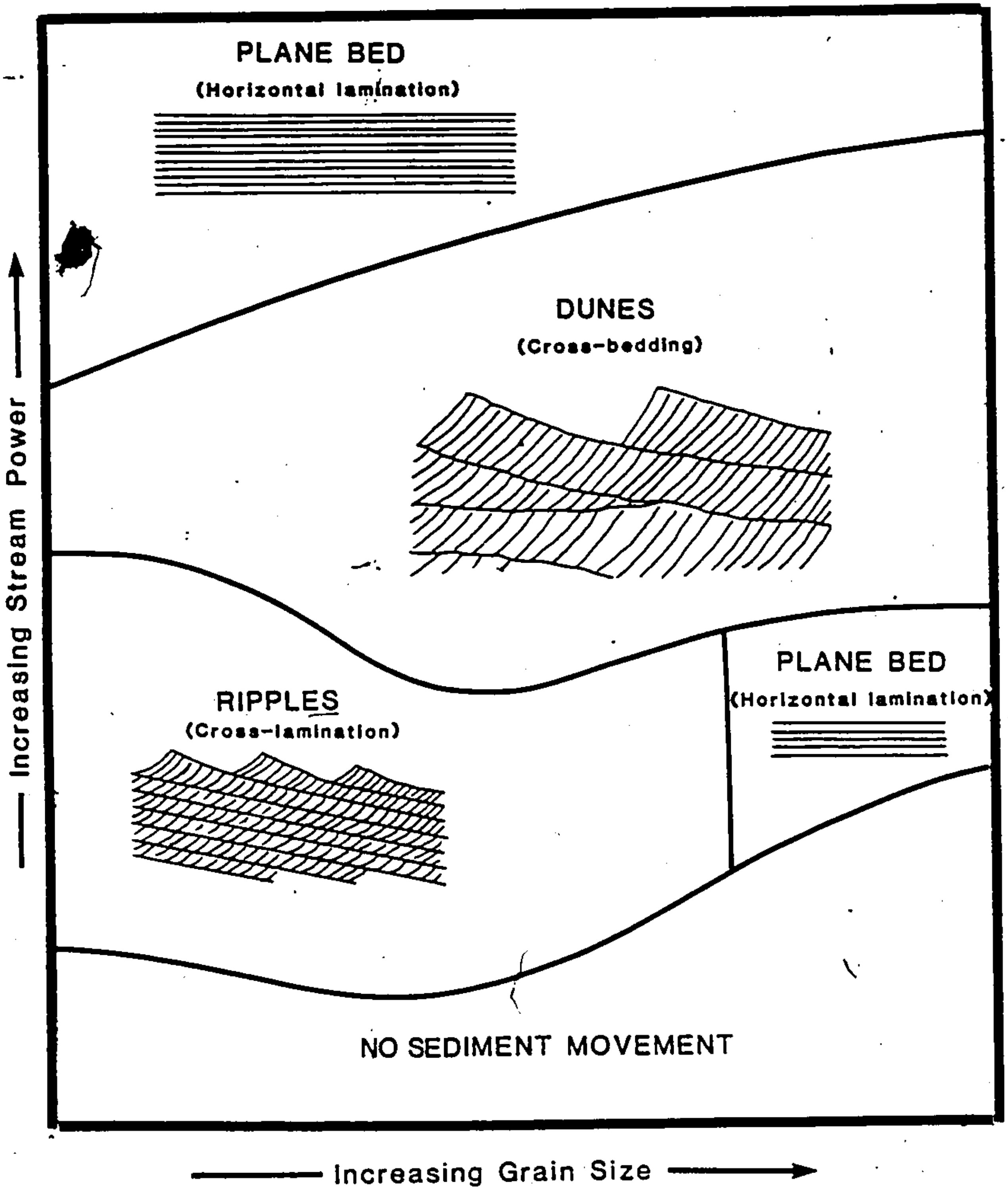


Figure 22: Characteristics of sediments deposited in an idealized channel bend in relation to mean flow velocity and stream power.

(adapted from Allen, 1970)



(adapted from Allen,1970)

Figure 23: Bed form in relation to relative stream power and relative grain size.

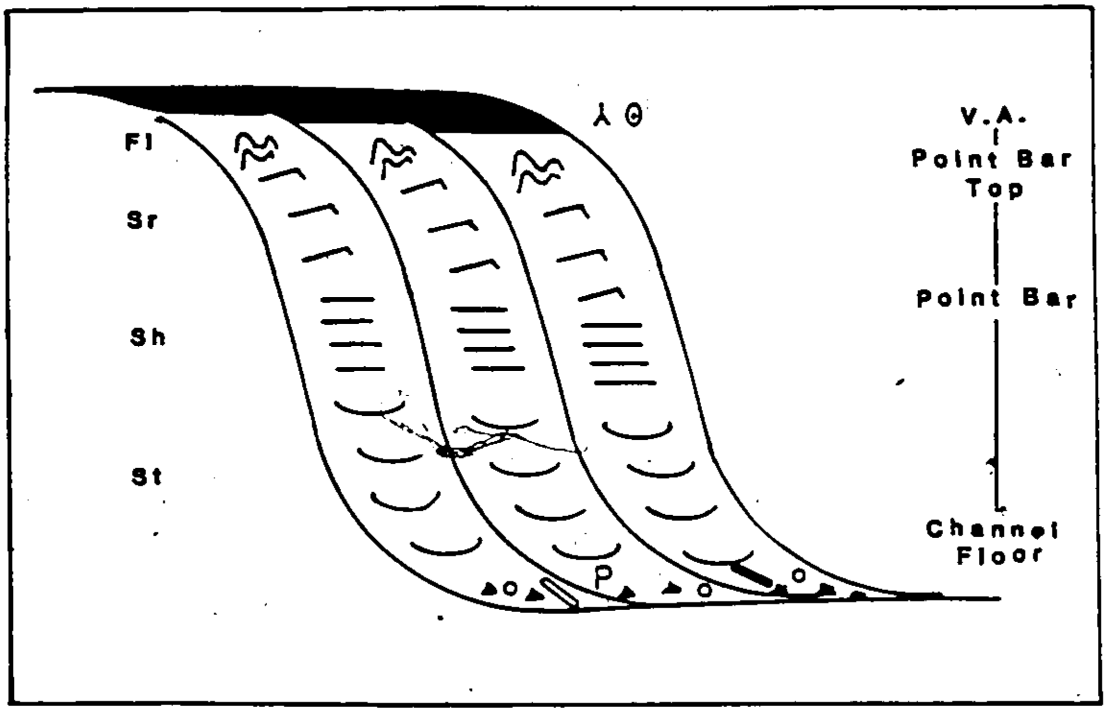


Figure 24: Internal features of a point bar deposit. Each segment marks one event. Lithofacies correspond to this study. Symbols are listed in figure 15. V.A. is vertical accretion. No vertical scale implied.

3.3 LATERAL EXTENT

The sandstone facies assemblage has been described as an upward fining cycle. Generally these units have a varied thickness, ranging from 2.5 to 14 m. In vertical profiles, constructed from drill logs and cliff sections (figures 18, 19 and 25), the sandstone bodies are found to extend for distances greater than 4 km.

Sigmoidal cross-strata have been recognized in various modern and ancient localities by Moody-Stuart (1966); Allen (1966, 1970); and Jackson (1978) and are attributed to the lateral accretion of a point bar deposit. A few sigmoidal cross-strata are recognized in the study area (photo 26). These lateral accretion surfaces are marked by thin (2 to 30 cm thick) units of fine-grained rippled sandstone, siltstone and shale (photo 27). These are presumably drapes on the upper point bar surface (Reineck and Singh, 1975); subsequent flows were not of sufficient energy to erode this layer. The sigmoidal shape is an internal form reflecting the thickening from a channel edge to mid-channel body (figure 24).

Generally each lateral accretion deposit is 2 to 4 m thick, increasing in thickness towards the centre of the channel, up to 10 m. Laterally, each accretion surface varies to thicker St units of the central channel area or continues to thin towards the overbank area. In the overbank area, these lateral accretion deposits may end abruptly in a

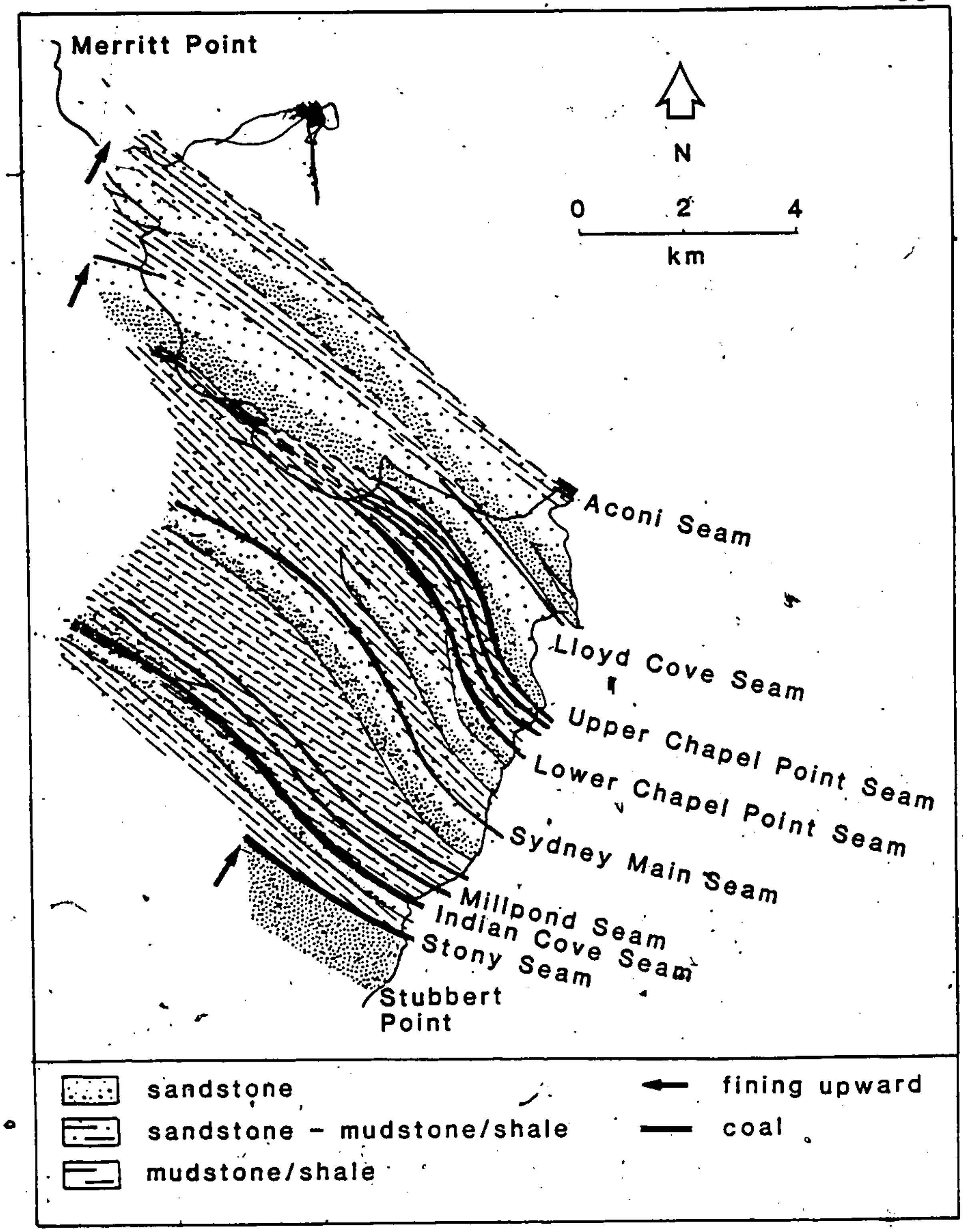


Figure 25: Lateral extent of the major sandstone bodies and coal seams, from cliff sections and drill logs.

convex channel edge or, as is usually observed, interfinger with and overlap the overbank and levee deposits.

The dip-wise lateral extent of an accretionary surface has been adopted to be 2/3's of the bankfull width (Ethridge and Schumm, 1978); this concept was first introduced by Allen (1965). Bankfull depth has been defined as the average thickness of the lateral accretion unit (Moody-Stuart, 1966). More recently, investigators have established correction factors to compensate for the fact that depth varies in different parts of the system (depth in straight reaches is less than in the meanders) and to allow for compaction (Ethridge and Schumm, 1978). Various investigators found that a consistent ratio of 0.585 occurred between straight versus meander bend depths. A compaction factor of 0.9 readjusts the sediments to their original thicknesses (Ethridge and Schumm, 1978), Thus, the original dimensions of a channel can be summarized:

$$W = W_l \times 1.5$$

$$D = D_l \times 0.585/0.9$$

for a straight reach and

$$D = D_l$$

for a meander bend.

where W_l is the lateral extent of the point bar and D_l is the thickness of the epsilon cross-strata. From the bank-full depth and bank-full width, the width : depth ratio of a system may be determined (Ethridge and Schumm, 1978). The width : depth ratio is then used to calculate the sinuosity of the system:

$$P = 3.5\ F^{-0.27}$$

(Schumm, 1963); where F is the width to depth ratio and P is the sinuosity. When such measurements and calculations are made, it should be remembered that the dip of the point bar should be at right angles to the channel flow to avoid measurement of apparent widths and depths.

In the study area, preserved point bar deposits are not common, however it was possible to obtain measurements from a few deposits throughout the area. The measurements, width : depth ratios and sinuosities are listed in table 5. The mean sinuosity of the channel sandstones is 1.87. Based on Rust's (1978) and others division of sinuosity to distinguish between meandering and non-meandering channels, that is < 1.5 sinuosity is a non-meandering channel and sinuosity > 1.5 is a meandering channel; the measured point bar is the result of a highly sinuous channel.

Table 5: Sinuosity data, measurements are from lateral accretion units.

width	depth	bank-full width	width:depth ratio	sinuosity
149.4 m	9.6 m	224.1 m	23.3:1	1.50
81.6 m	10 m	122.4 m	12.2:1	1.78
65.6 m	7.2 m	98.4 m	13.7:1	1.73
37.7 m	6.8 m	56.6 m	8.3:1	1.98
26 m	9 m	39 m	4.3:1	2.36
			mean sinuosity	1.87

Chapter IV

ALTERNATING FACIES ASSEMBLAGE

4.1 INTRODUCTION

This assemblage consists of alternating beds of fine-grained sandstone, siltstone, mudstone, shale and coal. The predominant lithofacies types are Sr, Fm, Fl and Sh, with minor amounts of Fl(c), C and D; proportions and thicknesses for the major lithofacies are summarized in table 6. Organic material is common as *in situ* trees, roots and concretions. Mudstones are red and grey coloured. Calcareous sandstones and siltstones are commonly associated with the red mudstones. The sandstones are fine to very fine-grained. Stratification in the sandstones, is thin bedded to thinly laminated (10 to <0.3 cm), horizontal and rippled. This assemblage comprises approximately 40% of the total succession (parts of figures 11 and 16, minor parts of figures 13 and 15). The vertical and lateral arrangement of the lithofacies in this assemblage indicate levee, crevasse splay, flood plain and lacustrine deposition, as well as coal and paleosol development.

Table 6

Alternating Facies Assemblage				
Lithofacies	%	Unit Thickness metres		
		minimum	mean	maximum
Fm	28.6	0.5	1.3	4.4
Sh	24.6	0.3	1.4	2.8
Sr	19.3	0.5	1.3	4.0
Fl	16.6	0.2	1.4	2.8
Fl(c)	7.1	0.2	1.0	4.8
C	3.2	0.1	0.4	0.8
D	0.7	0.3	0.4	0.5

4.2 VERTICAL DISTRIBUTION

Markov chain analysis was applied to this assemblage and the mudstone assemblage combined (appendix A), as both of the assemblages are attributed to the various overbank deposits. From the combined analysis, two distinct cycles were observed (figures A3&4); one contains a wide variety of lithofacies : Sr, Sh, Fl(c), C and Fl; the other cycle is dominated by the lithofacies Fm. The Fm lithofacies dominated cycle is assigned to the mudstone facies assemblage and is discussed in that chapter V. The other cycle is attributed to the alternating facies assemblage, due to the wide variety of lithofacies present; these correspond to the greater variety of processes which affect these deposits.

The alternating facies assemblage shows an overall fining upward cycle (figure 27); from the lithofacies Sh or less commonly from an erosional base and the lithofacies St. Lithofacies St consists of small (< 20 cm wide X < 8cm deep) trough-cross stratified fine-grained sandstone. The erosinal bases and lithofacies St are attributed to crevasse splay deposits. Allen (1970) described this type of deposit as forming from single channels which cut the levees and extend into the flood basin terminating in a fan or lobe of sediment. These correspond to Coleman's (1969) single-channel crevasse splay deposits (figure 28). Both Allen (1970) and Coleman (1969) describe a single channel crevasse splay as a fining upward sequence from an erosional or sharp base to

trough-cross stratified sandstones which fine upward. These deposits are not common
in the study area, which may be due to the fact that the system was highly sinuous which prevented the development of distinct, continuous levees .

Within the alternating facies assemblage, lithofacies St fines upward into horizontally laminated fine-grained sandstone and siltstones. The Sh lithofacies commonly occurs above and below rippled sandstones and siltstones (Sr). These lithofacies may be attributed to crevasse splays or natural levee deposits (Reineck and Singh, 1975). Coleman's (1969) second type of crevasse splays occurs most commonly in the lower reaches of the Brahmaputra River. In this part of the Brahmaputra River, numerous broad sinuous bends occur which resemble meander loops. The fluvial processes involved in this area are likened to those in a meandering fluvial system. The crevasse splays in this area form anatomosing channel patterns (figure 29). Coleman (1969) describes the multi-channel (anastomosing) crevasse splays as units of horizontally and rippled sandstones and siltstones. These are similar to levee deposits described by Reineck and Singh (1975), into which the crevasse splays are transitional . From the vertical profiles of the study area (figures 18 and 19), interfingering and overlapping of the finer parts of the upper Morien Group is common and the units are most commonly laterally and vertically gradational with each

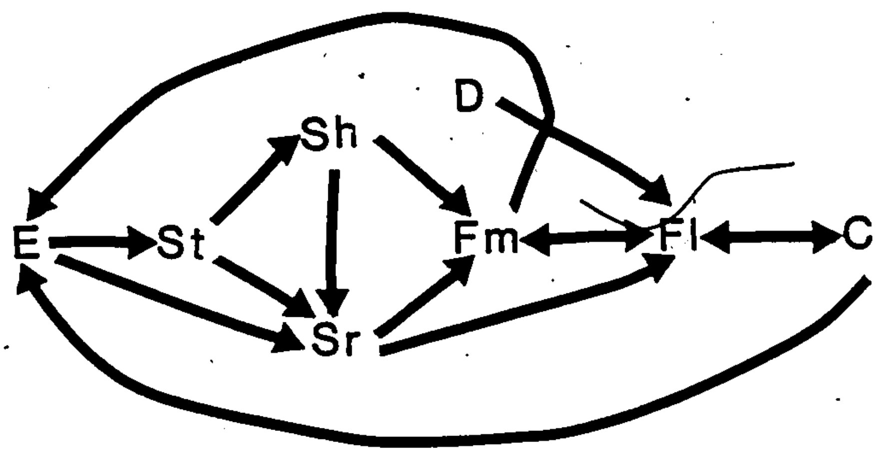


Figure 26: Overbank Preferred Sequence

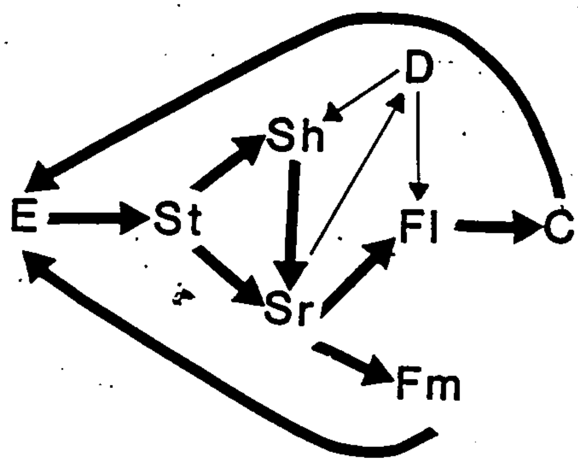
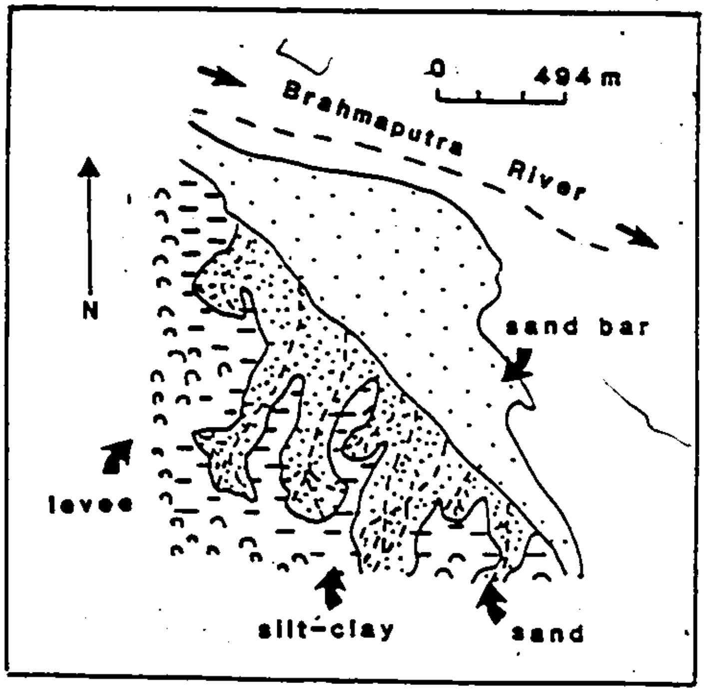
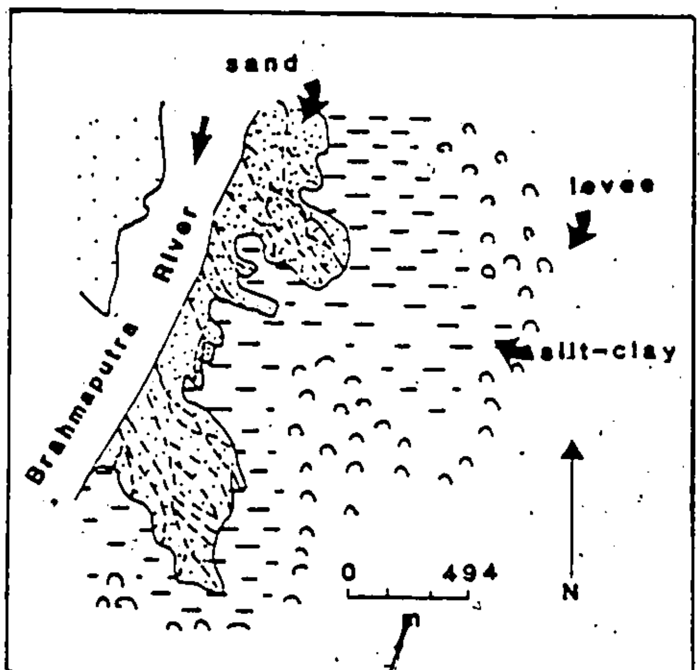


Figure 27: Alternating facies assemblage preferred sequence.



(Coleman, 1969)

Figure28: Single channel crevasse splay.



(Coleman, 1969)

Figure 29: Multi-channel crevasse splay.

other. This indicates that the crevasse splay deposits of the upper Morien Group were commonly the multi-channel type, gradationally building outward from the levees and upward from the flood plain.

Within the fining upward sequences of the alternating facies assemblage, lithofacies Sh and Sr continue to fine upward into lithofacies Fl in response to waning energy levels as flood waters receded. It should be noted that in rapidly changing rivers, abundant sandy and muddy sediment in the flood waters causes the various overbank deposits to be rather undifferentiated.

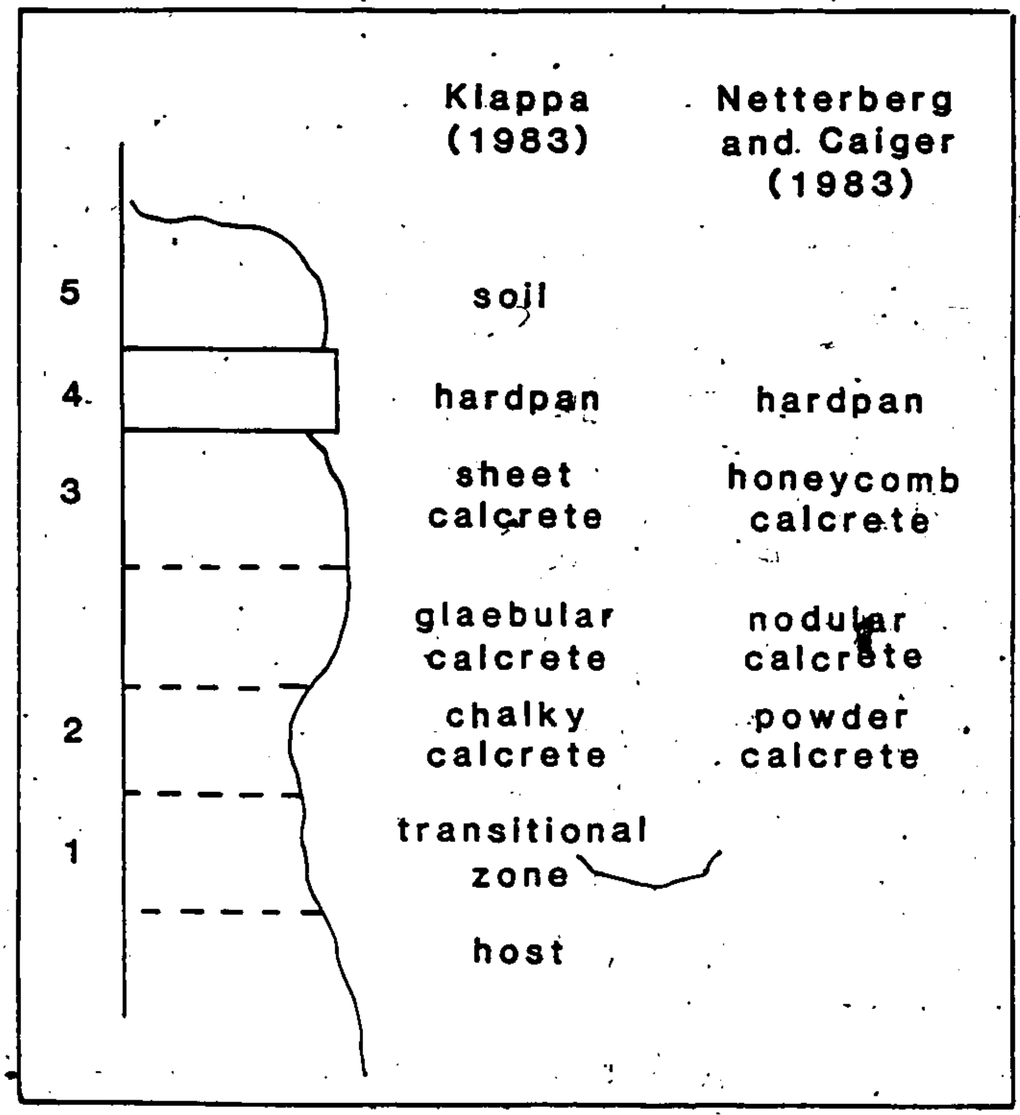
The finest parts of the alternating facies assemblage consist of inter-bedded siltstones and mudstones and lenticular interbeds of mudstones and siltstones. These deposits are indicative of more distal flood -plain areas.

Coal beds formed from peat accumulation during periods of high water table and exclusion of clastic sedimentation. The coal seams are gradational from shaly or seat earth units, which are gradational from the lithofacies Sh and Fl. Occasionally observed within the alternating facies assemblage are coarsening upward cycles. These sequences coarsen upward from lithofacies Fm to lithofacies Sh and Sr (figure 11, section a, 145 to 155m). These cycles are 1/2 to 3 m thick. They most commonly occur in close association with limestone and clammy-shale units. These coarsening upward cycles are attributed to delta formation from a single-channel crevasse splay into a lake (figure 53). Similar small-scale lake deltas were described by Gersib and McCabe (1981) from the Port Hood Formation, Nova Scotia.

Some limestone units occur as beds which are gradational from lithofacies Fl and Sh, as increasing carbonate content in the sediment develops into nodules. This is attributed to paleosol formation, similar to increases in carbonate content upward in the soil profile described by Klappa (1983) and Netterberg and Caiger (1983) (figure 30). These calcareous sandstones are commonly closely associated with red mudstones which occasionally show desiccation cracks providing further support for sub-aerial exposure.

In a few cases, these limestone units occur as pinch and swell beds below a coal seam (photo 17); this implies an unusually rapid change from relatively dry pedogenic conditions to a swamp environment. Rising water tables caused soil development to cease and allowed peat accumulation to occur.

As well, there are pure limestone units which contain ostracods, gastropods and fish bones and scales. In these occurrences, the limestones are most commonly overlain by black shales, which also contain a fresh-water fauna, suggesting lacustrine deposition (photos 24 and 25).



(adapted from Klappa, 1983)

Figure 30: Idealized calcrete profile. Numbers correspond to table 11.

4.3 LATERAL EXTENT

Great lateral extents (70 m to a few kms) of exposure in this assemblage are quite common. Occurring within these deposits are abundant organic material and in situ trees, indicating overbank areas - flood-plain and back swamps. The individual lithofacies overlap, interfinger and are gradational with each other as is evident on the vertical correlations constructed in the area (figures 18, 19 and 25). This assemblage commonly interfingers and overlaps the upper parts of point bar deposits and it distally fines away from channels. This is observed as increasing thicknesses of mudstone (Fm). As described by Coleman (1969) and Reineck and Singh (1975), levee, crevasse splay and flood-plain deposits are commonly indiscernible from each other when associated with a rapidly changing system. From the high sinuosity previously estimated (1.87), it is clear that this was a highly migratory system. Thus, well developed and distinct levee, crevasse splay and flood-plain deposits would not be expected and are only distinguishable in a few cases.

The lenticular interbeds of siltstone and mudstone could be due to a gullying effect on the flood-plain, created by concentrated high energy crevasse splays, channeling the initial flood flow and carrying a heavier load. This would also allow the elevated areas to dry out and develop redbeds and calcretes (figure 31); the same effect would also result from a hummocky topography on the flood plain.

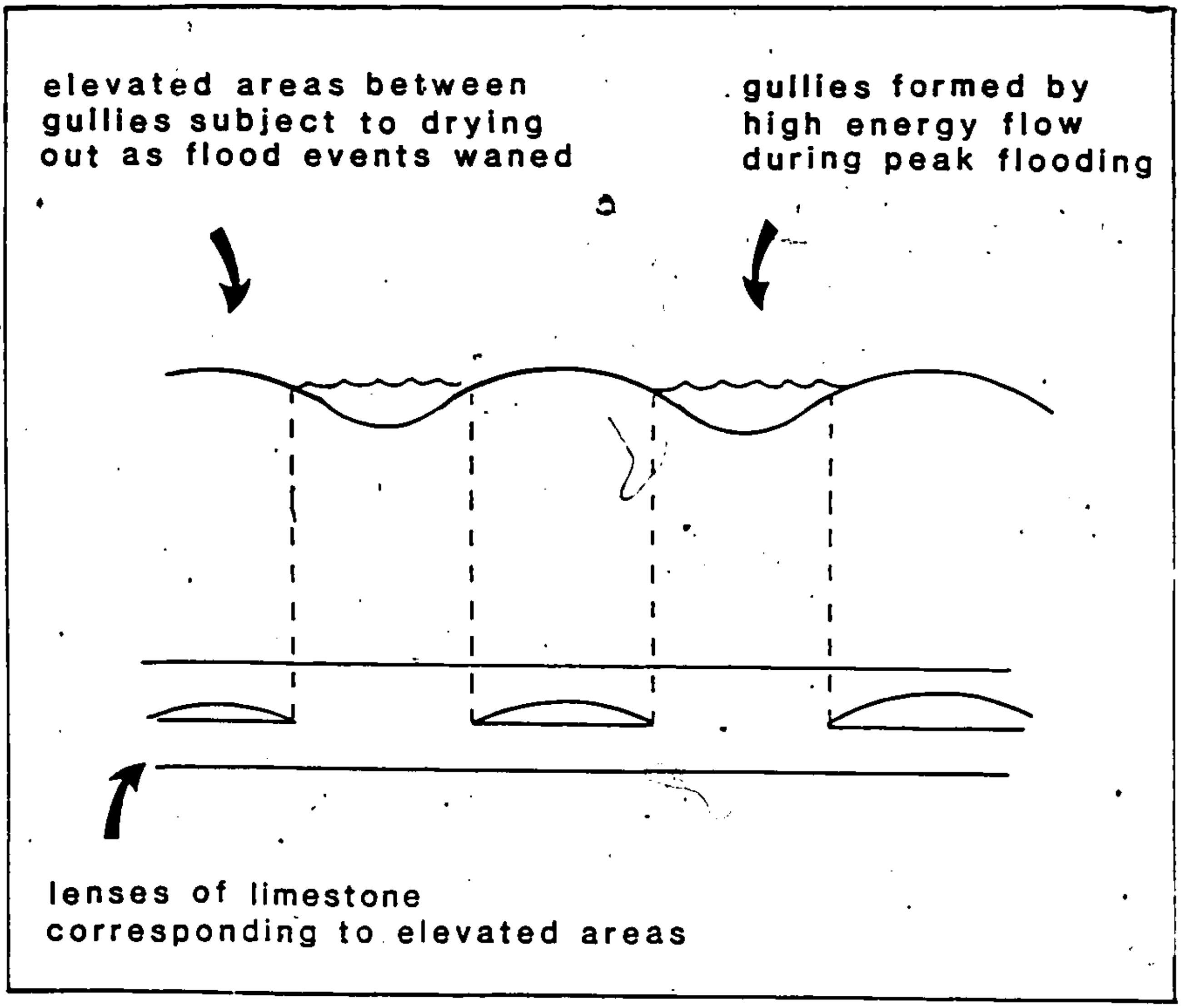


Figure 31: Possible formation of calcrete lenses and pinch-swell units. Section is normal to flood direction. No vertical scale implied.

Chapter V

MUDSTONE FACIES ASSEMBLAGE

5.1 INTRODUCTION

This assemblage comprises approximately 30 % of the upper Morien Group in the study area. It consists predominantly of lithofacies Fm, Fl and lesser amounts of C, Sr and Sh; the proportions and thicknesses of the lithofacies are listed in table 7. This assemblage is observed in the upper part of the Morien Group, near Cranberry Head and below the Aconi seam (figures 5 and 11). These deposits are attributed to flood-plain and flood basin deposition.

5.2 VERTICAL DISTRIBUTION

The second cycle from the overbank Markov chain analysis is dominated by lithofacies Fm and Fl and has been attributed to this facies assemblage. This cycle consists of a preferred sequence from lithofacies Sr and Sh to lithofacies Fm and Fl (figure 32). The fine-grained sandstones and siltstones (Sr and Sh) are not common; they are interpreted as the most distal crevasse splay deposits and flood- plain deposits. Coleman (1969) and Allen (1970) describe these deposits as alternating units of fine-grained sandstone and siltstone, which are rippled or horizontally laminated

Table 7

Mudstone Facies Assemblage				
Lithofacies	%	Unit Thickness metres		
		minimum	mean	maximum
Fm	38.1	0.2	1.1	8.2
Fl	35.2	0.2	1.5	6.4
Sr	9.0	0.2	0.9	1.8
Fl(c)	8.0	0.1	0.8	1.6
Sh	6.9	0.2	0.7	1.7
C	2.8	0.2	0.4	0.8

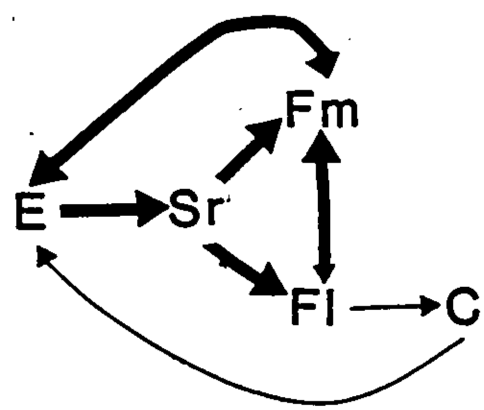


Figure 32: Mudstone facies assemblage preferred sequence.

and both fine and coarsen upward corresponding to increasing and decreasing energy levels as flood waters receded and transgressed.

The flood basins are the lowest areas of a flood-plain. They act as settling basins for the suspended sediments which settle in alternating units of laminated mudstone and siltstone and are commonly convoluted (Reineck and Singh, 1975). They are similar to the extremely fine parts of this assemblage (figure 12), in which strata are commonly convoluted. The mudstones generally fine upward from the siltstones and fine-grained sandtones. Desiccation cracks are uncommon (photo 29); together with the red colouration of some of the mudstones and the abundant concretions, they are attributed to sub-aerial exposure between floods (Reineck and Singh, 1975). The sandstones and siltstones are commonly calcareous, probably representing theinitial formation of a soil profile (Klappa, 1983; Netterberg and Caiger, 1983). In addition, the abundant organic material further indicates shallow waters with extended periods of non-sedimentation.

Drill log correlations for the area (figures 18 and 19), show that the mudstone-dominated sediments often occur in stratigraphic contact with channel sandstones. This indicates frequent migration of the channels across the flood plain.

5.3 LATERAL EXTENT

Similar to the alternating facies assemblage, the mudstone facies assemblage extends laterally in sheet-like units up to 4 km (figures 18, 19 and 25). Lateral pinching and swelling of the units is common, but this does not interrupt the overall lateral persistence. The great lateral extent and consistency of this assemblage indicates a large area, distal from the influence of active channels (photo 33).

Chapter VI

PALEOCURRENTS

Paleocurrents were measured primarily on wave-cut platforms, with a few trough measurements taken from cliff faces. Trough cross-stratified sandstones and rippled sandstones are the main paleocurrent indicators. The data for these two structural groups were kept separate for two reasons: 1) to demonstrate the approximately orthogonal relationship between paleocurrents in the main channels and those in related overbank sandstones and siltstones; and 2) to compare with Miall's (1974) hierarchy of sedimentary structures, in which St is a rank 3 and ripples are a rank 6. As well, two groups of rippled sandstones were distinguished. The first group is interpreted as the upper parts of the point-bar. These sandstones are directly above channel sandstones and give trends closely corresponding with the channel trends. The second group yields directions at high angles away from the main channel trends and is interpreted as overbank deposits. Values for $\bar{\theta}$, vector magnitude and probability of randomness are based on Curray's (1956) analysis of two-dimensional orientation data. Data, equations and an example of the format are given in appendix B.

Orientations of trough axes were recorded in each major sandstone body. The number of observations varied from 3 to 28, with a mean of 15.5 observations per body. The values for $\bar{\theta}$ vary from 305.6° through north to 175.5° ; the majority of directions were in the north-east quadrant (figure 33). Vector magnitudes are calculated per sandstone body; most exceed 90%. Probabilities of randomness are less than 1×10^{-2} in all cases.

Rippled sandstone measurements are based on groups of values from lateral cliff exposures of up to 500 m. This is due to the common problem of lack of sufficient good exposures. The ripple paleocurrents for both groups have a greater directional variance than the St directions, as expected from Miall's (1974) hierarchy of structures for paleocurrent directions and their reliability. The two groups of rippled sandstones give two distinct trends: 1) directions parallel to St directions in associated facies; 2) directions at high angles to the St directions, (figure 34). The first trend, parallel to major channel flow (St), is attributed to deposition on the upper parts of point bars. The second trend, perpendicular to main channel flow (St) is interpreted as resulting from overbank flow away from the main channel.

The ripple paleocurrent directions vary from 15.3° through to 325.7° (figure 34). There seems to be only a minor void of directions towards the south-west (figure 35). The vector magnitudes

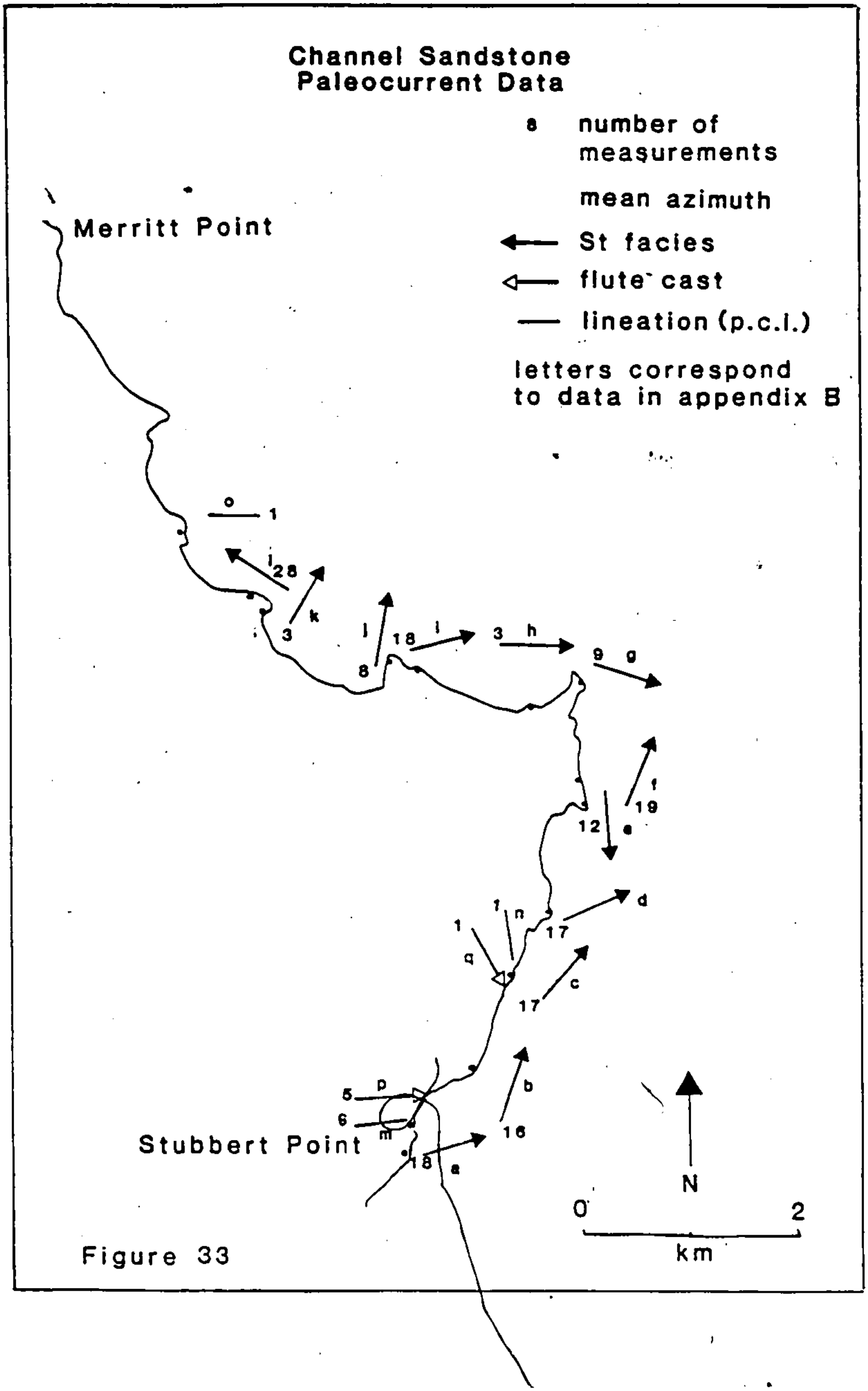

Channel Sandstone
Paleocurrent Data
a number of measurements
mean azimuth
St facies
flute cast
lineation (p.c.l.)
letters correspond to data in appendix B
Merritt Point
Stubbert Point
N
0
2
km

Figure 33

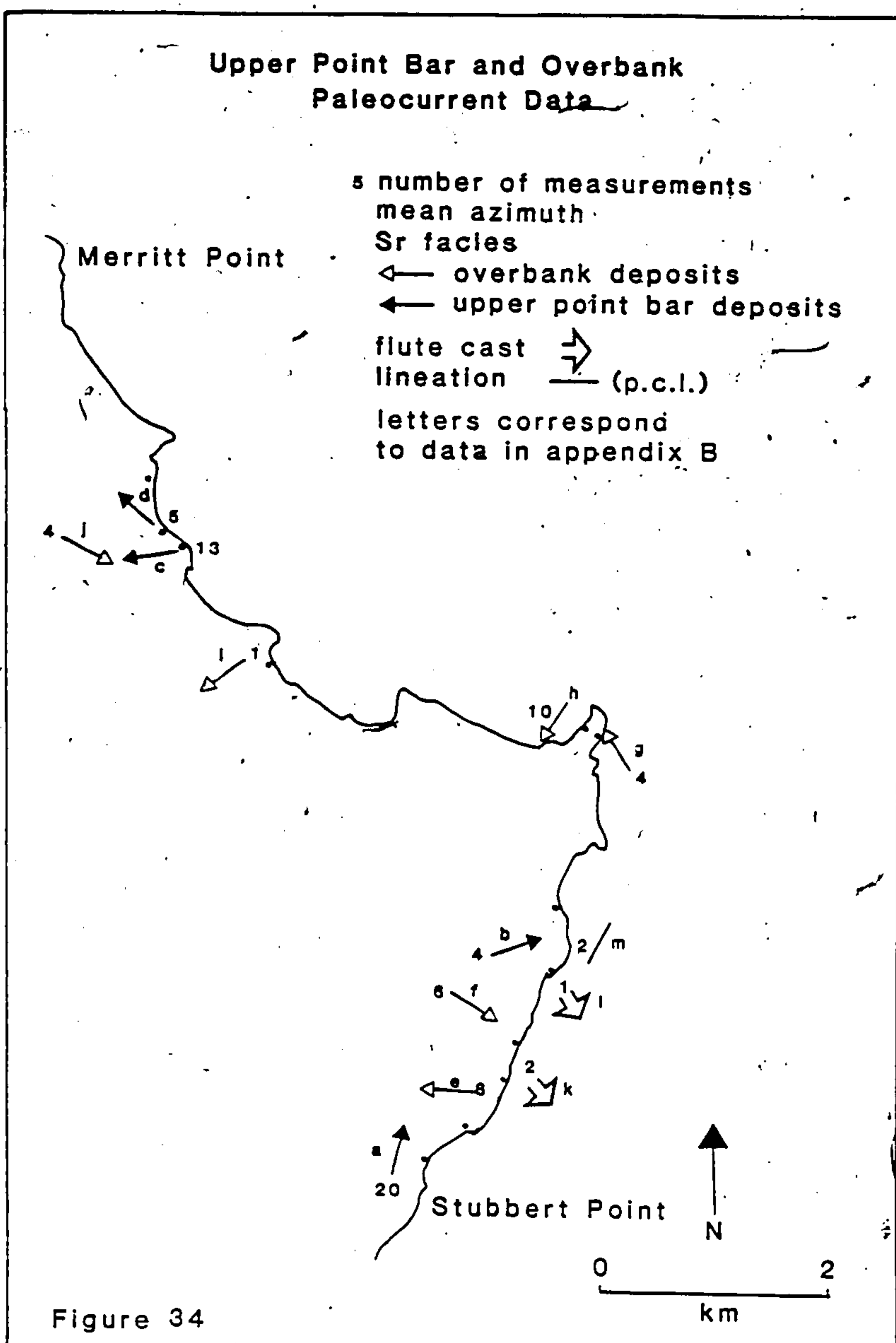

Upper Point Bar and Overbank
Paleocurrent Data
5 number of measurements
mean azimuth
Sr facies
overbank deposits
upper point bar deposits
flute cast
lineation (p.c.l.)
letters correspond
to data in appendix B
Merritt Point
Stubbert Point
N
0
2
km

Figure 34

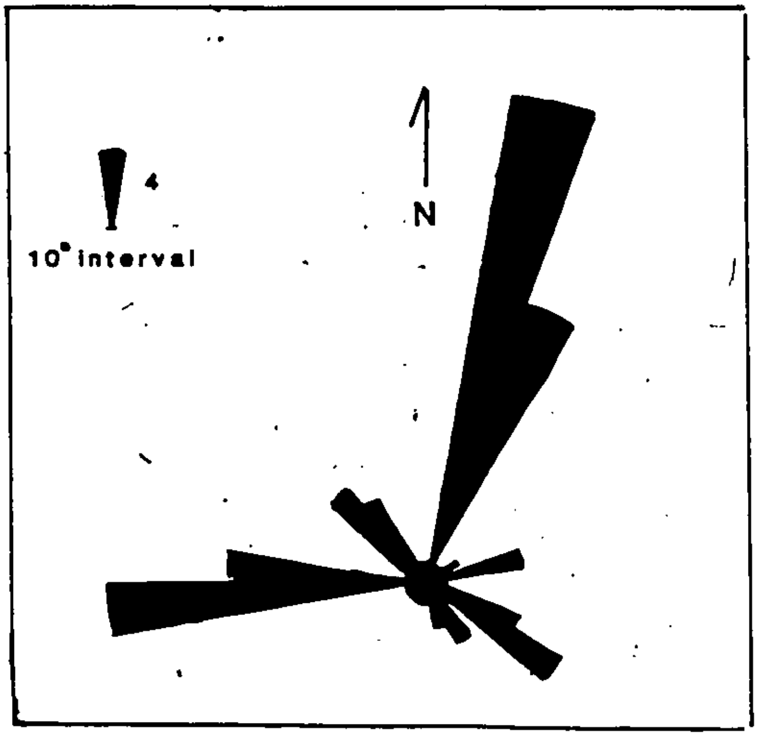


Figure 35: Rose diagram of the upper point bar and overbank deposits paleocurrent trends.

are more variable than those for St, with a range from 30 to 100%. The probabilities of randomness are also higher than for St, but values are all below 1×10^{-1}. Again, the contrast of magnitudes and probability of randomness between the St and Sr directions reflects the respective ranks in the hierarchy, St ranked above Sr. The number of observations for Sr, varied from 1 to 20, with a mean of 7.8 observations per lateral cliff exposure of 500 m.

In general, there is an overall northeastward trend for all the data, which broadly corroborates the regional trend shown by Duff et al.(1982) and local trends by Giles (1983). Giles (1983) indicated a longitudinal trend to the northeast. Evidence in Rust et al.(1983) indicates that the Boisdale and Coxheath Hills acted as local highs influencing the paleocurrents. This can be related to the position of the Morien Group depositional site with respect to the main Sydney Basin. The depositional site is presently believed to have been located on the southwest edge of an east-west elongated basin (figures 50a & b). There is a marked change in the paleocurrent trends upward within the Morien Group. A consistent paleocurrent pattern in the lower Morien Group alters to a more diverse pattern of paleocurrents in the upper Morien Group (Dilles and Rust, 1983; Giles, 1983; Rust et al., 1983; Masson and Rust, 1983; this study). This change reflects an upward increase in channel sinuosity as the depositional style changed from braided to meandering.

Chapter VII

PETROLOGY

Petrographic analysis was done on samples collected from throughout the study area (figure 36). The samples were grouped into trough cross-stratified sandstones (St); overbank deposits (Fl, Fm, Sh, Sr) and paleosols and limestones. Detailed descriptions are found in appendix C. Only the St thin sections were point-counted, because the high percentage of clays, organic materials and sericite in the overbank samples made identification of constituents difficult.

The St samples are all quartz rich, all contained muscovite and some percentage of clays and organic materials. Overall trends show an increase in K-feldspar and calcite cement upward through the succession and a decrease in lithic grains. The lithic grains consist of polycrystalline quartz, chert, siltstone, intraclastic mudstone and carbonate fragments, metamorphic rock fragments, some porphyritic (?) volcanic rock fragments and some granitoid fragments. Overall, the fragments are sub-angular to angular, very coarse to medium grained sand grains, and the sandstones classify as arkoses to lithic arkoses (figure 37).

The overbank sediments consist of very fine sandstones, siltstones and mudstones. These are very consistent in thin section,

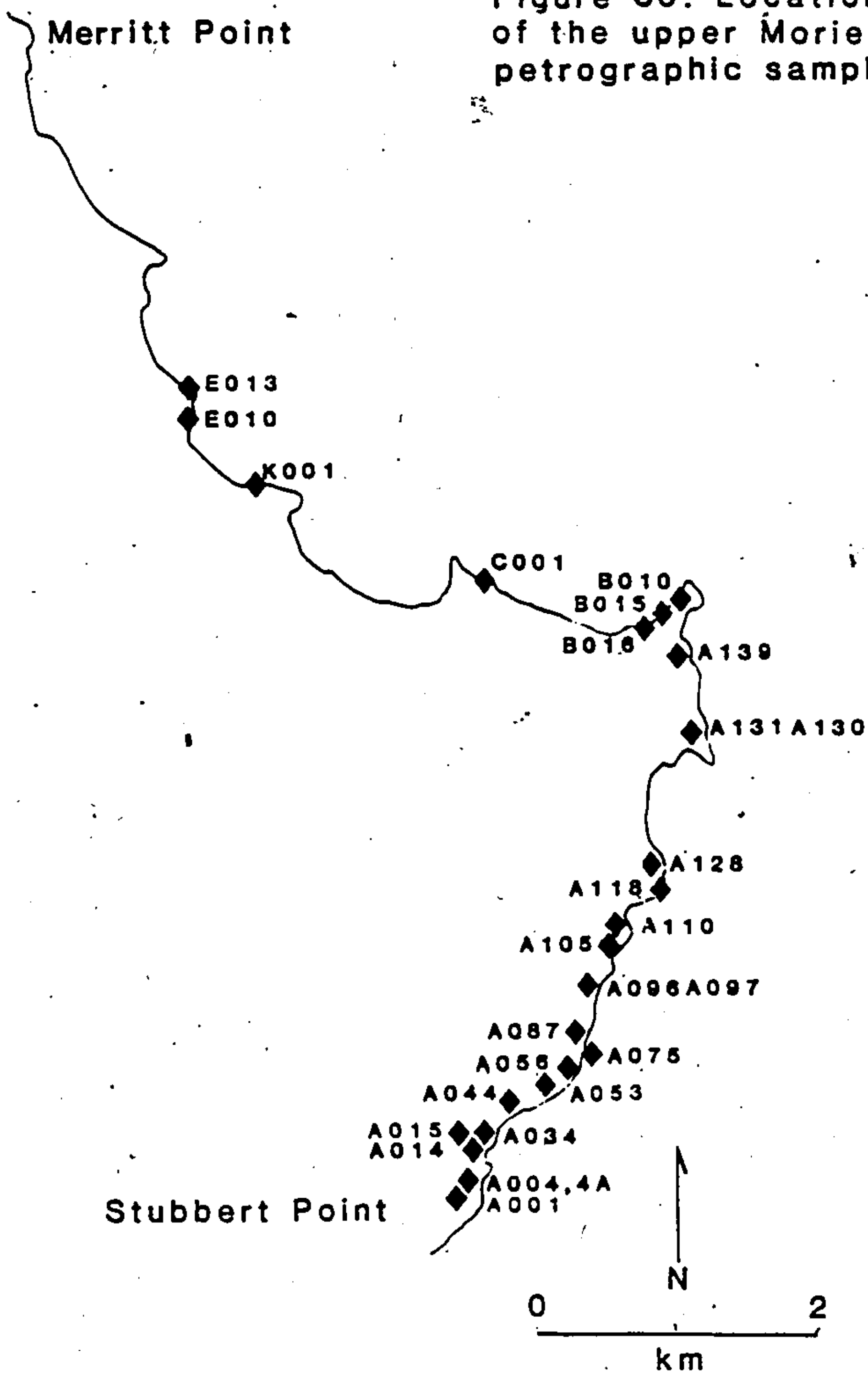


Figure 36: Locations of the upper Morien petrographic samples.

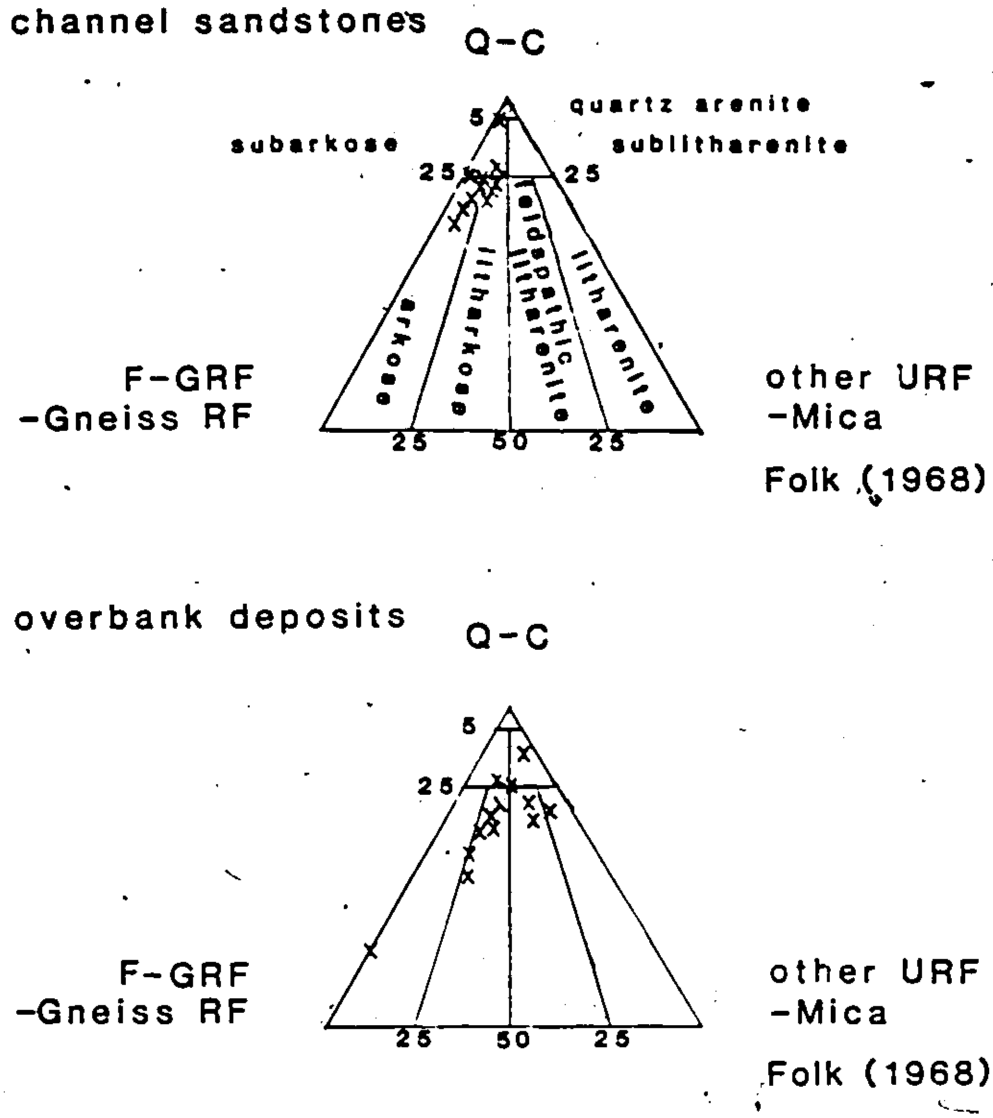


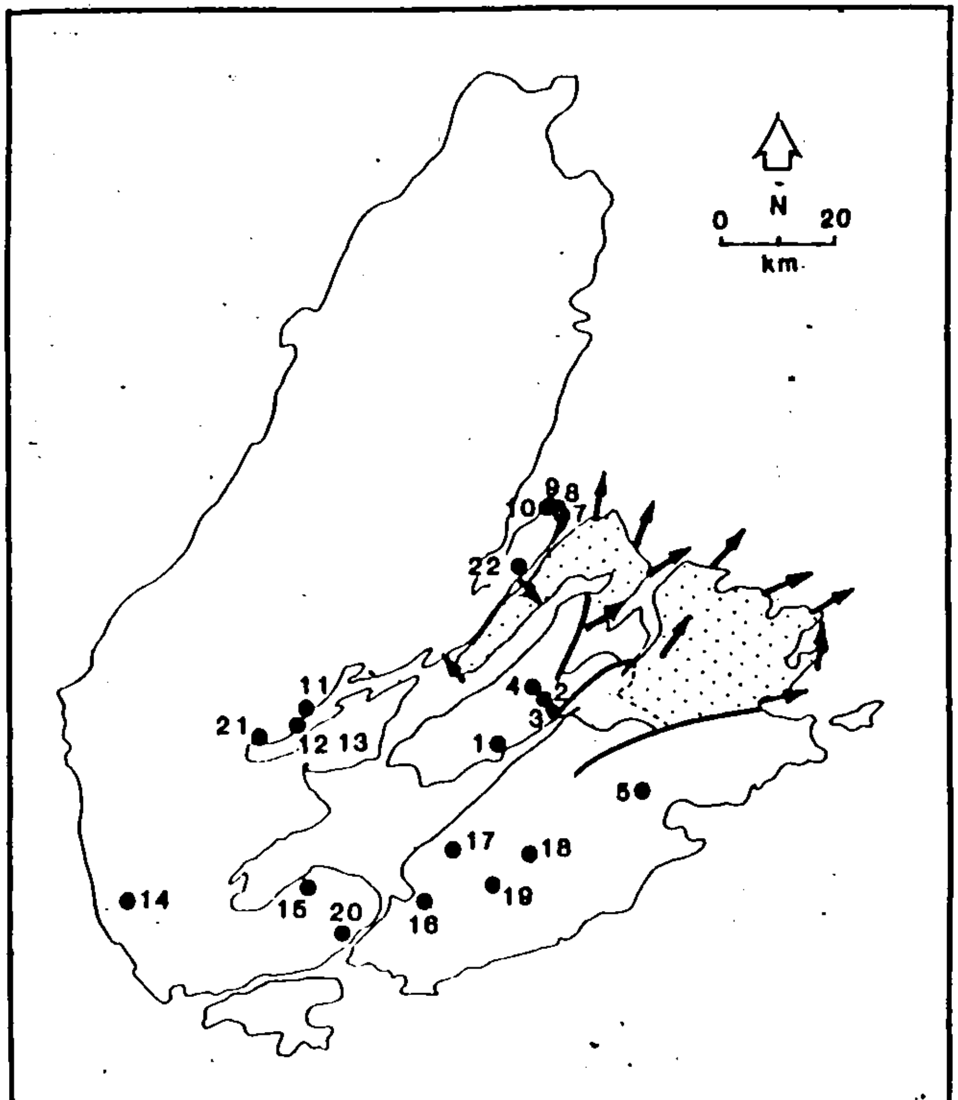
Figure 37: Classification of sandstones.

comprising 30-40% quartz, 5-15% muscovite, 30-40% clay and sericitic material and 10-20% organics. There are rare phosphate grains, probably formed by reprecipitation of dissolved phosphatic fossils or altered organic materials, possibly from the alteration of coprolites or fish bones. The grains are sub-angular and the sediments are well to moderately sorted. Horizontal and ripple laminae are marked by concentrations of organic material and mica grains (photos 9 and 39).

The third group (limestones) has been described in the chapter on paleosols.

Selected basement rocks (pre-Morien Group) were also examined petrographically to determine possible source areas (figure 38). The basement rocks consist of various sedimentary rocks (shale, limestone, mudstone, siltstone, sandstone and conglomerate); volcanic rocks (rhyolite, felsic and mafic tuffs); metamorphic rocks (schists, gneisses, meta-conglomerate, calc-silicate, marble); and igneous rocks (syenite and granite). Samples were selected on the basis of geographic and topographic relation to the basin and the thin section descriptions are listed in appendix C.

The most distinctive petrographical feature of the Morien sediments is the abundance of muscovite. The most common sources for mica include granites, granite-pegmatites, low grade schists and gneisses (Mason and Berry, 1968).



Morien Group

6 ● basement samples

Carboniferous
20- Riversdale Group
7-, 8- Windsor Group
21- Horton Group

Devonian
14-, 16- Fisset Brook Formation
2-, 3- McAdam Lake Formation

Cambrian
5- Bourinot Group
11- granitoid 17- Irish Cove Pluton
18- Loch Lomond Pluton
1- granodiorite
10- diabase dyke

Hadrynian
15- Forchu Group
4-, 12-, 13- George River Group

Pre-Cambrian
9- granite
22- basement complex

detailed rock descriptions in appendix IV

← paleocurrent direction

Paleocurrent data primarly from St facies from Giles (1983), Rust et al (1983) and this study.

— fault

Figure 38:Location of basement samples and Morien Group paleocurrent trends.

The presence of chert, mudstone and sandstone clasts indicates the erosion of sedimentary source(s). The presence of biotite and phlogopite grains indicate the contribution by granodiorite, gabbro, ultra-basic and/or marble bodies. The sub-rounded to sub-angular shape of the grains implies a limited distance travelled to the depositional site. In addition to pre-Morien basement sample locations, Figure 39 shows general paleocurrent trends for the Morien Group. Paleocurrents are predominantly from the lithofacies St and were obtained from this study, Giles (1983) and Rust et al. (1983). From petrographic and paleocurrent data, the most probable source areas were to the southwest (figure 39). These sources would have included units in the George River Group, especially the marble; the McAdam Lake Formation (arkose and conglomerate); Cambrian granodiorite; the Windsor Group limestone; the PreCambrian basement (schists and gneisses) and the early Carboniferous Horton Group, the sandstones and siltstones. The various rock types found in each of these groups or formations are listed in table 8.

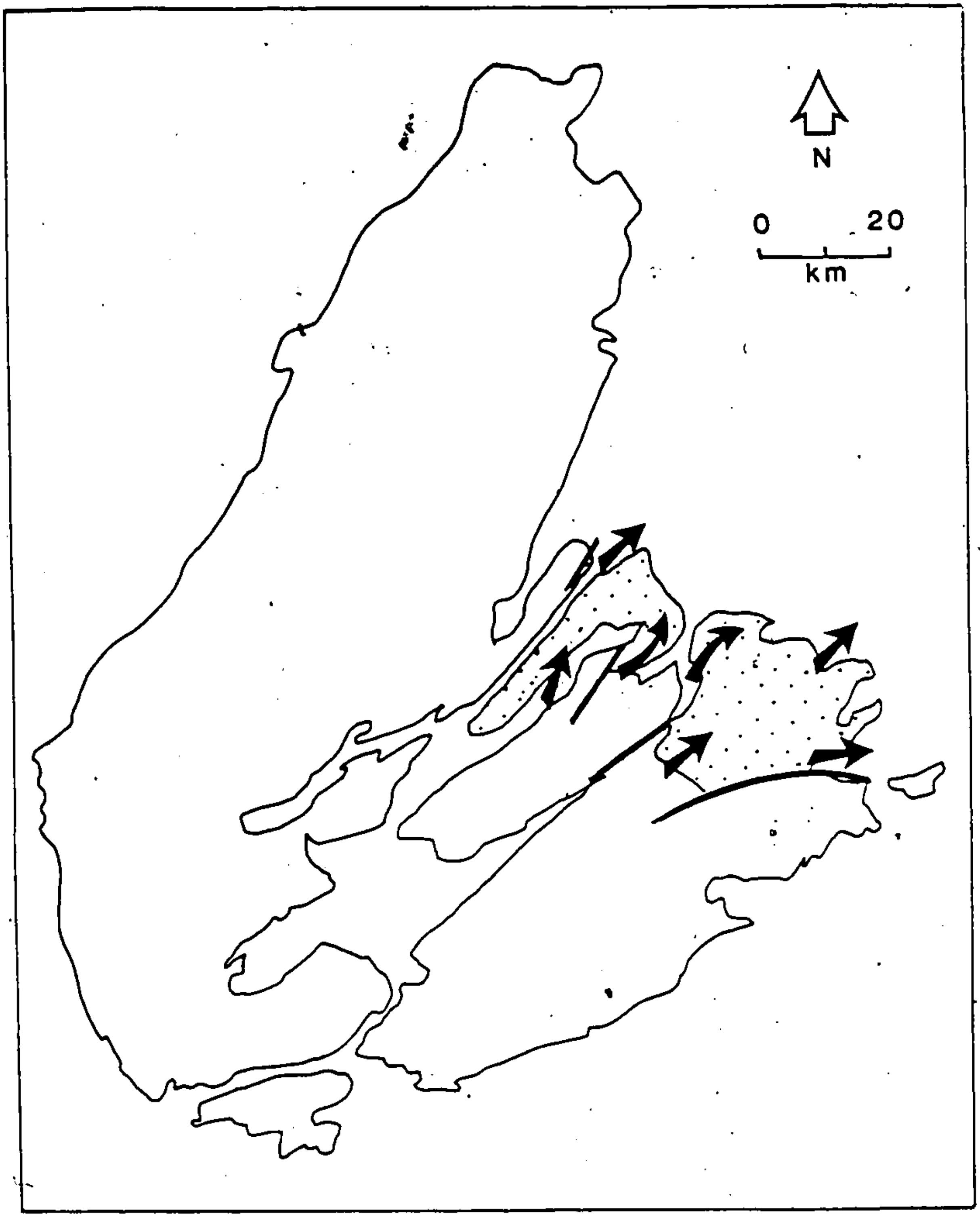


Figure 39:Probable flow trends from source areas for the upper Morien Group.

Table 8 : Pre-Morien basement rocks (Keppie, 1978).

Carboniferous	
Riversdale Group	siltstone, sandstone, shale, coal, limestone
Windsor Group	red siltstone, mudstone, sandstone, shale, conglomerate, gypsum, anhydrite, halite
Horton Group	red and grey sandstone, siltstone, conglomerate, limestone, shale
Devonian	
Fisset Brook Formation	mafic and felsic tuff, basalt, siltstone, rhyolite, conglomerate, sandstone
McAdam Lake Formation	conglomerate, arkose, shale and felsic tuff
Cambrian	
Bourinot Group	basalt, rhyolite, mafic and felsic tuff, shale, siltstone
	granitoid, granodiorite, diabase
Hadrynian	
Forchu Group	felsic and mafic tuff, basalt, andesite, rhyolite, slate, quartzite, chlorite schist, meta-wacke
George River Group	marble, calc-silicates, mafic and felsic meta-volcanic, slate, phyllite, schist, gneiss, quartzite, meta-conglomerate, paragneiss
PreCambrian	
Basement Complex	gneiss, schist, granitoids, amphibolite

Chapter VIII

OVERBANK DEPOSITS

8.1 INTRODUCTION

The upper Morien Group in the western part of the Sydney Basin contains approximately 80% overbank deposits. These deposits include levee, crevasse splay, lacustrine and flood basin deposits. Flood plains are generally the result of long accumulations of fine suspended sediment and subsidence. The deposits generally consist of clay and silt with coarser materials (fine sand) occurring nearer the active channel. In the Sydney Basin, the climatic conditions were conducive to thick accumulations of peat, except brief periods during which redbeds and paleosols developed.

8.2 LEVEE

Levee deposits form as flood waters top their channel banks and velocity is reduced, causing deposition of the load carried by the flood-waters. These deposits form asymmetric ridges which slope away from the main channel. Between periods of flooding, the levees are exposed to long periods of oxidation and disturbance by plants and animals. Levee deposits are generally marked by abundant interfingering of fine and coarse materials (Allen, 1965). These units may then be capped by finer grained deposits, which accumulate during the waning flood stage. The internal stratification of levees generally consists of ripple cross-lamination and horizontal lamination (Collinson,1978).Less common are small trough cross-sets of thinly laminated sandy-silt in some levees (Singh, 1972). These troughs may locally contain concentrations of coarser material. Allen (1965) described the geometry of the levees as prismatic bodies with a triangular cross-section and a gently dipping slope away from the channel. The levees have a fairly simple shape when associated with a low sinuosity river. However, when the levees are formed from sinuous channels, the geometry is much less distinct, the levees mesh -interfinger and overlap - with the overbank deposits (Allen, 1965).

Channel edges are not a common occurrence in the study area, yet when edges are observed, the levees are not simple prismatic wedges, but are more indistinct features, meshing with the overbank deposits and obscuring the wedge form. This is due largely to the highly sinuous nature of this fluvial system (mean sinuosity 1.87). However, in a few cases there is an extremely gentle dip away from the channel in the overbank deposits (photo 30). More commonly though, levee deposits are represented by the interfingering and overlapping of the channel edge with rippled and horizontally laminated sandstones, siltstones and mudstones. These deposits also contain abundant plant material, including _in situ_ trees.

8.3 CREVASSE SPLAYS

Levees may be broken by distinct flood channels called crevasses . The crevasse splays are formed by deposition of sediment carried through crevasses and occur as fans or tongues elongated away from the main channel (Allen, 1970). There may be basal erosion and an abrupt contact between the splay and flood plain deposits; or, the basal contact may be gradational and the deposit to flood plain gradient is gentle (Coleman, 1969) (figure 40). Internally, the deposits display waning flow stratification sequence: small-scale trough cross-strata to ripple cross-lamination to horizontal lamination (figure 23), capped by muddy sediments (Reineck and Singh, 1975), which is usually interbedded with flood-plain silts and clays (Allen, 1965).

The splay channels may occur as single channels onto the flood-plain (Allen, 1970), or as a multi- (anastomosing) channel form (Coleman, 1969) (figures 28 and 29). The single channel splay displays a scoured base near the main channel, with no scouring distally from the main channel. Distally, these deposits end abruptly, in a steep angle of repose (Allen, 1970) (figure 40). The multi-channel splays do not scour, but may locally create cut and fills. These splays gradationally die out into the flood-plain (Coleman, 1969) (figure 37) and are more sheet-like in form.

The type of crevasse splay deposit depends on the levee development; where levee gradients are high, the flood waters tend to leave the

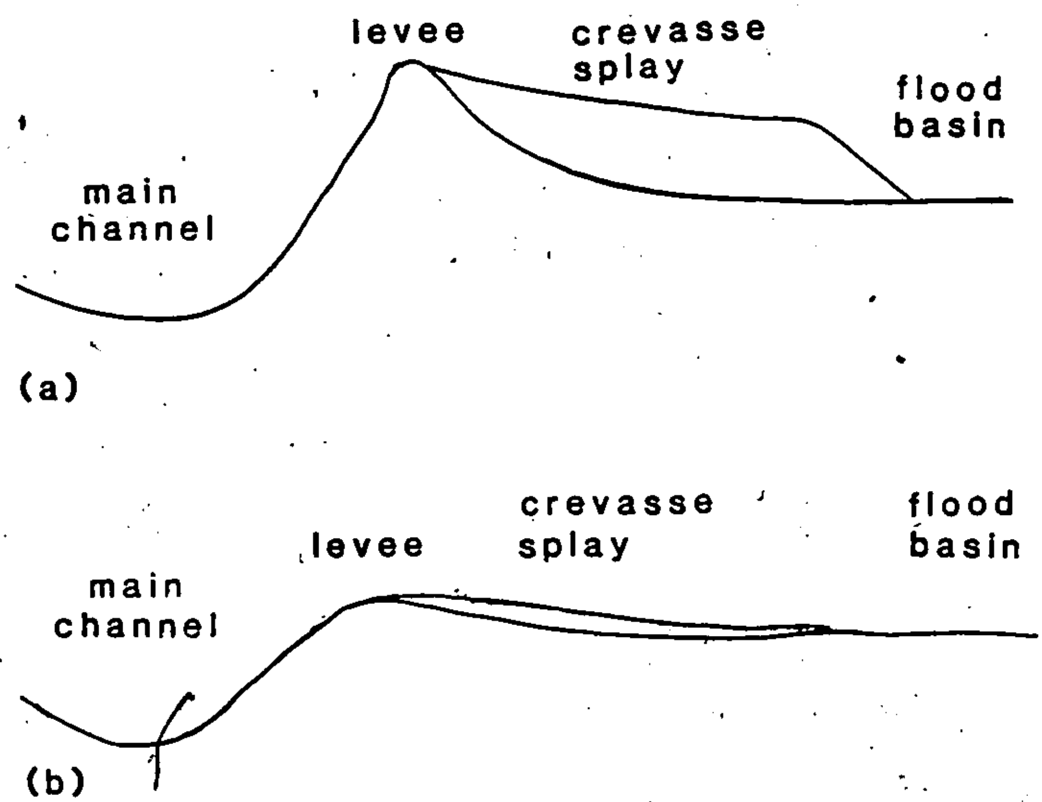


Figure 40: Cross section through
(a) single channel crevasse splay;
(b) multi-channel crevasse splay.

adapted from: Allen, 1970;
Coleman, 1969;
Reineck and Singh, 1975.

river in a single channel, scouring into the underlying sediment and distally fanning out into a delta-like form (figure 28). These are indicative of more stable fluvial systems such as anastomosing or braided rivers.

Multi-channel crevasse splays occur when levee development is poor and the gradient is low; this forms an anastomosing pattern and thin sheet-like units which fan away from the active channel (figure 29). These crevasse splays are more common in meandering fluvial systems. This is largely due to the migration of the channels which restricts levee development and hence allows sheet-like floods to occur.

The internal characteristics of crevasses are described as a series of overlapping and interfingering sands separated by finer deposits (Reineck and Singh, 1975; Reading, 1978). These have a highly variable lateral dimension extending from metres to thousands of metres into the basin deposits. Duff and Walton (1973) described multi-leaf bodies of sandstone with shale and mudstone partings from the Pictou Group at Joggins, Nova Scotia. The basal contacts were generally sharp and not necessarily erosional. These crevasse splay channel sandstones extend laterally and up to approximately 30 m, eventually interfingering with basin depsoits.

The overbank materials of the upper Morien show various stages of interfingering and overlapping. Thin (1 to 3 m) trough cross-stratified sandstones grade upward and laterally into finer sandstones and interbeds of siltstones, shales and mudstone (photo 31). These are obviously too thin for main channel deposits and are attributed to crevasse splays and splay channels. These thin channels laterally interfinger and overlap with attributed levee and other flood-plain deposits commonly observed in overbank deposits (Allen, 1970). The thin occurrences of these small channels (1 to 3m) also correspond closely with the thickness of similar units (3 m) reported by Duff and Walton (1973) and Coleman (1969). Basal erosion is present in some cases, with concentrations of organic material and mudstone and sandstone clasts. More commonly, these sandstone bodies do not show basal erosion, but are gradational with other flood-plain deposits.

Abandoned channel forms (photo 32), up to 2 m deep and 6 m wide are also attributed to crevasse splay channels. These are infilled with interbeds of red and grey mudstones and siltstones, occurring within sequences of interbedded fine material attributed to flood plain deposition (Allen, 1965).

The crevasse splay deposits of the upper Morien Group, fit both forms of crevasse splay channels, single and anastomosing channels, as described by Coleman (1969). Coleman's criteria and the features of the crevasse splay channel deposits of the upper Morien Group are listed in table 9. The development of levees due to the high sinuousity of the fluvial system resulted in the more common occurrence of the sheet-crevasse splay deposits in the Morien Group.

Table 9: Crevasse splay criteria (Coleman, 1969) compared to the upper Morien Group crevasse splay deposits.

	multi-channel crevasse splay	single channel crevasse splay	upper Morien Group
flow pattern	anastomosing	single channel	commonly sheet-like; occasionally single channel
termination	gentle gradient to the flood basin	abrupt gradient to the flood basin	interfingering and overlapping of units
basal contact	no erosion	erosional proximal to the main channel	erosional in the single channels; gradational in the sheet-like deposits
thickness	less than 1.2 m	a few metres to greater than 3 m	sheet units are less than 1.5 m; channels are less than 3 m
stratification	coarser sands override finer sands; small scale cross-bedding	silty-clay layer overlies the coarser sands; small scale cross-bedding; rapidly colonized by plants	cycles which often coarsen then fine upward; also interfingering and overlapping of units; commonly bioturbated and rich in organic debris

8.4 LACUSTRINE DEPOSITS

There are three groups of criteria which aid in the identification of lacustrine deposits: physical, chemical and biological. Physical processes in lakes are similar to those found in marine basins, but with tidal influences being non-existent, except in very large lakes. Wind and wave action are very important, especially in mixing of suspended sediment into the basin (Collinson,1978). Thermal overturns in lakes and marine basins, due to seasonal temperature variations and to current related changes, cause differences in both the physical and chemical characteristics of the sediments.

Chemical criteria may be diagnostic, because of possible abnormal minerals and mineral assemblages and, due to the rapid fluctuations in chemistry which may occur in lakes. These chemical changes may be observed as varves. These features are more diagnostic of permanent than temporary lakes, but also vary with the character of each lake.

Biologically, there is an absence of marine fauna and in many cases a distinctive non-marine fauna including gastropods, bivalves, ostracods , stromatolites and certain fish and other vertebrates. The diversity of the non-marine fauna is highest at the near-shore environment (Link and Osborne, 1978).

The upper Morien Group lacustrine deposits have been most recently described by Masson and Rust (1983). They recognize a lacustrine environment on the

lack of marine fossils, the presence of non-marine fauna and the fluvial association.

In the study area, no well developed stromatolitic units were observed, however a thin section of one limestone unit contains possible algal filaments (photo 21) and the lamination plane exposes a possible cross-section through a columnar stromatolite (photo 20). A limestone unit within section A (see figure 11, 245 m) contains a crossopterygian bone fragment (photos 18 and 19), which may be from a marginal to non-marine environment. This particular limestone unit is overlain by a unit of black shales which are rich in pelecypods, ostracods and coprolites. Similar shale units occur throughout the study area.

Link and Osborne (1978) described a series of lacustrine facies, similar in part to those present in the Morien Group (table 10a and 10b). The facies present represent marginal lacustrine environments, involving a complex array of sediments deposited in shoreline, nearshore and offshore areas. The best representative sequence of this array is seen in figure 11, section a, 245 m. This consists of a calcareous sandstone to fish-bearing limestone unit overlain by a 6 to 8 m unit of black shale, which contains abundant non-marine fossils (pelecypods, ostracods and coprolites) (photos 24 & 25).

Lacustrine deposits are not abundant in the upper Morien due to the ephemeral nature of these lakes and their

Table 10a : Sedimentological criteria of the upper Morien lacustrine deposits compared to the Pliocene Ridge Basin (Link and Osborne, 1978).

Ridge Basin	upper Morien Group
Shoreline	
sandstone, mudstone and shale	abundant
horizontal lamination	abundant
trough cross-bedding	rare
planar cross-bedding	----
ripple marks	abundant
desiccation cracks	rare
molluscs, ostracods and fishes	common
plants	abundant
stromatolites	rare
burrows	rare
Nearshore	
sandstone, mudstone and shale	abundant
horizontal lamination	abundant
trough cross-bedding	rare
planar cross-bedding	----
ripple marks	abundant
desiccation cracks	rare
ostracods and fishes	common
plants	abundant
stromatolites	rare

continued on next page
table 10b

Table 10b : continuation of table 10a

Ridge Basin	upper Morien Group
Offshore	
mudstone and shale	abundant
dolomite	----
horizontal laminations	abundant
deformed bedding	abundant
small scale cross-bedding	common
ripple marks	common
turbidites	----
dish structures	----
plants	abundant
ostracods	common
burrows	rare

relatively small size (formed in cut-off chutes, but more likely in local areas of depression of the flood basin). As well, the presence of extensive and thick coals indicates a relatively high and consistent water table, with abundant flora, allowing lake development only in small areas of local depressions or cut-off chutes.

8.5 FLOOD PLAIN DEPOSITS

Flood plain deposits vary in character depending on their proximity to active channels. Due to low sedimentation rates, low concentrations of sediment in the flood waters and extended periods of non-induration, flood plain deposits are generally thin layers of silts and clays. These deposits commonly fine upward and may be similar to the multi-channel crevasse deposits, though the flood plain deposits have a higher percentage of fines (Allen, 1965). Local scouring during flooding may create pinch and swell within the beds, although it does not necessarily restrict the lateral extent of the unit. If the flood plain habitually dries out between periods of flooding, evidence of exposure includes desiccation cracks (photo 29), redbeds (photo 33) and soil profiles. In humid climates water tables are generally high on the flood plain and it may develop into a swamp with peat deposits or a lake. Drying out of the flood plain may also occur in dry spells within the humid environment; this may occur more if the flood basin is quite large and the channel.

activity is restricted to one side of the basin for substantial periods of time. In areas of little vegetation, wind activity plays an important role.

In the study area, thin red and grey mudstones and calcareous siltstone units are abundant in the upper parts of the succession, especially near Cranberry Head (figure 12, section b and the upper 60 m of figure 11, section a). These mudstone and siltstone units have gradational contacts, fining and coarsening upward. They are very extensive, laterally extending for a few kms (photo 33). The red colouration of the mudstones and the calcareous siltstones indicates relatively low water tables, with periodic sub-aerial exposure. asymmetric ripples in the siltstones developed at the peak of flooding. Therefore, these laterally extensive deposits are attributed to flood plain deposition distal to the channels. However, fluctuations of the water table and migration of the channel created enough water saturation to cause re-vegetation of the area and peat accumulation resulting in the overlying Aconi seam (figure 11, section a, upper 5 m; photo 34). The basin-wide extent of the Aconi seam implies that the rise in the water table and re-vegetation was widespread.

8.6 FLOOD BASIN DEPOSITS

The flood basins are the lowest areas of a flood-plain. Generally, they are poorly drained featureless areas, with little or no relief (Reineck and Singh, 1975). Their deposits are quite thin (<2 1/2 cm) and formed from the settling out of suspended clay and silt (Coleman, 1969). Very rarely some of the flood basin mudstones may contain thin (1/2 to 1 cm) layers of clay. These layers are discontinuous, extending laterally up to 4 km.

Due to the generally active migration of the main channel, the flood basin deposits only occur as thin discontinuous veneers on top of the other overbank deposits. This is similar to the accounts by Wolman and Leopold (1957) and Coleman (1969) of flood basin deposits in Maryland and North Carolina and the Bengal Basin, respectively. It is in these areas that thick accumulations of peat can occur, if climatic conditions are favourable (Reineck and Singh, 1975; Coleman, 1969), due to the low sedimentation rate and rapid vegetation growth in areas of the flood basin. Extensive flood basins in the Morien Group are reflected in the presence of abundant and laterally extensive coal seams. Thin discontinuous clay layers occur only rarely. These are probably the result of peak flood conditions in the fluvial system which were high energy enough to deposit some sediment in these distal areas, but were not intense enough or proximal enough to seriously interrupt peat accumulation.

Chapter IX

PALEOSOLS

9.1 INTRODUCTION

Paleosol is a term used for ancient or fossil soils. They are formed on horizons exposed sub-aerially long enough to allow modification by soil forming processes, including physical and chemical weathering and the action of organisms. Paleosols can be recognized from a variety of structures, such as: 1) massive bioturbated layers, with gradational contacts; 2) complex cracking and veining; 3) leached, reddened and mottled layers; 4) pseudo-anticlinal structures (gilgai-like structures) and slickensides; 5) pseudomorphs after plant roots; 6) nodular horizons and layers; 7) calcareous and other crusts; 8) distinctive petrographic textures (Wright, 1982; Retallack, 1983). Important criteria for the development of the soil profile are: 1) the duration of the exposure which influences the thickness and induration of the soil profile; 2) the elevation and mobility of the water table (Gardiner, 1972).

Calcrete is a carbonate-enriched soil, formed by the combined effects of evaporation and change in the partial pressure of CO_2 in the soil zone. The carbonate is considered primary if one of the following are present : calcium-rich primary minerals, certain plants which contain calcium in their tissues, detrital carbonate grains, or skeletal organisms, (Klappa, 1983). Leaching of the calcite enriches solutions, which transport the calcium downward as bicarbonate eventually to be precipitated as carbonate, forming a calcrete (Wright, 1982). Thus, calcretes result from the progressive calcification of the soil, in a sequence of stages, outlined in table 11 and figure 30.

In the upper Morien Group, various stages of pedogenic paleosols and calcretes were observed. With reference to Klappa (1983) and Netterberg & Caiger (1983), calcareous soils, calcified soils and nodular calcretes can be distinguished. The calcrete soil profiles occur in a variety of sequences: calcareous soils to calcified soils; and calcareous soils or calcified soils to nodular calcretes. Non-calcrete paleosols are also distinguishable.

To justify the paleosol interpretation, the following points are noted: 1) The presence of siltstones and sandstones with minor disseminated carbonate grains throughout the clays (photo 35)(and no carbonate nodules) effervesce in dilute HCl, corresponding to stage 1 of table 11. 2) The presence of siltstones and sandstones that contain abundant carbonate cement, but no carbonate nodules (photo 36) (stage 1 to 2 of table 11). 3)Calcified layers containing carbonate infilled root casts (stage 2, table 11).

Table 11: Stages in the development of calcretes (Netterberg and Caiger, 1983).

Stage	Host Material	
	Mixed Texture	Clean sand or gravel
1	scattered calcrete glaebulas in host soil	calcrete coated grains
2	glaebular calcrete	calcified sand or gravel (calcite cement)
3	honeycomb calcrete (partially coalesced nodules)	
4	hardpan calcrete (rock-like horizon)	
5	calcrete boulders, cobbles or gravels (discrete fragments formed by weathering)	

4) Layers of carbonate nodules and pedotubules (stage 3 to 4, table 11). 5) Calcrete micro-structures, such as: crystallaria and soil peds, (photos 37 and 38). 6) Reddened mudstones; mudstones with abundant bioturbations; mudstones with pseudo-anticlinal structures; (photo 14). 7) Close association of calcareous sandstones and siltstones and red mudstones.

9.2 CALCRETE FEATURES

The upper Morien calcretes fit various stages in the process described by Netterberg and Caiger (1983) and outlined in table 12. The Morien Group contains examples of calcareous paleosols, calcified paleosols, nodular calcretes and leached paleosols.

Calcareous paleosols of the upper Morien Group effervesce in dilute HCl, but generally contain little carbonate cement and few nodules. They are siltstones and fine-grained sandstones, and are well sorted with less clay than their non-calcareous counterparts. Strata and grain size do not affect the carbonate content:strata are both horizontal and rippled in units 5 to 20 cm thick. This is the most common type of calcrete in this part of the upper Morien Group.

Calcified paleosols are not as common as the calcareous paleosols. They are siltstones, with faint horizontal strata, pedotubles may be present.

Table 12: Classification of calcretes (Netterberg and Caiger, 1983).

Calcrete Type	Diagnostic Features
Calcareous soils	soils with little or no cementation or development of carbonate nodules but which effervesce in dilute HCl; stage 1, table 11.
Calcified soils	soil horizon cemented by carbonate; carbonate generally evenly distributed, few nodules; stage 2, table 11.
Powder calcrete	loose silt-sized and fine sand-sized carbonate with few or no host soil particles; any nodules present are friable; stage 2, table 11.
Nodular calcrete	silt-sized to gravel-sized particles of carbonate-cemented host soil in a matrix of usually calcareous soil; 25 % or more of the particles are 2 mm; stage 2, table 11.
Honeycomb calcrete	large and numerous nodules which are partially cemented together; interstitial voids are often infilled with loose soil;stage 3, table 11.
Hardpan calcrete	formed when most of the voids in a honeycomb calcrete become cemented or when a calcified soil becomes more heavily cemented than the rest of the horizon; may be sandy, gravelly or nearly pure limestone; stage 4, table 11.
Calcrete boulders and cobbles	weathering of hardpans forms boulders, cobbles and smaller fragments, usually in a matrix of non- or slightly calcareous soil; stage 5, table 11.

Nodular calcretes occur as isolated nodules and as horizons of nodules (photo 16). They occur within calcareous or calcified sandstones and siltstones and in non-calcareous sandstones and siltstones. The nodules range in size from 2 to 15 cm; they occur most abundantly as pedotubules and rhizoconcretions along bedding planes (photo 24) and as vertical cylinders, presumably following root systems. These nodular calcretes tend to be gradational from calcareous and calcified paleosols, and in some cases are gradational upward into a hard-pan calcrete (photo 39).

Also present are calcretes capped by carbonaceous shales and thin coals; these shales and coals are thought to have been deposited under the influence of rising water tables. Similar units were described from the Pictou Group in New Brunswick by Legun (1980), who ascribed them to leached soils. The upper Morien shales in this unit are soft and yielding.

9.3 NON-CALCAREOUS PALEOSOLS

The non-calcareous paleosols occur in heavily bioturbated and reddened mudstones. The red mudstones alternate with grey mudstones (photo 33). Some of the mudstones show desiccation cracks (photo 29) indicating sub-aerial exposure. Both mudstones are very rubbly; the grey mudstones showing abundant rooting features. The red mudstones are generally closely associated with one or more of the calcrete stages. Exclusive to the red mudstones are pseudo-anticlinal or gilgai-like structures (Wright, 1982), which are approximately 30 to 60 cm in height (photo 14). These features are believed to form by alternation of contraction and expansion of the clays. Contraction occurs during dry periods, but during flooding or rainfall the clays expand; this increased volume causes stresses to build up within the muds, resulting in shearing and buckling (Wright, 1982). Though not an exclusive feature of pedogenesis, the common association, in this study, of the redbeds and calcretes implies pedogenic formation.

The paleosols in this part of the upper Morien Group are immature. This is due to maintenance of a relatively high water table, indicated by the presence of extensive and economic coals. The paleosols began developing during temporary dry periods or on topographically high areas formed by the small incision of channels during flooding in the alluvial terrane. The lack of lateral extent of the paleosols (except for the non-calcareous paleosols) supports restricted areas of soil development.

Chapter X

COAL

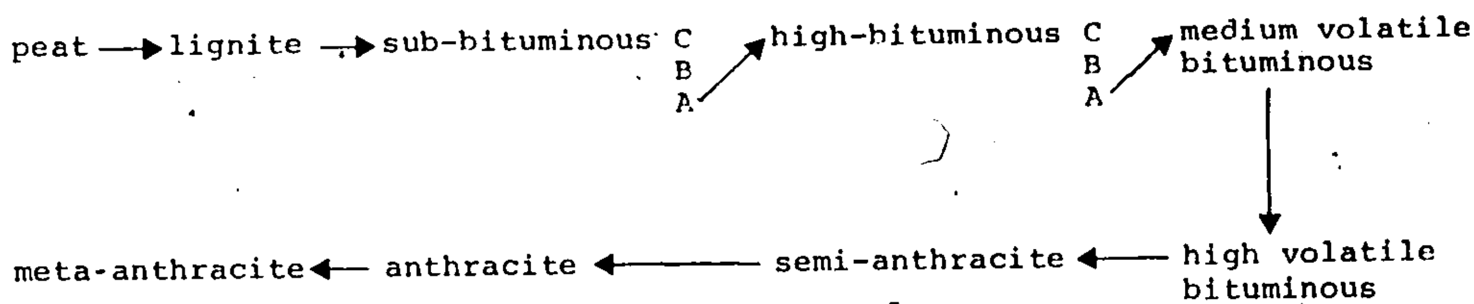
10.1 INTRODUCTION

Coalification is defined as the development from peat through the stages of lignite, sub-bituminous and bituminous coals to anthracite (table 13); based on the degree of physical and chemical alteration. The surrounding sediments are relatively unaltered due to the high susceptibility of the peat to temperature and pressure changes.

Principle causes of coalification are : the rise of temperature and time. The temperatures effectively 'cook' the peat, causing coalification reactions. The longer the 'cooking' time, the higher the level of coalification reached. Although pressure is not a major contributor in coalification, it is most influential in the initial peat to sub-bituminous stage. It is, at this stage, that decreases in porosity and moisture content cause the coalification of the peat and simple compaction and lithification in the surrounding sediments.

Coal generally originates from peat deposits in swamp or swamp-like areas. Depending on the original position of these areas relative to marine waters and continental basins, three types of coal deposits are distinguished : limnic; paralic

Table 13 : Development of coal with increasing temperature and time.



and fluvial. Limnic coals are inland coals associated with lacustrine deposits. Paralic coals are formed on coastal plains and are closely associated with deltaic and lagoonal deposits. The third type is transitional between paralic and limnic coals. Fluvial coals are associated with fluvial systems and flood-plains, with characteristics from each of the other two types (table 14).

10.2 REQUIREMENTS FOR COAL DEVELOPMENT

Crucial aspects to the formation of peat swamps (limnic, paralic and fluvial) are: the evolution of plants; climate; structural and sedimentary restrictions.

As plants evolved through geological time, the frequency, thickness and quality of coal increased. Economic coals are first found in the rocks of the lower Carboniferous. During the Carboniferous extensive swamp forests developed, giving rise to abundant economic coal deposits. Continued floral development and diversification in Permian, Mesozoic and Tertiary times resulted in continued formation of thick economic coal deposits. Due to the diversity of the coal forming flora, the microscopic characteristics of these coals is highly variable.

Warm, wet climates are conducive to luxuriant plant growth, rapid rejuvenation of flora and rapid decomposition of dead plant materials. Warm moist climates with abundant peat deposits are especially evident in the Upper Carboniferous, Upper Cretaceous and Tertiary of North America.

Table 14 : Characteristics of the three types of coal.

Limnic	Fluvial	Paralic
hypoautchthonous peat accumulation	autochthonous peat accumulation	autochthonous peat accumulation
little lateral extent	elongate	laterally extensive
thick	moderately thick	thin
coal composition in seams changes lateral	coal composition consistent	coal composition consistent
woody coal composition	woody coal composition	non-woody coal composition
variable number of seams	few seams	large number of seams
termination: lithification	termination: splitting and pinch out	termination: splitting and pinch out
low ash	very low ash	high ash
low sulphur	low sulphur	high sulphur
high volatile matter	high volatile matter	low volatile matter
fluvio-lacustrine association	fluvial association	marine (deltaic) association

Rich coal deposits are also found in Siberia and areas in the southern hemisphere, which had humid to cool climates (from paleomagnetic reconstructions).

Thick peat deposits are also the result of certain structural and sedimentary controlling elements. These elements are: 1) steady subsidence, allowing groundwater to rise and keep up with peat accumulation; 2) protection of the area from major marine inundation; 3) restricted fluvial influence, thus a relatively low relief area. Generally these requirements are satisfied by a rapidly subsiding basin, probably related to local tectonic activity.

If groundwater rises too rapidly, it will drown the peat and halt organic growth; limnic, marine or fluvial sedimentation takes over causing a break or cessation of peat accumulation. Regardless of the area of accumulation, the primary requirement is for stagnating groundwater at or near the surface to prevent oxidation of the accumulated material.

10.3 AREAS OF DEPOSITION

Thick peat accumulations are found in association with three different depositional systems, resulting in different characteristic features for each coal type (Table 14). Briefly, these characteristics are: limnic coals are thick, discontinuous bodies contained in an enclosed basin. They contain low amounts of sulphur, low ash and are rich in volatile matter; they also have a woody composition, pre-dominantly from hypoallochthonous peat, peat derived from locally transported organic material.

In contrast to limnic coals, Paralic coals are thin and very extensive tabular bodies. They have high sulphur and ash contents and moderate amounts of volatile matter; these coals have a predominantly non-woody composition from autochthonous peat. Marine sediments are always present amongst the large number of thin seams.

The third transitional coal type is associated with fluvial sediments. These coals are low in ash content and have moderate amounts of sulphur; they are rich in volatile matter. The woody coals form from autochthonous accumulations of peat. The seams are moderately thick extensive bodies, often elongate parallel to major fluvial channels.

From this study, and previous works by Hayes, Bell and Goranson (1938); Hacquebard and Donaldson (1969); Giles (1983) and Rust et al.(1983), the coal deposits of the Sydney Basin are largely associated with continental sediments described as a braided to meandering fluvial system on a broad flood plain.

Coal deposits associated with a meandering fluvial system were described by Gersib and McCabe (1981) from the Carboniferous coal-bearing sediments of the Port Hood Formation, Nova Scotia. The depositional model for the Port Hood Formation was described as a large meandering river which cut across a swampy flood plain. The flood plain was littered with cut-off chutes and meander cut-off lakes. These lakes became vegetated as they infilled with flood and crevasse-splay deposits. The coal and carbonaceous mud-rocks were deposited in the swampy areas where dead plant material accumulated and was preserved.

Fluvial channel-dominated facies with associated coal beds have also been described by Flores (1981) for part of the Fort Union Formation, Powder River Basin in Wyoming and Montana. This formation contains abundant channel deposits of a meandering, highly sinuous fluvial system. The coals formed in the poorly drained back-swamps in a broad flood basin. Their distribution was influenced by the location of channels and the inter-channel topographically low areas. Flores (1981) attributed splitting of the seams to the interruption of peat accumulation by the deposition of crevasse-splay sandstones and flood deposited siltstones and shales.

The upper Morien Group of the Sydney Basin was previously assigned to the paralic coal group (Hacquebard and Donaldson, 1969). However, comparison with the descriptions given by Flores (1981) and Gersib and McCabe (1981) for fluvial coal deposits indicated that the Sydney coalfield corresponds to the fluvial coal group (table 15).

Table 15 : Characteristics of the Sydney Coal Field.

Fluvial Coal	Sydney Coal Field
autochthonous peat accumulation	autochthonous peat accumulation (Hacquebard and Donaldson, 1969)
elongate	broadly elongate
moderately thick	thick
consistent coal composition	consistent coal composition (Hacquebard and Donaldson, 1969)
woody coal composition	woody coal composition (Hacquebard and Donaldson, 1969)
few seams	12 economic seams
termination is due to splitting and pinch-out	termination is due to splitting and pinch-out
very low ash	low ash
low sulphur	high sulphur
high volatile matter	high volatile matter
fluvial association	meandering fluvial system on a broad flood plain

10.4 SYDNEY COAL FIELD

Twelve economic coal seams occur in the upper part of the Morien Group in the Sydney Basin. The seams range in thickness up to 4 m, and extend laterally across the basin with variable thickness and some splits (Hacquebard and Donaldson, 1969) (figures 18, 19, 25 and 41).

Hacquebard and Donaldson (1969) attributed the thickness variation mainly to differential compaction reflected in the underlying sediments (figures 18 and 19). As underlying fine materials are compacted, they create local areas of poor drainage and subsidence, allowing thicker accumulations of peat. A similar effect was recognized by Flores (1981) in the Powder River Basin. Splitting of seams is due to active channel migration across the area of peat accumulation; crevasse splay progradation; or increased subsidence causing lake formation (Flores, 1981). All these processes interrupt peat accumulation, renewing sediment accumulation. Thinning and splitting also occurs at the termination point of the seams. Hacquebard and Donaldson (1969) showed in stratigraphic sections that the coal seams thin, split and interdigitate with sediments to eventual pinch-out, similar to terminations described by Flores (1981).

Hacquebard and Donaldson (1969) also recognized, for some of the seams, a westward migration of the main locus of peat accumulation on the basis of vertical sections correlated across the basin and the change in thicknesses of some of the coal seams (figure 41).

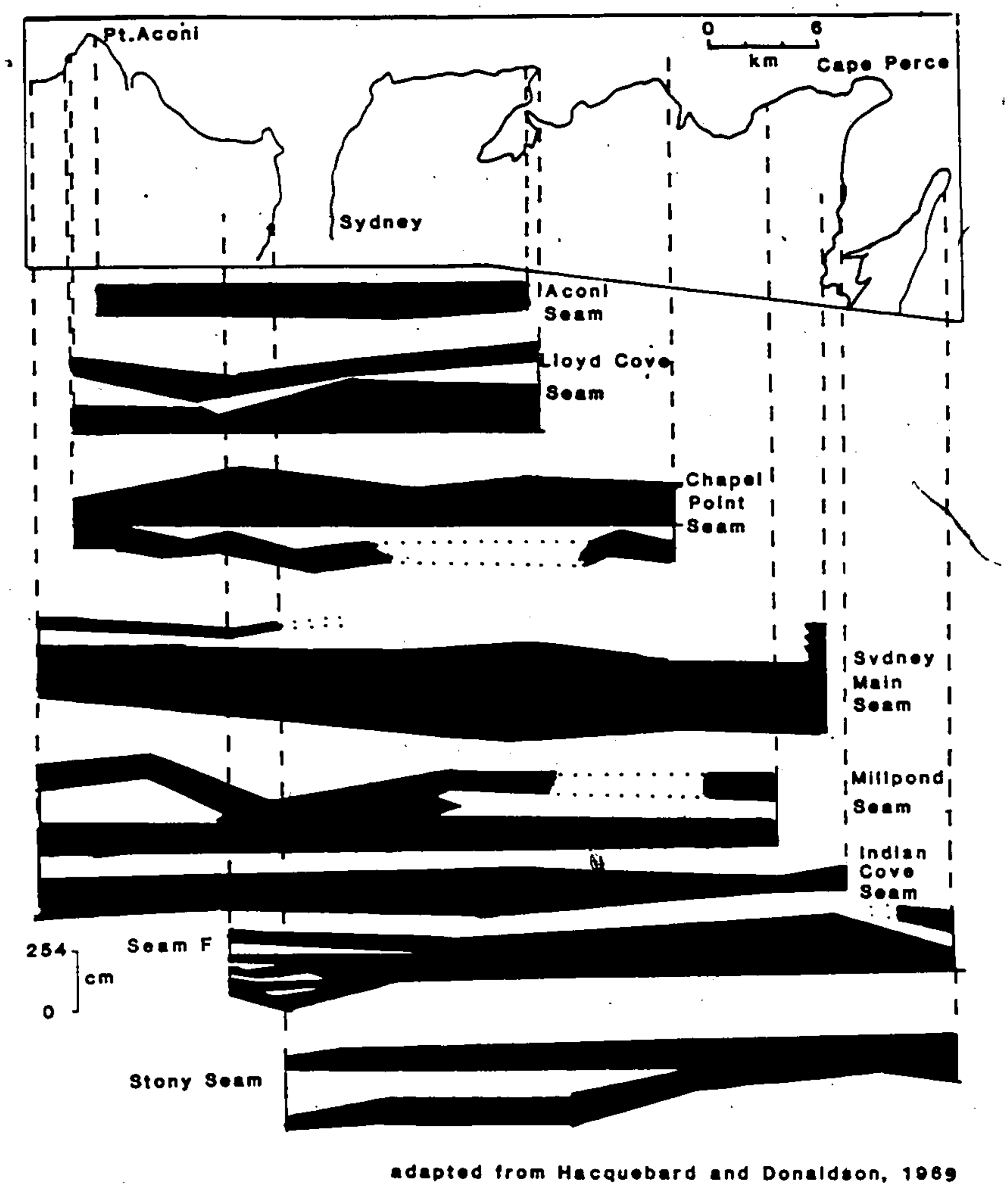


Figure 41:Cross-section through the major coal seams.

The thickest parts of the older seams occur in the east part of the basin, near Glace Bay and New Waterford . The same authors related this westward migration to the paleotopography. With originally higher ground to the west, the original fluvial systems and peat accumulations would have occurred in the eastern area and as the basin infilled in the east, the fluvial system, peat development and accumulation migrated westward. Probably only the depocentre of peat accumulation migrated, resulting in thickening of seams but no actual terminations of the seams within the basin.

The main influence on the physical characteristics of coal seams in a fluvial system is the migration of channels within the basin. As the main channel occupied various parts of the basin, peat accumulation occurred elsewhere. So, individual seams thicken and split independently of each other, but dependent on the channel's position in the basin. This feature has been recognized in the Powder River Basin by Flores (1981). In the Sydney Basin this feature is also recognized, with coal seams becoming thicker away from the active channel and splitting more frequently close to the active channel. The extent of the coals across the basin (figures 25 and 41) shows that the peat swamps were very extensive and implies that channels were widely separated, and therefore large.

The Sydney coals are ranked as high volatile 'A' bituminous coals. This broad category encompasses all the seams, with rank increases within this category with increasing depth of the seams (Hacquebard and Donaldson 1969).

The Sydney coals were formed from the development of autochthonous peat accumulations (Hacquebard and Donaldson, 1969). Reasons cited are: the presence of in situ trees; preservation of whole leaves and other delicate plant materials; minor fluctuations of ash content within and between seams; megascopic and microscopic composition- the presence of the lithotypes : vitrain, clarain, durain and fusain, all the seams have good maeceral preservation; (Hacquebard and Donaldson, 1969).

From the chemical analysis of the Sydney coals (Table 16), especially the high sulphur content, (Tibbetts and Montgomery, 1960) their lateral extent, continuity and thickness and mode of seam termination, the Sydney coals resemble coals found in a paralic depositional site. However, sediment associations, lack of marine fossils and associations, the presence of non-marine fauna combined with the great abundance of in situ trees, suggest a fluvial environment for deposition (table 15). The great lateral extent and consistency of the Sydney coals are attributed to the area of deposition being a very broad floodplain with a relatively stable tectonic and climatic environment allowing for continued and generally uninterrupted peat accumulation and large, widely separated channels. The high sulphur content of the coals is attributed to contamination of the coals by parts of the underlying carbonate Windsor Group (Bell, 1928; Kaites, 1951).

Table 16 : Chemical Characteristics of Some of the Morien Group Coal Seams. (Tibbetts and Montgomery, 1960)

Seam	Mineral Matter %	Ash %	Volatiles %	Fixed C %	Sulphur %	Calorific Value Btu/lb
Sydney Main	0.6-2.3	4.1-11.4	34.0-38.0	53.0-57.3	1.6-2.8	13,390-14,615
	1.9-5.4	6.3-13.9	32.1-37.5	49.2-54.0	2.5-3.0	12,260-13,790
	0.6-4.1	6.4-10.7	34.4-38.2	51.7-54.6	3.2-5.1	12,895-14,250
	1.7-5.8	10.0-11.3	31.4-34.8	51.6-53.9	3.1-3.7	12,280-13,045
	0.8-3.1	4.5-6.1	34.2-36.9	56.6-58.6	1.3-2.0	13,640-14,430
	0.9-5.0	3.0-12.0	32.8-39.5	50.9-57.8	1.4-3.1	12,695-14,610
Phalen	0.6-3.5	9.9-20.9	26.9-33.5	48.7-57.1	4.3-5.9	11,300-13,790
	0.7-3.7	5.3-10.3	31.3-34.5	56.1-60.5	2.0-3.5	13,390-14,430
Indian Cove	3.8-7.5	9.9-12.6	34.3-37.0	45.6-49.3	5.5-6.6	11,600-12,610
Tracy	1.7-10.4	10.0-17.5	29.4-35.8	44.6-52.3	5.4-6.7	10,600-12,775
	0.4-7.6	9.2-18.0	33.1-36.7	45.8-53.2	5.3-8.1	11,290-12,990

* % denotes weight %

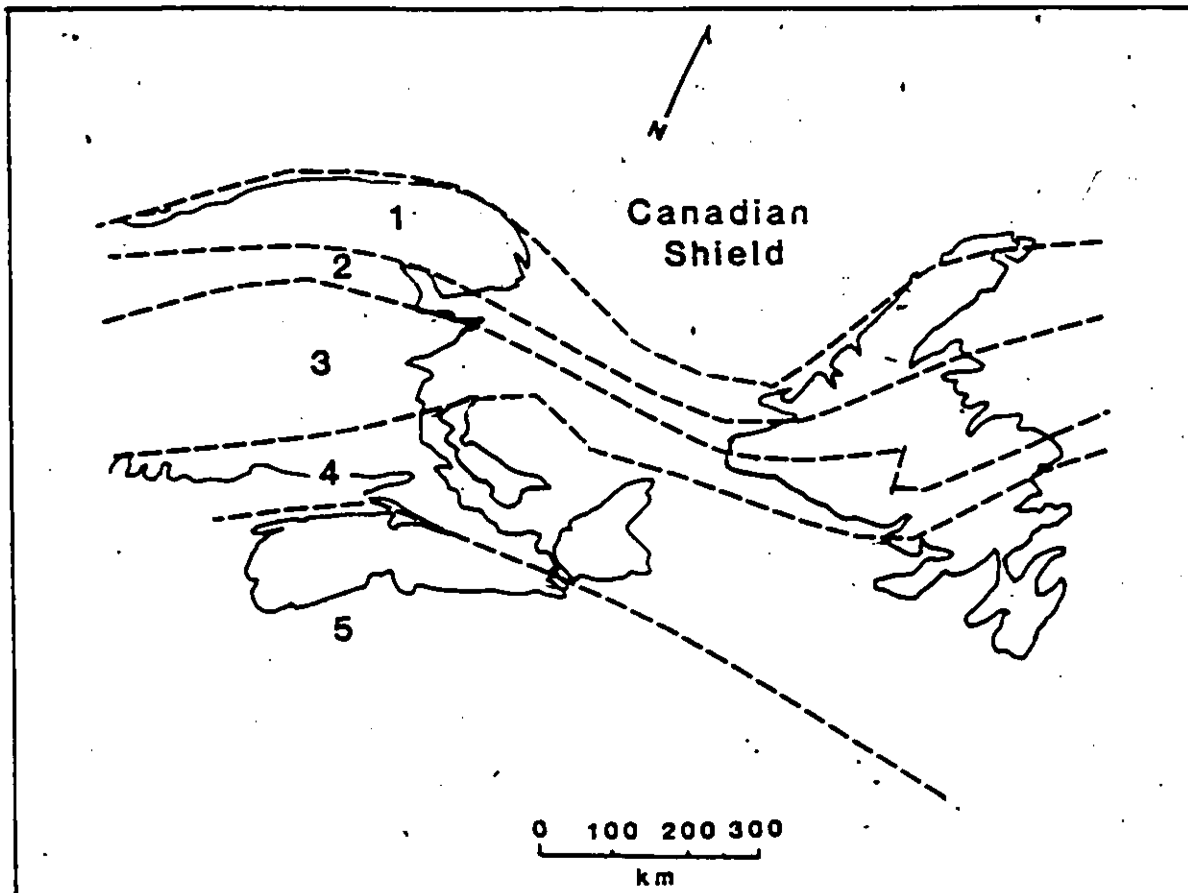
The setting for the Sydney coalfield is similar to that of the Port Hood Formation described by Gersib and McCabe (1981). Their conclusions were that since there were no associated marine sediments or deltaic sequences and the coals were distinctly not limnic, an entirely terrestrial fluvial depositional setting for coal formation was postulated.

Chapter XI

TECTONIC RECONSTRUCTION AND PALEOENVIRONMENT

11.1 DEVELOPMENT OF THE APPALACHIAN STRUCTURAL PROVINCE

The development of the Appalachian Structural Province has been interpreted by various theories since the acceptance of the Wilson cycle (1966). Until recently, the Province was seen as a series of broad structural zones elongate along the eastern seaboard (Poole, 1967; Williams, 1978, 1979; Williams et al, 1974) (figure 42). These zones were subdivided on the basis of distinct stratigraphic and structural characteristics related to plate movements during Cambrian to Silurian times (Poole, 1967; Williams, 1979). It was suggested that the three western zones are related to the generation and destruction of a proto-Atlantic (Iapetus) during Cambrian times. The two eastern are believed to be related to the closure of Iapetus, and may represent slices of continental material which formed the eastern shore of Iapetus (Williams, 1979) (table 16). Williams (1979) suggested that Silurian and younger rocks are related to deposition and deformation in basins formed across the destroyed margins and tract of Iapetus. These younger rocks may even relate to the site of a Paleozoic ocean, after Iapetus (Williams, 1979).



1	Humber Zone	4	Avalon Zone
2	Dunnage Zone	5	Meguma Zone
3	Gander Zone		

Figure 42: Tectonic stratigraphic zonation of the maritime part of the northern Appalachians from Williams, 1979.

Table 17: Evolution of the Appalachian Structural Province (Poole, 1967; Williams, 1979).

Age	Orogeny	Major Event
Triassic		rifting and onset of the modern Atlantic Ocean
Carboniferous	Hercynian/ Alleghanian	development of successor basins
Silurian-Devonian	Acadian	destruction of the continental margins and oceanic tract related to the Iapetus cycle
Ordovician-Cambrian	Taconic	development of continental margins and platformal areas; closure of Iapetus
late Pre-Cambrian-early Cambrian	Avalonian	rifting of the Grenvillian basement; opening of Iapetus

However, Williams pointed out that there is no evidence of obducted ocean floor from the mid-Paleozoic (Acadian) deformation.

A more recent interpretation of the Appalachian Structural Province involves the concept of suspect terranes (Keppie, 1983; Williams and Hatcher, 1982; Williams and Hatcher, 1983), which were accreted outwardly (on the eastern edge) of cratonic North America. Williams and Hatcher (1982, 1983) suggested that the Appalachian Structural Province is made up of a series of geological sub-provinces with unique and distinct features and sharp structural junctions (Williams and Hatcher, 1982). They are distinguished from each other by their geological contrasts related to changes in orogenic activity from province to province. Williams and Hatcher (1982, 1983) related the formation of the Province to the opening and closing of the Iapetus Ocean combined with various accretionary phases. These accretionary phases coincided with periods of deformation, plutonism and metamorphism.

Keppie (1983) described the northern Appalachians as a collage of terranes which are internally made up of separately derived pieces. Times of accretion are provided by the age of the youngest strata unique to the particular terrane. The Avalon and Composite compilation terranes were formed during late PreCambrian to early Ordovician times. During Ordovician times, the western part of the Appalachians was accreted to North America. The Acadian orogeny was marked by the accretion of the Acadian compilation terrane and movement of this terrane up the eastern seaboard (figure 43), in a sinistral transcurrent motion. The later collision of Gondwana with North America marked the Alleghenian orogeny (Keppie, 1983) (table 17).

It has been suggested that the complex and active tectonism of the Appalachians during the late Devonian and early Carboniferous is due to the rifting of a super continent. According to Fralick and Schenk (1981) Nova Scotia was proximal to a three point junction between the masses of Africa, Eurasia and North America. Further conjecture, from geological and paleomagnetic data (Williams, 1979), suggest that New England, Atlantic Canada, Ireland and Britain were part of one block during the late Devonian and early Carboniferous. Also, that the Acadian orogeny resulted from the closing of the Iapetus Ocean, between the above block and ancestral north Africa (Williams, 1979). The initial compression induced dominantly left- lateral strike-slip movements along northeast trending faults (figure 44). It is believed that re-shuffling of the continents in the Alleghenian caused reversal of some of the left-lateral faults to right-lateral movements (Fralick and Schenk, 1981).

Arthaud and Matte (1977) examined late Paleozoic strike-slip faulting in southern Europe, northern Africa and North America (figure 45).

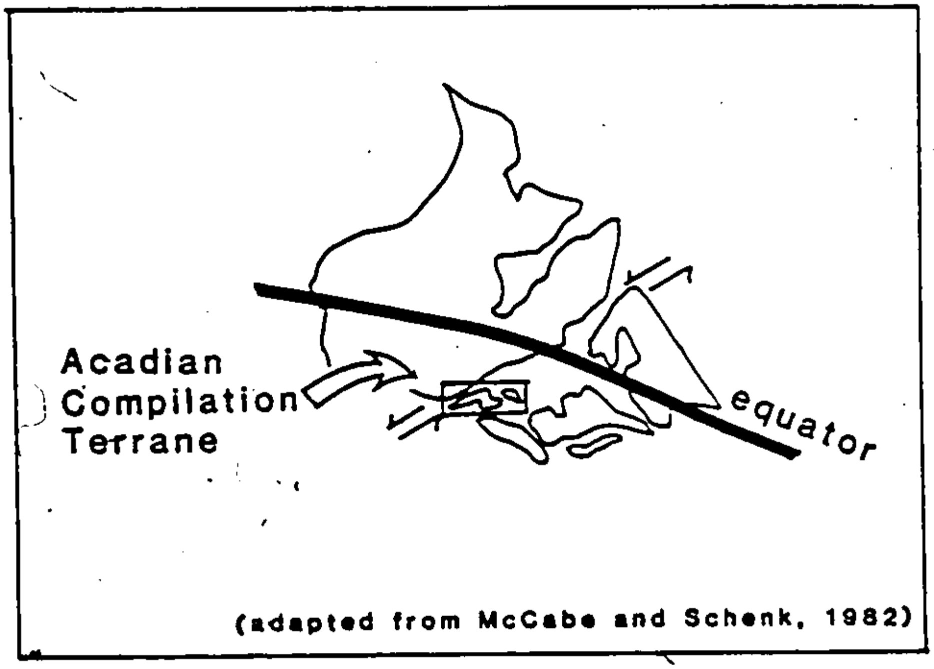


Figure 43: Relative motion of the Acadian compilation terrane with respect to cratonic North America.

Table 18 : Accretionary History of the Northern Appalachians (Keppie, 1983).

Age	Orogeny	Major Event
late Carboniferous -Permian	Hercynian/ Alleghanian	collision between Gondwanaland and North America
mid-Carboniferous		sinistral transcurrent movement as the Acadian Composite terrane moved up the eastern seaboard
Devonian	Acadian	terranes accreted to both sides of the Avalon Composite terrane to form the Acadian Composite terrane
late Ordovician		terranes in the north-western part of the Appalachians were accreted to cratonic North America
late Cambrian-early Ordovician	Penobscot Disturbance	collision of several terranes forming the Boundary Composite terrane
PreCambrian	Cadomian	formation of the Avalon Composite terrane from the collision of several terranes

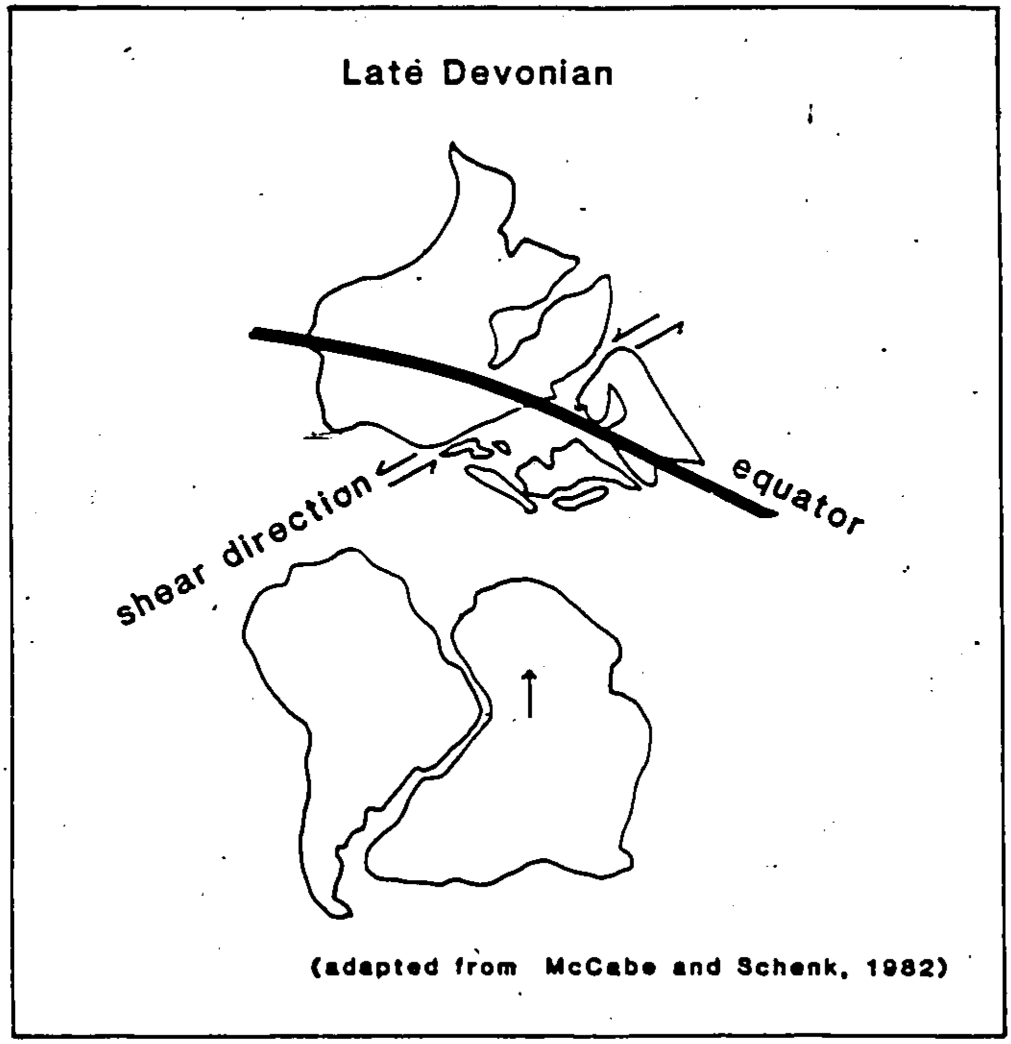
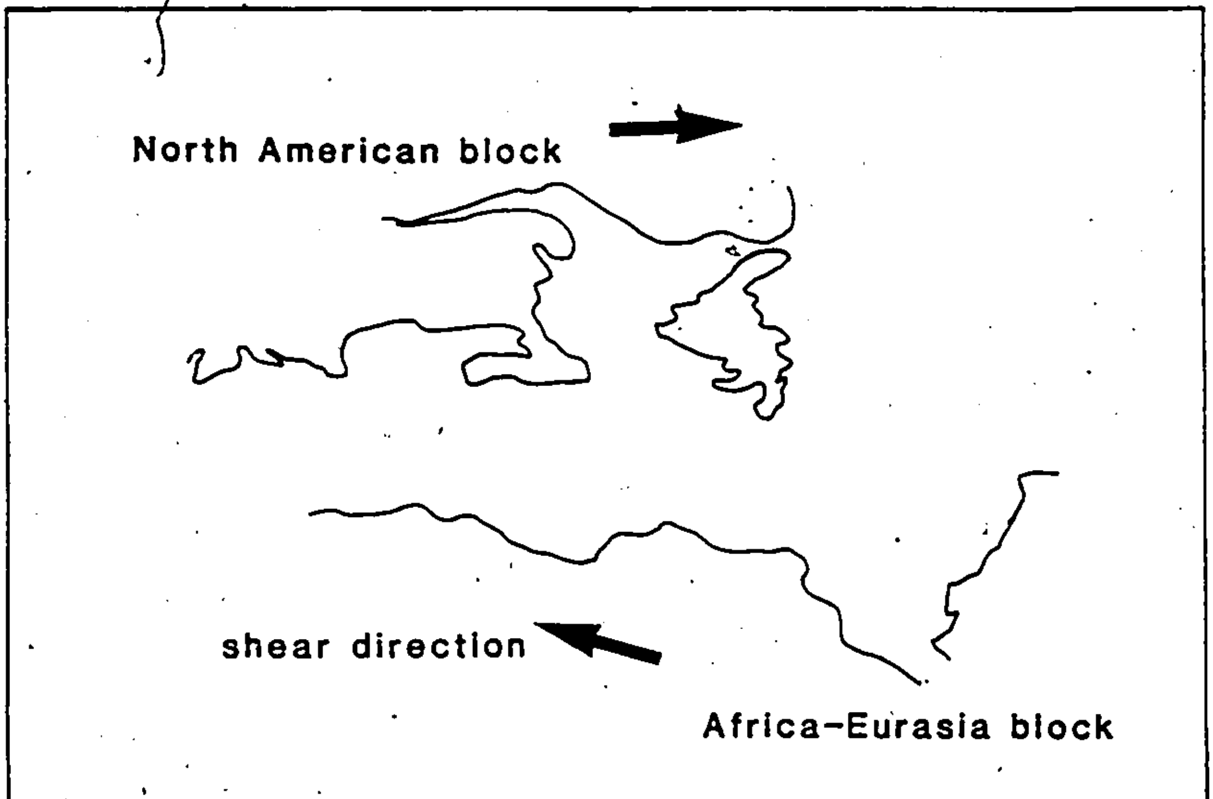


Figure 44: Paleomagnetic reconstruction of sinistral movement resulting from the closure of the Iapetus Ocean.



(adapted from Arthaud and Matte, 1977)

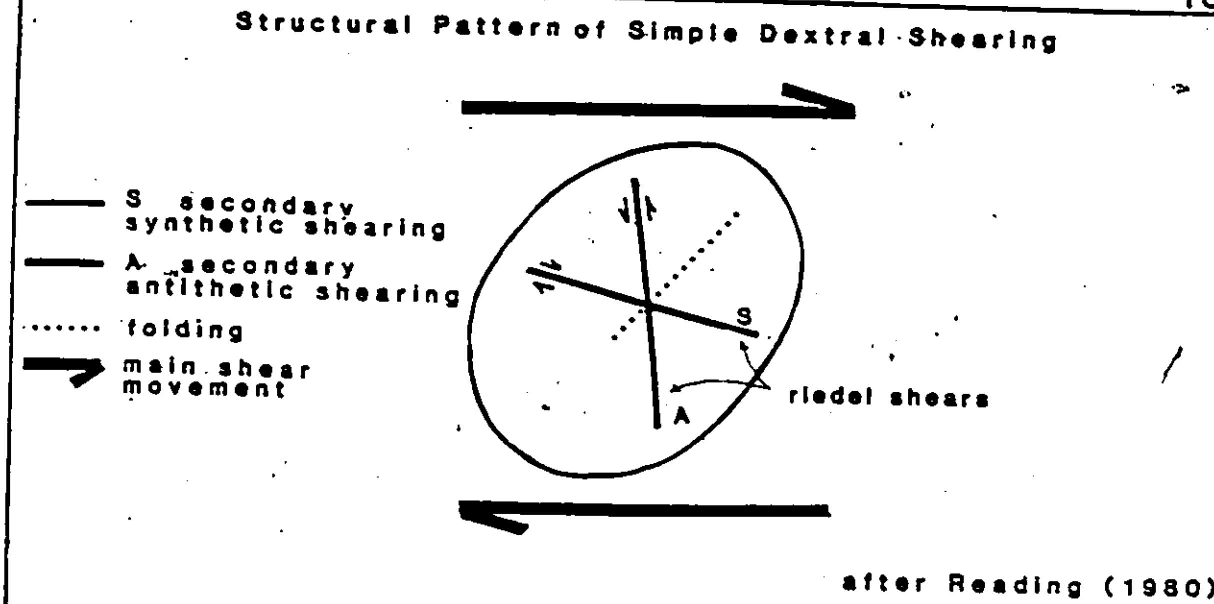
Figure 45: Dextral movement resulting from the collision of North America and Gondwana.

They related structural patterns in the three continents to a mega-shear zone between two plates (figure 46). The southern plate consisted of Africa; the northern plate included North America, Europe and Greenland. Arthaud and Matte placed the plates in their late Paleozoic positions and plotted the main fracture patterns. Dextral shearing between these two mega-continents would create the appropriate riedel shear patterns within the continents. As well, this dextral mega-shear would halt the sinistral movement created as Avalonia collided with North America and moved up the eastern seaboard (Fralick and Schenk, 1981) during mid-Pennsylvanian times.

Leeder (1976) suggested that certain faults in the maritimes are <u>én echelon</u> features which are part of this mega-shear zone (figure 46). Thus, this final strike-slip faulting between the mega- continents also created reversals in some local faulting, creating new uplifted areas and new basins during the Westphalian B of the Carboniferous.

Pull-apart basins formed along the riedel shears, with positive blocks forming in areas of compression. The Fundy Basin System contains various sub-basins (figure 8) formed by these <u>en echelon</u> faults and pull-apart basins, basin sedimentation occuring in these down dropped blocks.

The Stellarton sub-basin of the Fundy System lies between the angular contact of the Cabot and Chedabucto faults, which are thought to be riedel shears of Arthaud and Matte's



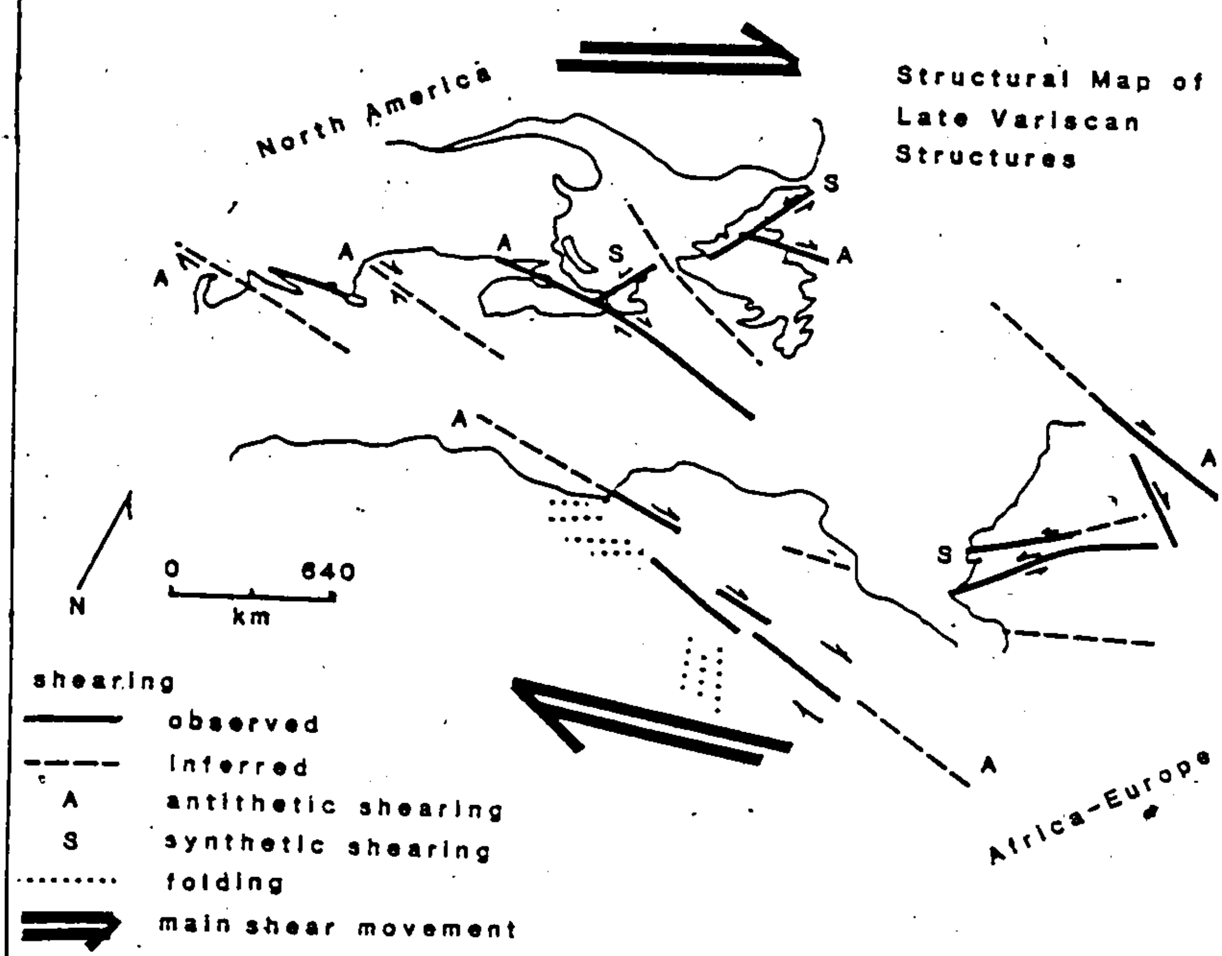


Figure 46

after Arthaud and Matte (1977)

mega shear zone. Fralick and Schenk (1981) have shown that these two large faults relate to more localized faulting and folding causing buckling and tilting of blocks and the creation of a strike-slip related basin adjacent to highland areas (figure 47). It is this event and a similar sequence of events that is proposed for the development of the Sydney Basin.

11.2 RECOGNITION OF STRIKE-SLIP BASINS

Strike-slip faults are those whose primary motion is both horizontal and parallel to the fault trace. They mark regions of transpression and compression. Experiments simulating strike-slip fault zones show characteristic fold patterns and secondary faults (figure 48); the folds form at oblique angles to the main shear; secondary faults form at low angles to the main shear with the same sense of movement (synthetic faults). Secondary faults also form at high angles to the shear, with the opposite sense of movement as the main shear (antithetic faults) (Wilcox et al., 1973) (figure 48).

Alternate zones of extension and compression occur along the strike-slip system. Extensional areas form basins, compressional areas are upland sources. These extensions and compressions are due to : 1) curvature of the shear zone; 2) anastomosing fault pattern; 3) fault terminations or fault side- stepping; (figure 49). Ancient strike-slip basins

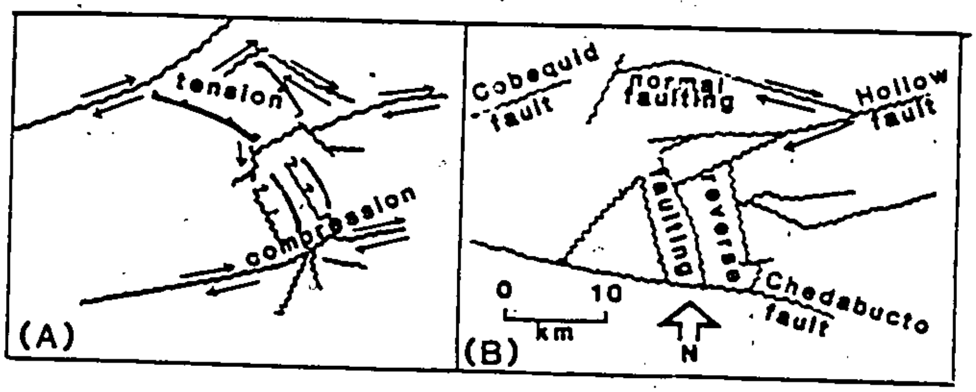
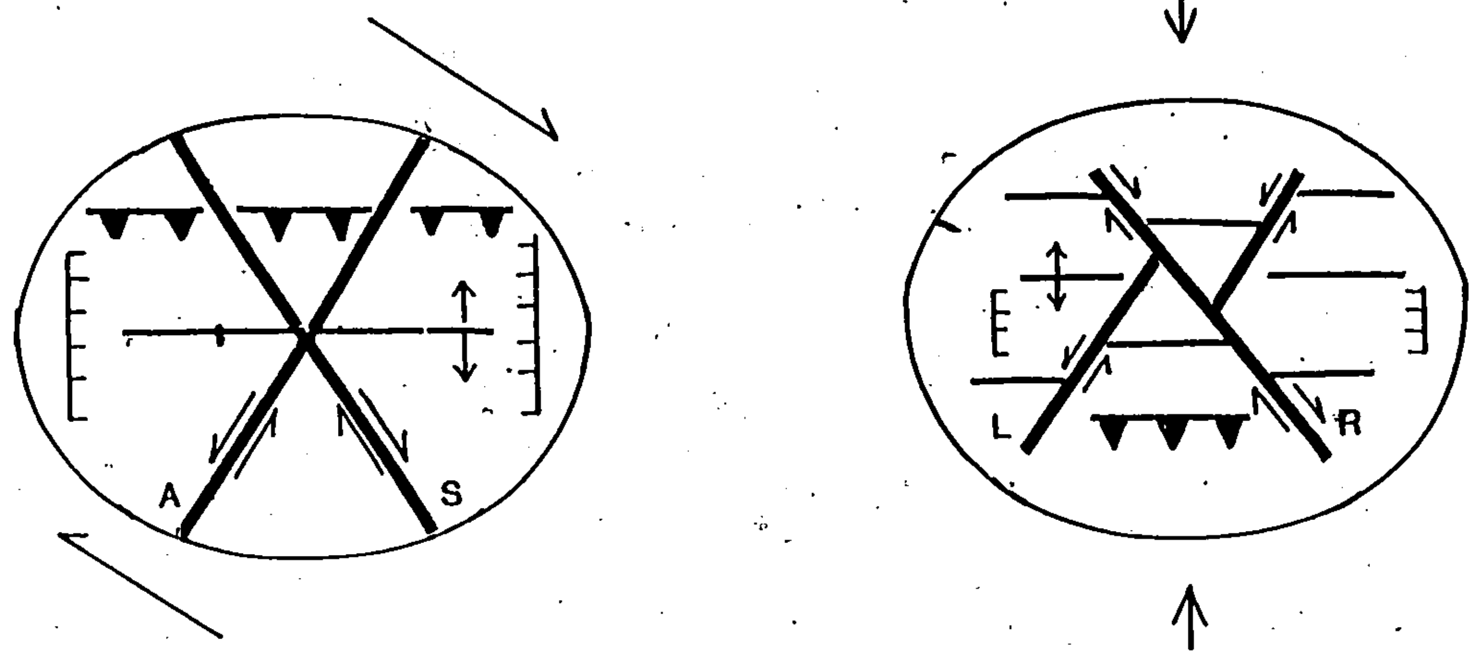


Figure 47: Comparison of the Stellarton Gap area (B) to a model for secondary faulting at the termination of a shear (A) (Fralick and Schenk, 1981).



(a) NW-SE Dextral Shear Couple.

A antithetic strike-slip fault
S synthetic strike-slip fault

normal fault
fold axis
thrust fault

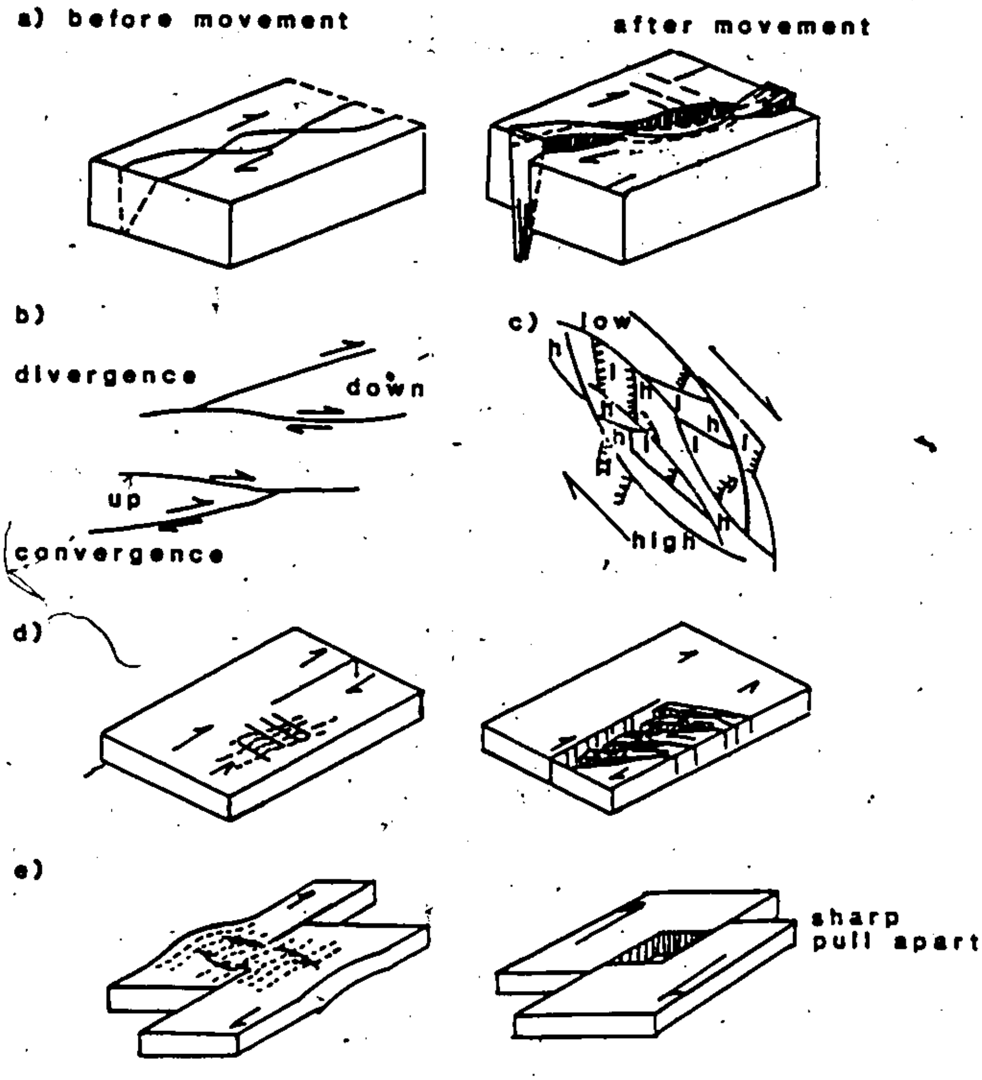
(b) N-S Compression

L sinistral strike-slip fault
R dextral strike-slip fault

adapted from Wilcox et al, 1973

Figure 48: Structural patterns formed from (a) shearing and (b) simple compression.

Types of Strike-Slip Fault Patterns Producing Subsiding Basins and Compressional Uplifted Blocks



(a) curved fault; (b) divergent and convergent faults; (c) anastomosing fault pattern; (d) fault termination; (e) side-stepping faults.

Figure 49

after Reading, (1980)

are related to compression, extension and transcurrent movement (Reading, 1980; Steel and Gloppen, 1980). These characteristics are listed in table 18.

11.3 STRIKE-SLIP CRITERIA FOR THE SYDNEY BASIN

The criteria previously cited for strike-slip sedimentary basins are listed in table 19 with their application to the Sydney Basin. It is postulated that the Sydney Basin is a marginal strike-slip basin, similar and contemporaneous with the Stellarton Basin, but more remote from direct influence of the basin forming strike-slip faults. As a result, strike-slip basin features are not completely developed.

The Sydney Basin is saucer shaped, elongate in an easterly direction. Mann et al.(1983) have described the development of strike- slip basins in relation to small circles. They recognized the occurrence of the longest pull- apart basins distal to the pole of rotation. Similarly, the Sydney Basin location is distal to the strike-slip forming basin faults and is elongate in shape. The Morien Group displays local paleocurrent trends to the northeast, but this is probably due to the location of the study area and the observed onland location of this part of the Sydney Basin with respect to the whole of the basin (figure 50a and 50b). Asymmetric fill of the basin is not clear, although Hacquebard and Donaldson (1969) suggest asymmetry of deposition of some of the coal seams in the Morien Group, though this is doubtful.

Table 19 : Criteria for the Recognition of Strike-Slip Basins (Reading, 1980; Steel and Gloppen, 1980).

1. overall elongate basin shape delimited by fault scarps or major fold axes.
2. rapid sedimentation rate
3. rapid lateral facies changes and/or extensive thin deposits
4. thick deposits in relation to lateral extent
5. proximal onlap of subsequent deposits
6. basin asymmetry
7. longitudinal mode of sediment dispersal
8. mismatch with postulated provenance of either clast size or composition
9. coarse marginal conglomerates
10. strike-slip fault structural system
11. scarce igneous and metamorphic activity

Table 20 : Criteria for the Recognition of Strike-Slip Basins Applied to the Morien Group of the Sydney Basin.

Criteria	Morien Group
Elongate Basin Geometry	Sydney Basin is an E-W elongated basin
Sedimentation Rate	relatively slow, allowing thick accumulations of peat to occur uninterrupted
Rapid Facies Changes	no?
Thickness	minimum of 1000 m
Proximal Onlap	no
Basin Asymmetry	fill occur from the SE to the N (?)
Longitudinal Mode of Sediment Dispersal	the Morien Group trends are to the NE, into the E-W Sydney Basin
Provenance Mismatch	no
Marginal Conglomerate	missing, eroded due to basin-ward migration of bounding faults
Wrench Fault Pattern	folds within the Sydney Basin are the final vestiges of the Chedabucto-Hollow shear couple
Sparse Igneous and Metamorphic Activity	yes

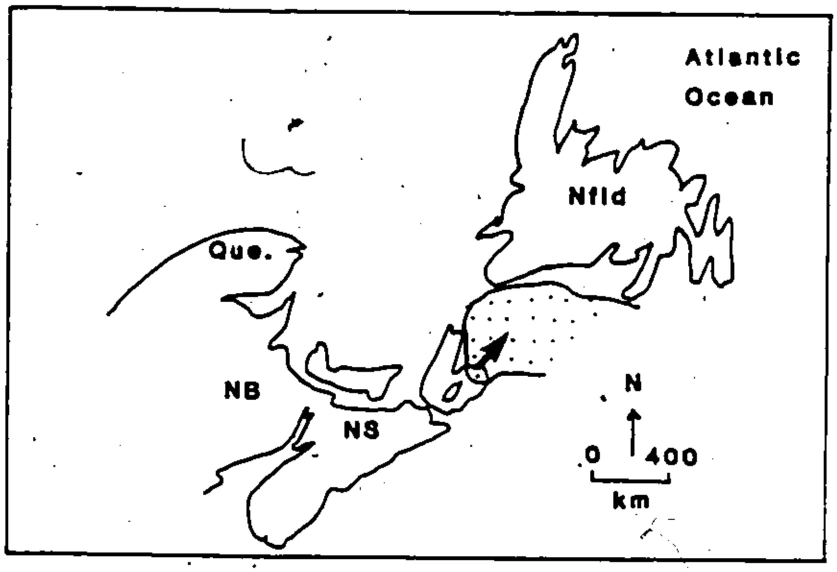


Figure 50a: Extent of the Sydney Basin with a generalized paleocurrent trend from the upper Morien Group.

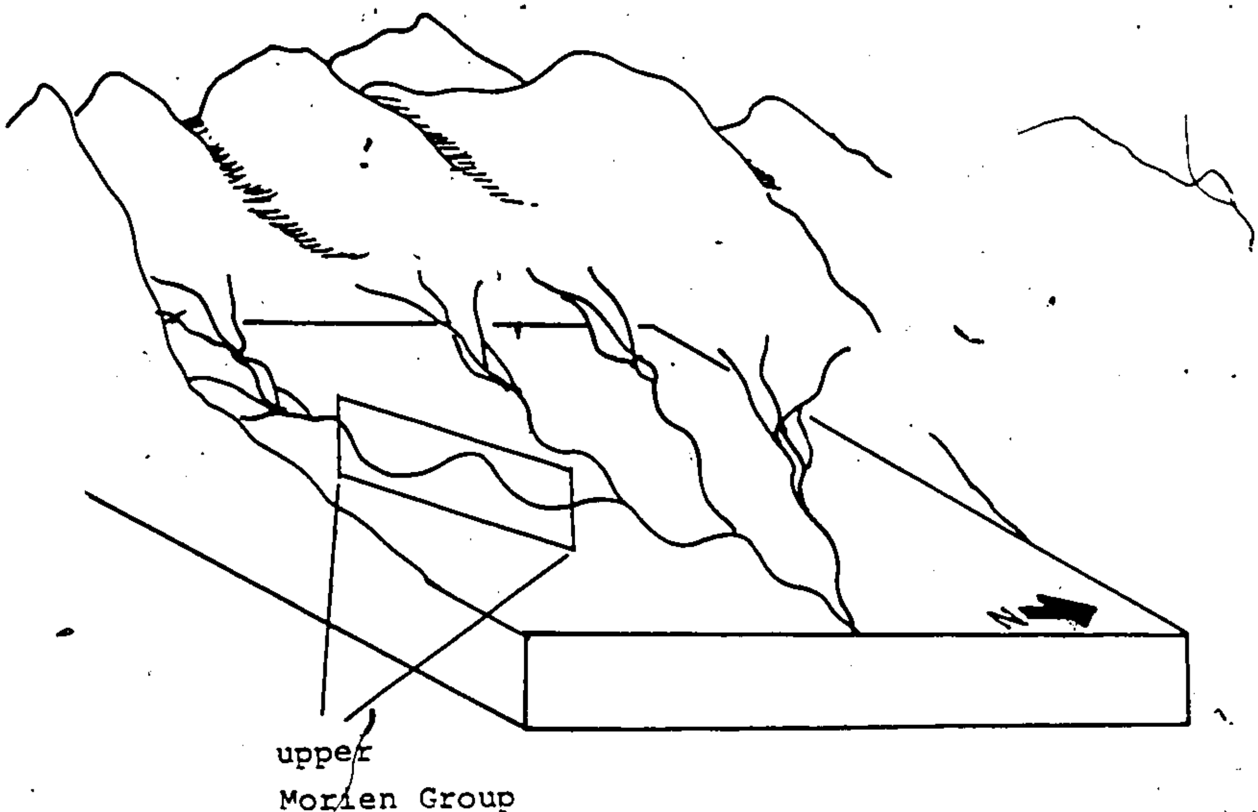


Figure 50b: Location of the upper Morien Group in relation to the whole of the Sydney Basin.

Evidence of tectonic activity is limited in the Morien Group, and it is believed that the asymmetry of the Morien sediments reflects a paleo-asymmetry in the basin. The sediment pile is relatively thick within the basin, reaching an approximate thickness of 2.8 km, from the base of the Grantmire Formation to the upper part of the Morien Group. Although no coarse alluvial deposits are present in the Morien Group, it is believed that side-stepping of the marginal faults towards the centre of the basin cut off fan deposits associated with the initial phase of deposition of the Morien Group (Rust, pers. comm.). Although paleocurrents indicate local basement highs as potential source areas, the initial provenance analysis of the light minerals combined with local paleocurrent trends, does not distinctly outline the source areas. Northeast trending synclines and anticlines, whose axes approximate the major east-west trend of the basin may be interpreted as strain folds related to the mega-shear zone of Arthaud and Matte (1977). Fault scarps which control the northern and southern edges of the basin consist of a sinistral southern fault (Keppie, 1979) which is considered to be a synthetic fault of Arthaud and Matte's mega-shear zone; the north bounding Mountain fault parallels the fold axes in the basin and is postulated to be an antithetic fault to the main shear zone (figure 51). These structures are seen as part of the <u>en echelon</u> fold system associated with strike-slip

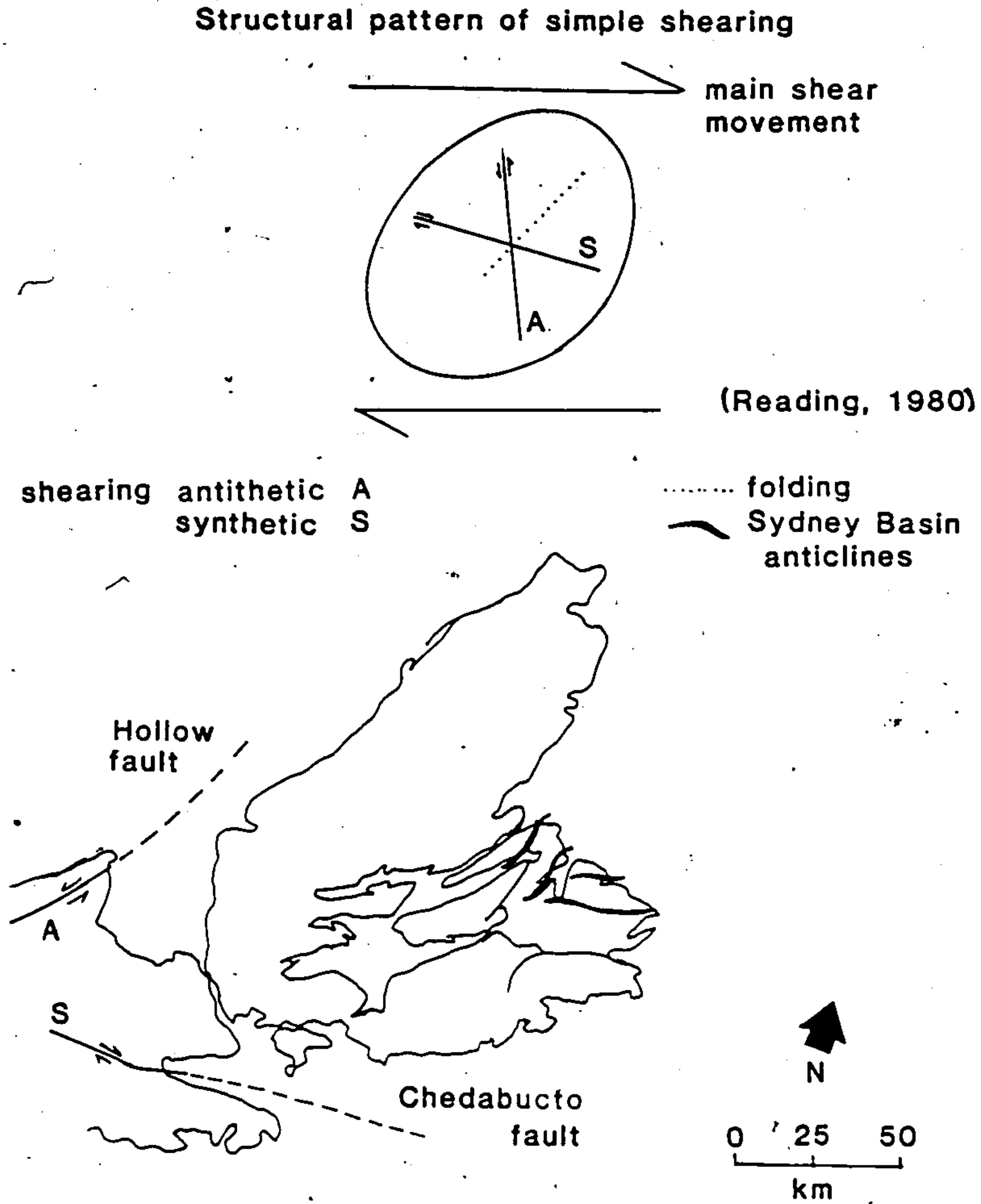


Figure 51: Sydney Basin folding in relation to the Chedabucto –Hollow shear couple.

fault zones (figure 48). Thus these features may have formed due to the regional dextral shear zone postulated by Arthaud and Matte (1977), although it should be mentioned that local compression in the area would create similar structures (figure 48).

11.4 BASIN RECONSTRUCTION

Initial sinistral shearing and later major dextral shearing during the close of the Acadian orogeny and throughout the Alleghenian orogeny (Poole, 1967; Arthaud and Matte, 1977) created many basins in the Maritime area; this was due to shear couples related to strike-slip movement.

Structural elements of the Sydney Basin can be broadly fitted to the strike-slip basin model (table 19). No sedimentological criteria of the Sydney Basin conflict with those criteria cited for the strike-slip basin model. However, due to the tenuous aspect of some of the Sydney Basin criteria, a modification is suggested. Initially, the Sydney Basin was influenced by strike-slip movement similar to that forming the Stellarton Basin (Fralick and Schenk, 1981). But, due to the geographic distance between the Sydney Basin and the shear couples (Cabot and Chedabucto faults) forming the strike-slip basin, the strike-slip features of the Sydney Basin are not prominent. The strike-slip characteristics also decrease eastward, again due to the increasing geographic distance between the strike-slip influences and the depositional basin they created. As well, infilling of the basin without re-activation of the basin forming faults caused an upward decrease in strike-slip basin characteristics. This would coincide with Reading's (1980) final phase (transpression) in the development of strike-slip basins.

The major strike-slip motion of the Chedabucto and Cabot faults created an area of transpression which developed into the Sydney Basin. Initial erosion of the local source areas formed the Grantmire Formation and the lower parts of the Windsor Group. Marine incursion occurred, depositing most of the Windsor Group. Marine regression resulted in deposition of the Point Edward and Cape Dauphin Formations. Unconformities between the Windsor Group and the Point Edward Formation occur only locally and this may be due to local movement and uplift, which would also aid the marine regression.

At this point, probably a final tectonic surge occurred, which uplifted and eroded local blocks providing source areas for the Morien Group and creating a major regional unconformity. Since within the Morien Group only a braided to meandering alluvium is observed, it is postulated that the lower-most Morien Group contained marginal fan deposits, subsequently lost by erosion. The proximal potential source areas for the basin would typically yield fan complexes, transitional distally through braided to meandering alluvium. As well, local paleocurrent trends are parallel rather than normal to marginal faults, particularly in the vicinity of the Bateston fault to the south (Rust et al., 1983). With these facts in view, it is suggested that movement along the marginal faults continued into the Morien and that these faults stepped basin-ward, uplifting the earlier fan complexes, which were then removed by erosion (Rust, pers. comm.).

Generally however, deposition of the Morien Group reflects pre-Morien basin trends, that is, deposition in an east- west elongate basin with a fluvial system infilling the basin. Local paleocurrent trends to the north-east are a result of the position of the depositional site of the Morien Group with respect to the whole of the Sydney Basin (figures 50a & b).

11.5 PALEOENVIRONMENT

The presence and extent of the coalfields in the Carboniferous suggests a largely world-wide humid climate. The humidity of the Carboniferous is mainly based on the presence of subtropical and tropical coals and may be due to a warm overall temperature of the earth. A warm earth would cause an increase in heat transport, thus increasing evaporation and precipitation and creating a high humidity. The high humidity may also be related to an increased humidity which occurs prior to any major glaciation (Frakes, 1979).

Paleolatitudes are given by world map reconstructions by Keppie (1977) and Habicht (1979) and others. For the upper

Carboniferous, Atlantic Canada is situated between 0 and 10 south (figure 52). A warm climate is indicated from the paleolatitude and the presence of organic reefs and carbonate buildups in midland U.S.A., midland Britain and Europe (Frakes, 1979), although the reefs decrease in abundance into the later Carboniferous, as glaciation began. The presence of redbeds and paleosols associated with the coals also indicates a warm climate (Habicht, 1979).

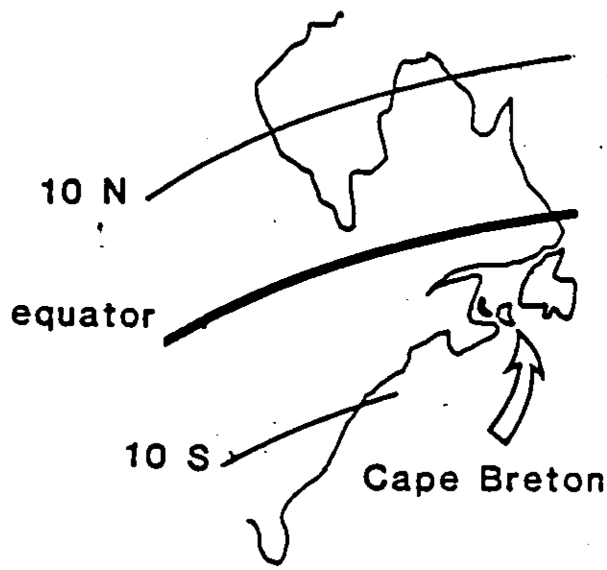


Figure 52: Carboniferous latitudes for eastern North America, Hablcht , 1979.

Chapter XII

CONCLUSION

12.1 SUMMARY

The upper Morien Group of the Sydney Basin is interpreted as the deposit of a meandering fluvial system on a broad flood plain.

The tectonic style of the basin is related to the early Carboniferous formation of the Fundy Rift System (Belt, 1968; Poole, 1967). Initiation of the Fundy Rift System occurred during the Acadian orogeny with sinistral shearing being the main movement. During the Alleghenian orogeny reshuffling of the continents resulted in dextral shearing and development of successor basins within the Fundy Belt, the Sydney Basin being one (figures 46 and 8).

Deposition in the Sydney Basin was controlled by faults along the northern and southern edges and upthrusted blocks to the west; this resulted in general flow patterns to the north-east. Initial deposition within the basin was a conglomerate (Grantmire Formation); then marine incursion deposited marine beds (Windsor Group), followed by a marine regression, which deposited mixed marine-terrestrial units (Point Edward and Cape Dauphin Formations). A final surge of tectonic activity caused uplift and erosion and created a major regional unconformity. Renewed sedimentation of the basin began with a marginal fan complex, which was later cut off by a basin-ward migration of marginal faults. Deposition continued with a braided fluvial system, which, as the basin infilled, developed into a broader flood plain and a meandering fluvial system (upper Morien Group).

12.2 EVIDENCE FOR MEANDERING FLUVIAL DEPOSITION IN THE UPPER MORIEN GROUP

1. Erosional bases of the trough cross-stratified sandstones, which fine upward into Sr and Sh and occasionally show epsilon cross-strata : point-bar deposits of major meandering channels (Allen, 1965 , 1970; Ethridge and Schumm, 1978).
2. Highly variable paleocurrent data, variance of approximately 180°, but with an overall trend to the north-east suggests a sinuous channel system, with one general flow direction.
3. Channel forms of width / depth ratios of 18:1 to 22.5:1 resulting in high sinuosity channels, 2.56 mean sinuosity : meandering fluvial system (Ethbridge and Schumm, 1978 and Rust, 1978).
4. Abundant fine materials which interbed, overlap and interfinger with coarser materials (fine sandstones); the presence of abundant organic material and <u>in situ</u> trees : various overbank deposits - flood-plain, levee and crevasse splay deposits.

5. Concave up channel shapes, infilled with mudstone and siltstones : abandoned channels.
6. Laterally extensive interbedded siltstones and mudstones : flood-plain deposits.
7. Limestone and black-shale units with abundant non-marine fauna : lacustrine deposits.
8. Redbeds, desiccation cracks and paleosols ; sub-aerial exposure and warm paleo-climate.
9. Abundant and highly diversified flora : terrestrial and humid, tropical environment.
10. Thick and extensive coal deposits : very humid and relatively warm environment; with a high water table.
11. Poor levee development: highly migratory system.

12.3 CONCLUSIONS

The upper Morien Group was deposited on a broad flood plain, elongated to the north-east, as part of a north-east trending fluvial system. A highly sinuous meandering river system developed in a warm humid climate. The broad flood-plain had a high water table and developed a lush and diverse flora. This resulted in thick peat accumulations. Cut-off chutes and local depressions developed into ephemeral lakes throughout the swampy flood-plain. As the basin infilled and became broader and flatter, there were periods when the main channel was occupied to one side of the broad flat basin, temporary drying

RECONSTRUCTION
of the
DEPOSITIONAL ENVIRONMENT

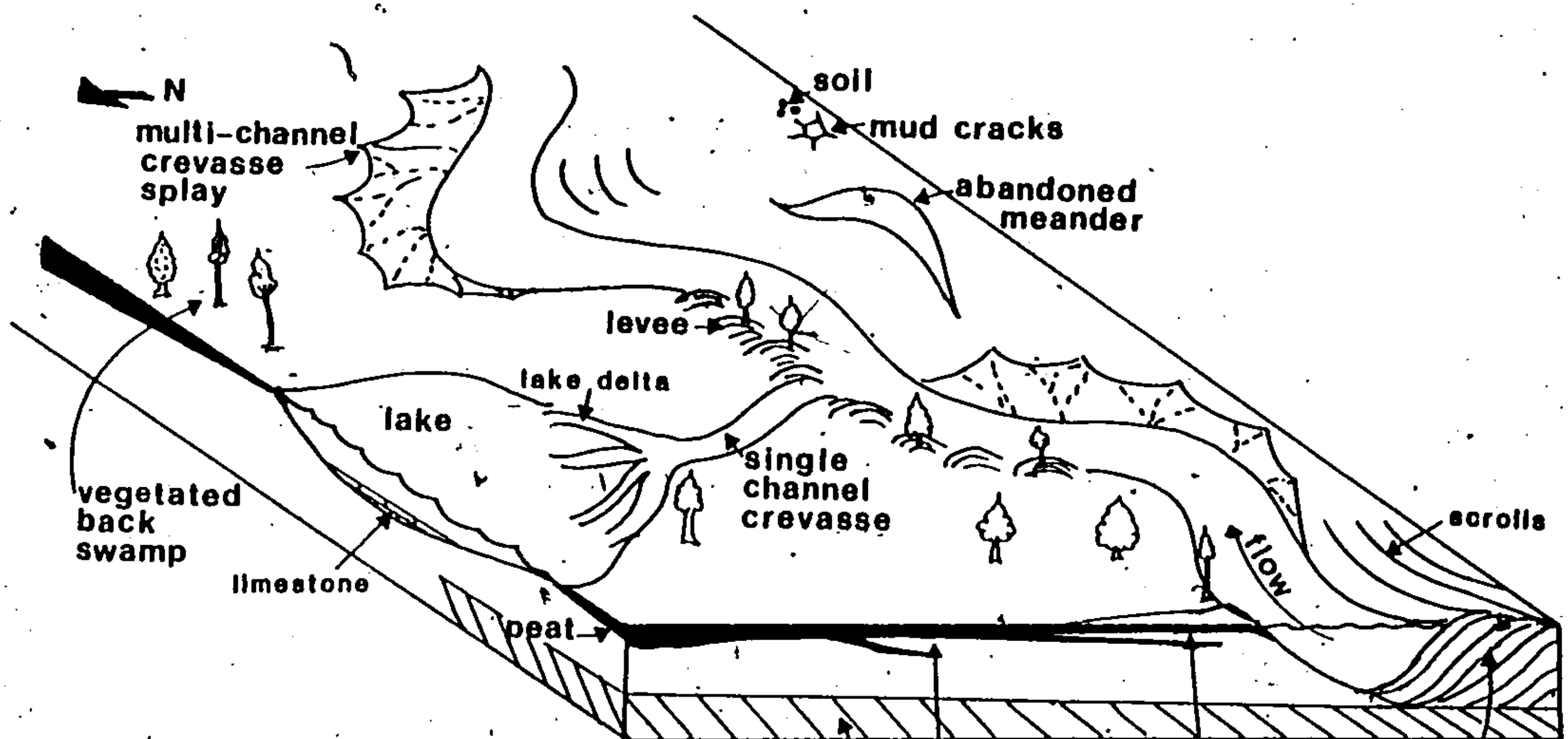


Figure 53

occurred in areas on the flood-plain distal to the active channel, so redbeds and paleosols developed. A schematic reconstruction is shown in figure 53.

12.4 RECOMMENDED FURTHER WORK

1. Detailed provenance study utilizing heavy minerals and rare earths , which can be unique to particular rock types.
2. Detailed analysis of the paleosols and clay mineralogy.
3. Relation of channel, levee and crevasse forms to mining. Geometric extent of these bodies and their relation to roof problems, cut-outs etc. The effect of these different bodies on the coal quality.
4. Diagenetic history as indicated by concretions.
5. Extension of basin analysis seaward on the basis of drill core, seismic records, etc.
6. Integration of results with mining records.

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Photo 1: Vertical cross-section of trough cross-stratification; plan view of trough cross-stratification is shown in photo 7. (Divisions on the meter stick are 5 cm; South of Chapel Point, section a, 295 m.)

Photo 2: Pebble lag concentrated in the trough axis. Lag primarily consists of quartzite, sedimentary and metamorphic pebbles. (Geological hammer is 32 cm long; Chapel Point, section a, 362 m.)

1

2

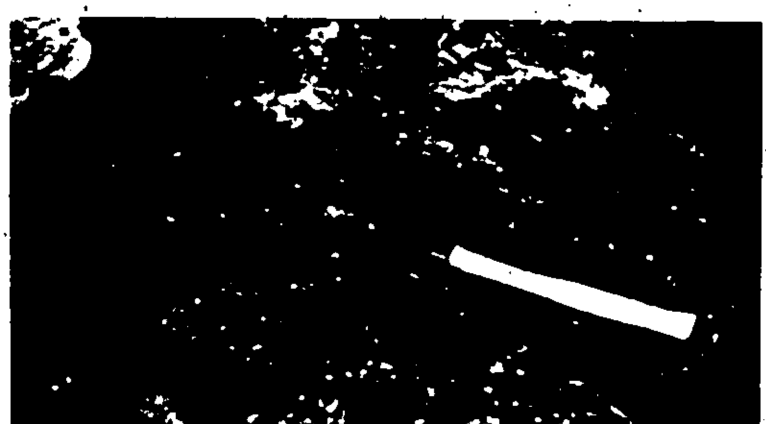

Photo 3: Concentrations in the trough axis of organic debris.
(Geological hammer handle is 22 cm long.)

Photo 4: Intraformational mud clasts occasionally are found in trough axes near erosional channel bases.
(Geological hammer handle is 28 cm long.)

3

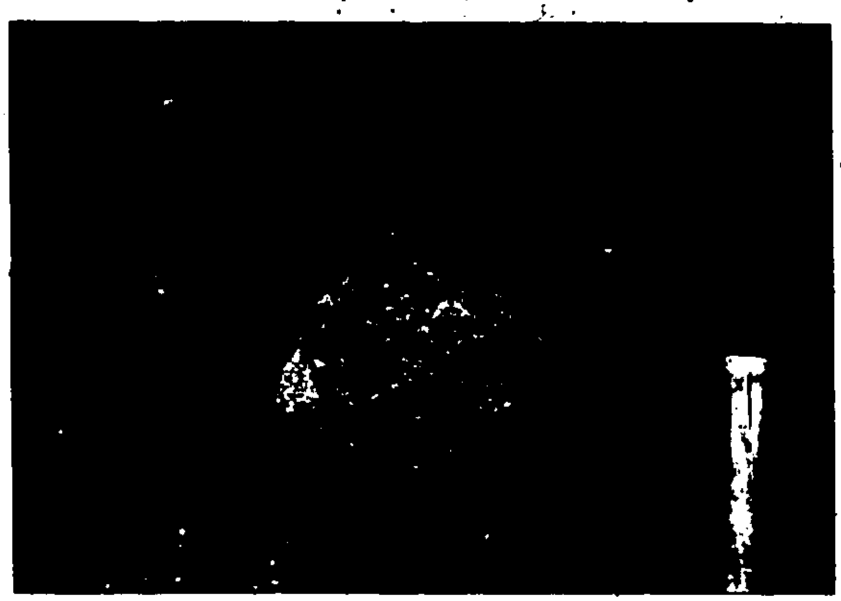

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Photo 5a: Geological hammer is orientated vertically across a coal block near the base of a channel sandstone (facies St). Undercutting of the bank by the channel causes blocks of peat to fall out into the channel. (Geological hammer is 32 cm long; Black Point, section c, 20 m.)

Photo 5b: Detail of the coal block in photo 5a. (Lens cap is 5 cm across.)

5a

5b

Photo 6: Non-erosional channel base. Facies St is in sharp contact with the underlying coal seam (upper Chapel Point seam). This is presummably due to the resistive nature of the original peat. (The stick is 80 cm in length.)

Photo 7: Plan view of troughs at Chapel Point. Geological hammers mark the trough intersections. The handles point in the direction of the paleocurrents, which is to the northeast. (Geological hammers are 32 cm long.)

6

7

Photo 8: Horizontally laminated fine-grained sandstone grades upward into ripple cross-laminated sandstone; ripples flatten upward. Laminations are marked by organic accumulations.
(Lens cap is 5 cm across; north of Mines Point, section a, 192 m.)

Photo 9: Photo-micro-graph of ripple cross-laminations. Black areas are organic concentrations which alternate with fine-grained sandstone and outline the ripple form.
(Lithofacies Sr.)

8

9

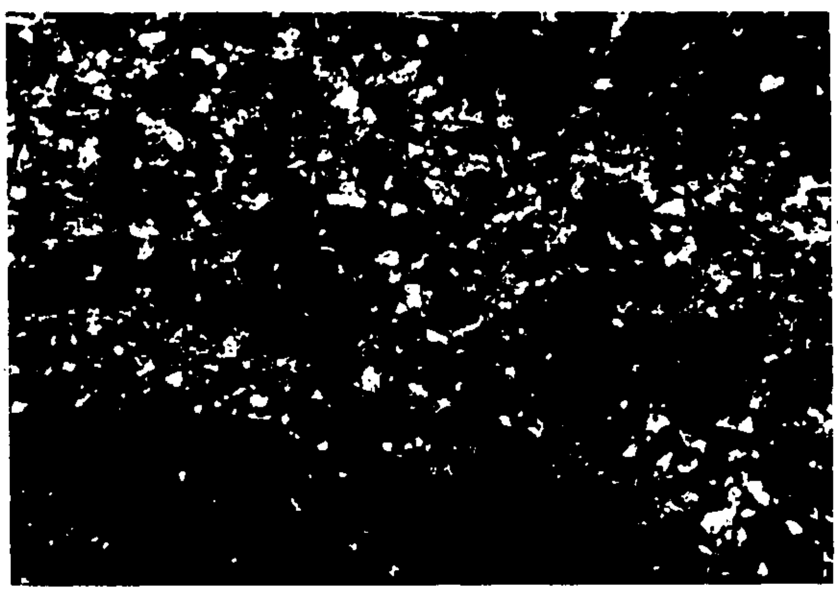

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Photo 10: Cliff exposure north of Mines Point, showing facies Fl and Fl(c) with abundant in situ trees; arrows point to a few trees. (Stick is 2 m in length.)

Photo 11: Facies Sr with ripples showing occasional climbing form. (Lens cap is 5 cm across; Stubbert Point, section a, 15 m.)

10

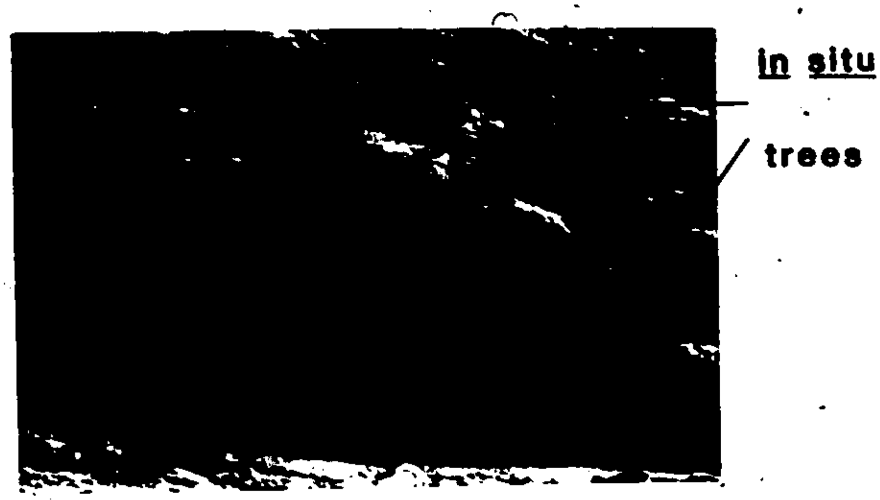

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Photo 12: Boulder of facies Fl showing the trace fossil Diplichnites sp., Cranberry Head. (Geological hammer is 32 cm long.)

Photo 13: The trace fossil Beaconites sp. on a boulder of facies Fl, northwest of Oxford Point. (Geological hammer is 32 cm long.)

12

13

Photo 14: Conical fracturing in red mudstone. Gilgai-like structures, probably from pedogenic induced alternating watering and de-watering of the muds. (Stick is 2 m in length; north of Mines Point, section a, 188 m.)

Photo 15: Mold of a stigmaria root with rootlets. (Meter stick is divided into 5 cm segments, north of Mines Point, section a, 192 m.)

14

15

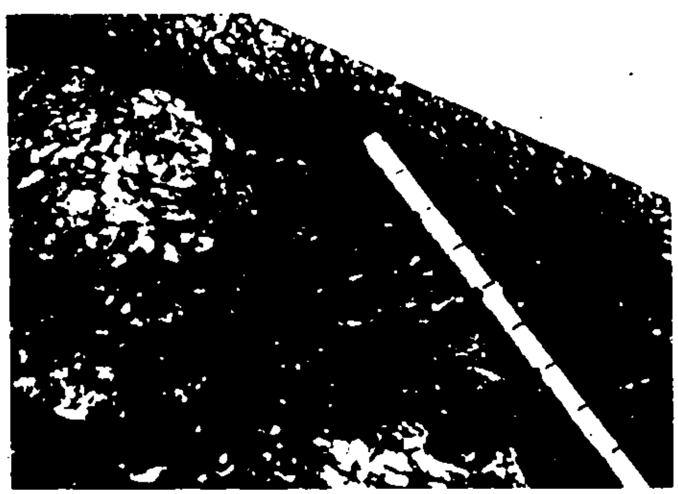

Photo 16: Facies Fl containing carbonate (light coloured) nodules which may form discontinuous hardpan units. Arrows point out a few nodules and the hardpan.
(Stick is 170 cm in length; north of Mines Point.)

Photo 17: Discontinuous limestone unit underlying a coal seam. The limestone is light coloured.
(Stick is 140 cm in length; north of Mines Point.)

16

17

Photo 18: Top view of the basisphenoid bone from a crossopterygian fish.
(Limestone unit in section a, 242 m.)

Photo 19: Under-side view of the bone in photo 18. The cavity has been infilled.

18

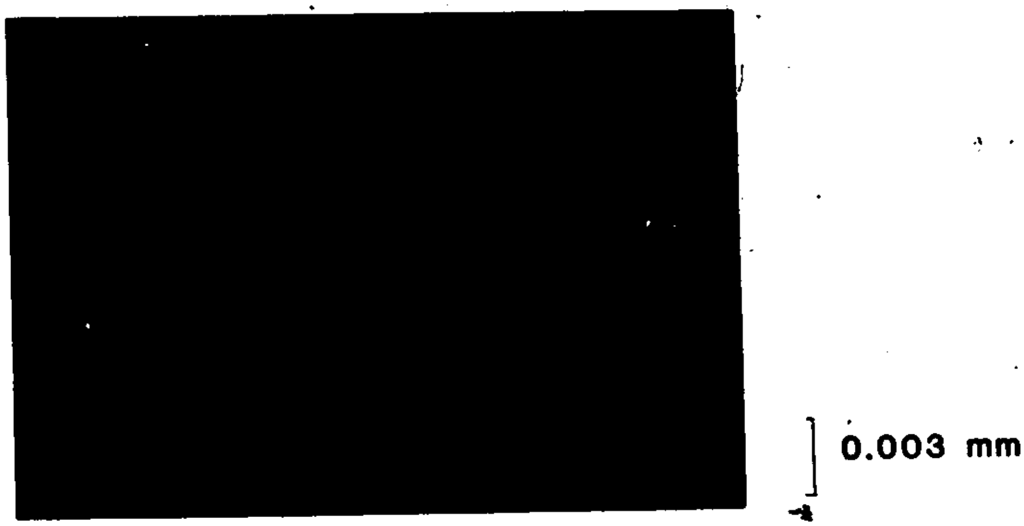

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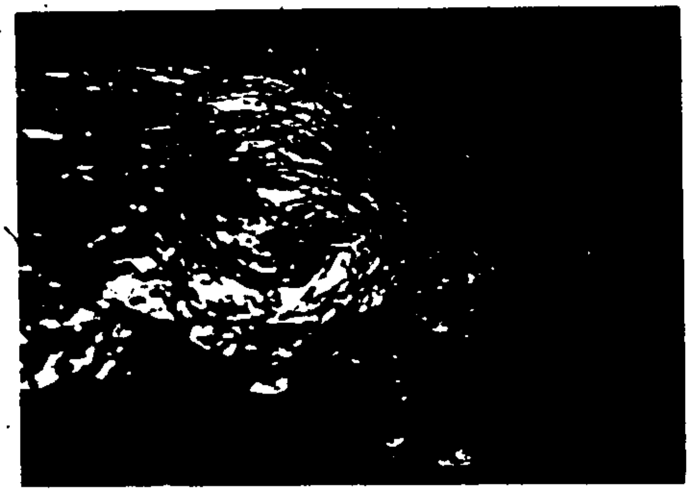
Photo 20: Cross-section through a columnar stromatolite. (Lens cap is 5 cm across; section a, 195 m.)

Photo 21: Photo-micro-graph of algal filaments (?) Light coloured horizontal bands are muscovite grains; the sample is predominantly carbonate-rich mudstone. (Thin section of stromatolite unit above.)

20



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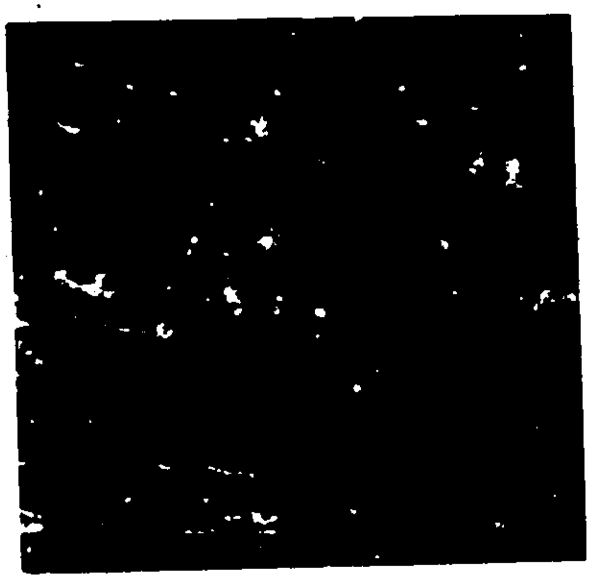

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Photo 22: In situ tree with a coalified bark extending downward into an underlying coal seam. (Stick is 80 cm in length; section a, 210 m.)

Photo 23: Photo-micro-graph of a septarian nodule. Fractures have been infilled with coarse-grained calcite. The nodule is sideritic and the light grains are quartz. Nodule from lithofacies Fl, near Stubbert Point.

22

23

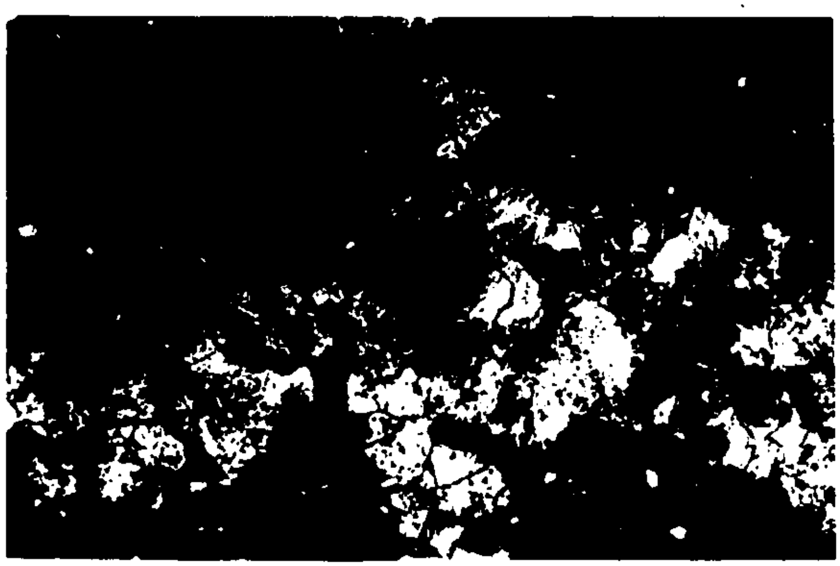

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Photo 24: Photo-micro-graph of a black clammy shale (facies Fl(c)). Fragments are from pelecypods, gastropods and fish bone, teeth and scales. (Section a, 245 m.)

Photo 25: Photo-micro-graph of a whole gastropod from facies Fl(c).

24

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25

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Photo 26: Lateral accretion unit showing epsilon cross-stratification. The channel overlies facies Fl and Fm, northwest side of Bonar Head.
(Cliffs are approximately 8 m in height.)

Photo 27: Detail of activation surfaces in a lateral accretion unit. These surfaces consist of rippled shales and rippled fine-grained sandstones.

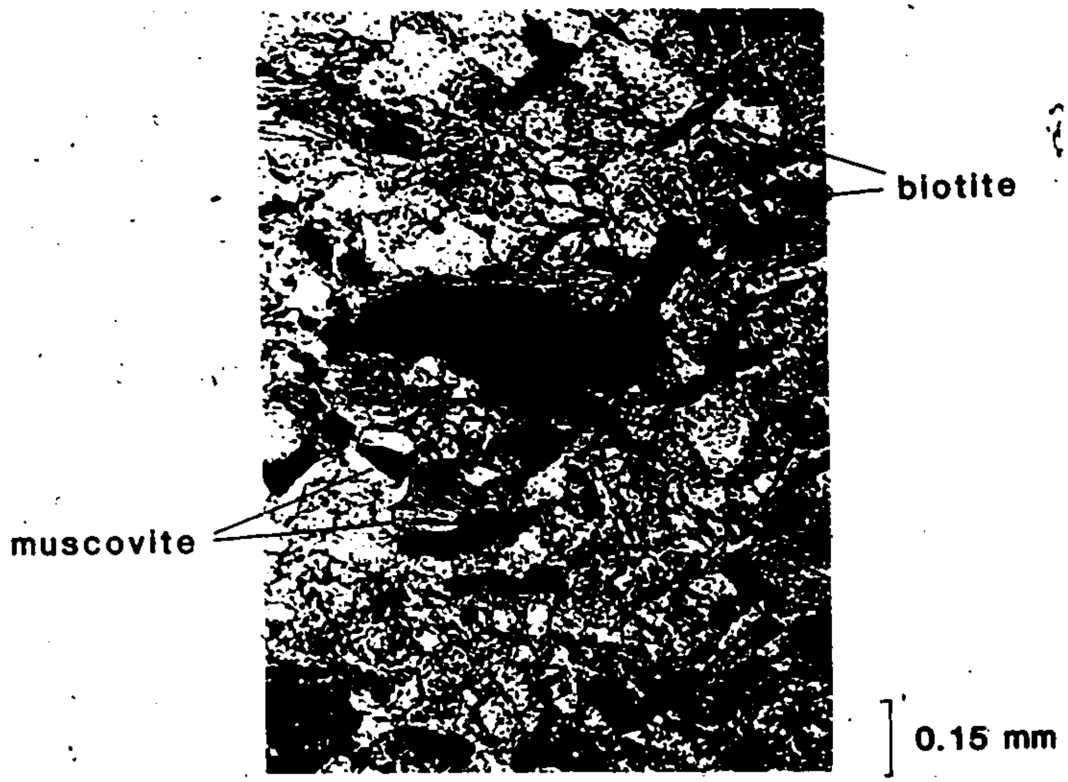
26

27

Photo 28: Photo-micro-graph of a medium-grained sandstone. Large light-coloured grains are quartz, dark grains are organic material, the grey grains are muscovite and biotite. The central organic grain still shows a cell-like texture. Lithofacies Sr.

Photo 29: Desiccation cracks in grey mudstone and infilled with red mudstone. (Geological hammer is 32 cm long; south of Chapel Point.)

28



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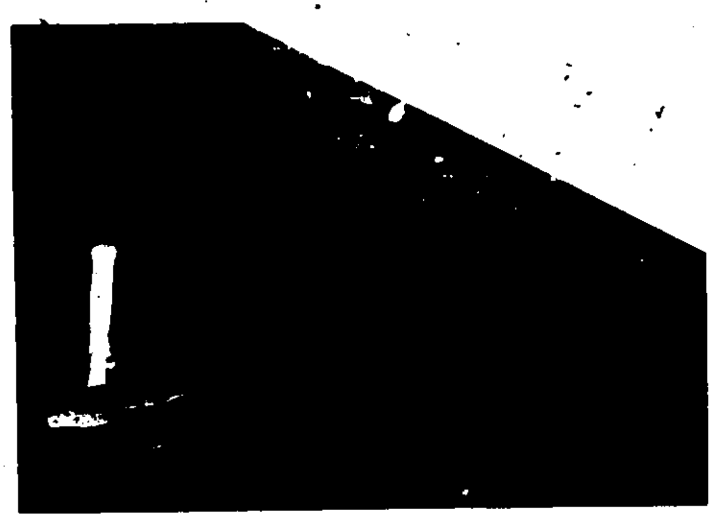


Photo 30: Channel edge to the left, concave up; levee to the right, gently dipping away from the channel.
(Stick is 2 m in length; Oxford Point, section k, 12 m.)

Photo 31: Small-scale channel which interfingers with overbank materials at its edge (to the left). The channel sandstone overlies facies Fl, Fm and C (the lower Chapel Point seams).
(Cliffs are approximately 8 m high.)

30

31

Photo 32: Abandoned channel (cut-off) infilled with alternating layers of red and grey mudstone (dark and light colours respectively). Note some possible slumping in the bank. (Geological hammer in the lower left, is 32 cm long.)

Photo 33: Cliff exposure showing lateral extent of red and grey mudstone and siltstone attributed to flood basin deposition, cliffs extend south west from Cranberry Head along the northwest side.
(Assistant is approximately 169 cm.)

32

33

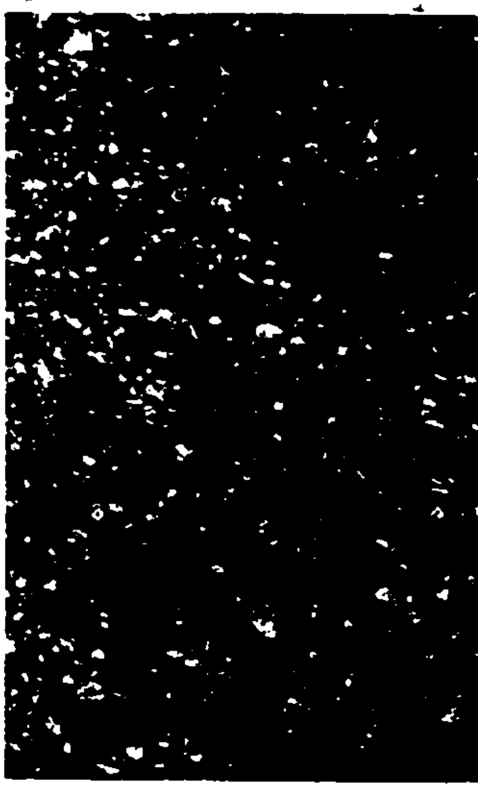
Photo 34: Aconi seam at Cranberry Head, overlying facies Fl and Fm. Note the *in situ* tree on the right.
(The tree is approximately 120 cm in height.)

34

Photo 35: Very fine-grained calcareous sandstone. Large light coloured grains are quartz, large dark grains are organic debris, matrix is very fine calcite and sericite.

Photo 36: Coarse-grained secondary calcite infilling voids and cementing the grains and soil peds.

35



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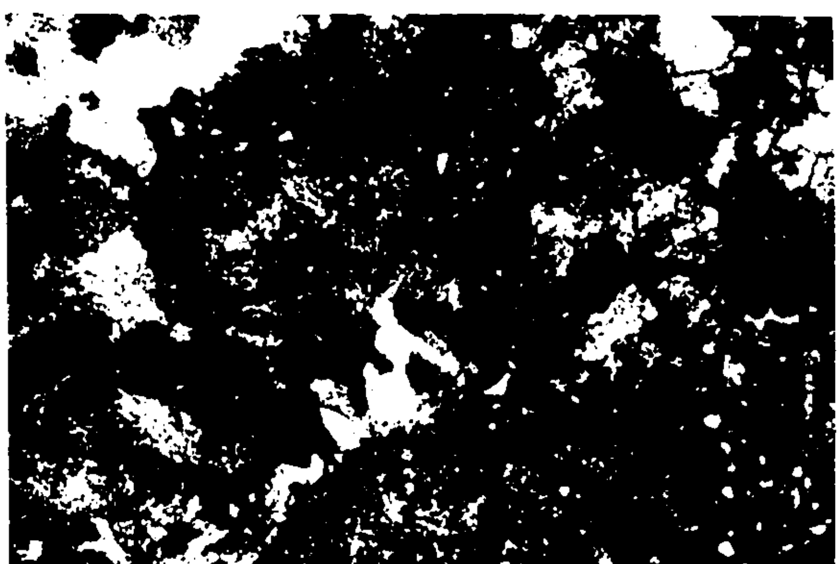

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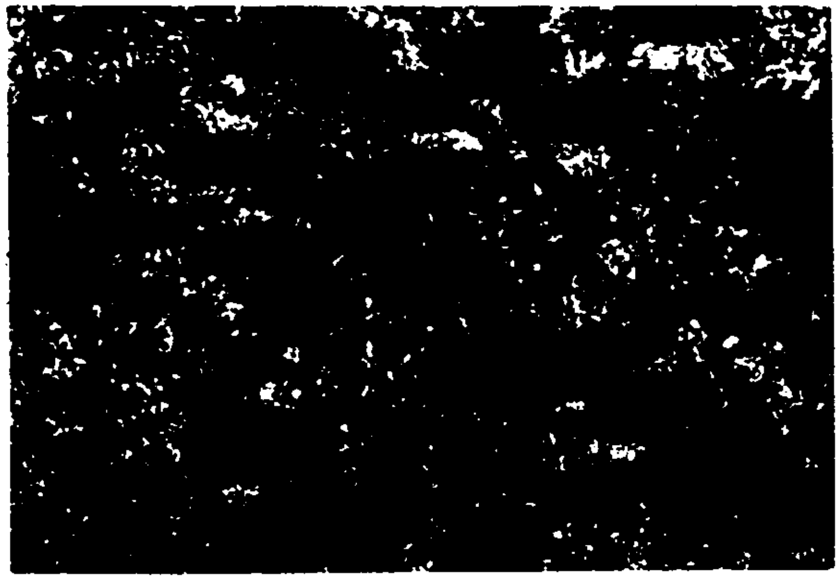
Photo 37 : Photo-micro-graph of pedogenic crystallaria structures in a calcrete.

Photo 38: Photo-micro-graph of ped structures attributed to pedogenic processes.

37



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38

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Photo 39: Carbonate nodules coalesced to eventually form this hardpan, southwest of Mines Point. (Geological hammer is 32 cm long.)

39

Appendix A

MARKOV CHAIN ANALYSIS

A.1 INTRODUCTION

A Markov chain is defined as :

> "a stochastic process which moves through a finite number of states, and for which the probability of entering a certain state depends only on the last state occupied"(Kemeny and Snell, 1960, p.207).

It is used to determine the most probable sequence of states in a non-random sequence.

Stratigraphically a sequence is sub-divided into states, which may or may not be facies. The only condition of sub-dividing is that the sub- divisions are consistent throughout the sequence. A series of matrices are constructed based on the observed transitions from one state to another. These matrices adjust for randomness within the sequence and deal with the probability of the order within the sequence. The first matrix is an observed transition matrix; the second is an observed probability matrix; the third is the independent trials probability matrix; the fourth is the difference matrix, which defines the Markov chain.

The observed number of transitions from one sub-division to anotheris summarized in a transition count matrix. This transition count matrix has the dimensions N x N, where N is the number of sub-divisions.

For the matrix transitions from state i to j, the code Fij is used; row totals are SR; column totals are SC and combined row and column totals are T. The equations for each function are summarized:

$$SRi = \sum_{j=1}^{N} Fij$$

$$SCj = \sum_{i=1}^{N} Fij$$

$$T = \sum_{j=1}^{N} \sum_{i=1}^{N} Fij$$

The upward transition probability is the number of times the transition from i to j occurs relative to the total number of times i is present. This is the observed trials probability matrix and it is defined by:

$$Pij = Fij / SRi$$

An independent trials probability matrix is the probability of a transition from i to j occurring without being affected by whether j is preceeded by i, except by the relative abundances of all the states - that is, the transition from i to j is dependent on the relative abundances of all states). This matrix is defined by:

$$Rij = Scj / (T - Sci)$$

and thus predicts random transitions.

To compare the actual observed transitions to the probability of random transitions, a difference matrix is computed:

$$Dij = Pij - Rij$$

Large positive elements indicate transitions which occur more frequently than can be attributed to random trials. From this, a preferred relationship from one state to another can be constructed.

A.2 APPLIED MARKOV CHAIN ANALYSIS

Markov chain analysis was applied to the study area and a series of matrices were constructed (tables A1 to A4). The Markov chain was applied to the whole succession, as well as to subdivided parts of the succession. Due to the relatively distinctive characteristics of the channel units and overbank deposits, the analysis was applied separately to these two groups. (This was done primarily because of the two different flow regimes encountered in these two areas; due to this, it was felt that a clearer relationship between states would be obtained).

The succession as a whole is a complex series of transitions from one lithotype to another (figure A1 and table A1). However, a fairly clear pattern of two cells of events is observed : channel deposits of a higher energy cell and overbank deposits of a lower energy cell (figure A2).

The preferred facies sequence within the channel cell is shown in figure A2 and the matrices are in table A2. This sequence of lithofacies corresponds closely with Allen's (1965) and Walker and Cant's (1979) description of channel deposits in meandering fluvial systems.

The overbank deposits are more complex than the channel deposits due to the more varied processes which affect flood- plains (ie. flooding; soil forming processes; crevasse and levee progradation.) Within the Markov chain analysis for these deposits, two distinct sub-cells can be identified (figure A3). One sub-cell begins with trough cross-stratified sandstone, the other begins with rippled sandstones (figure A4). Presumably, the St cell is attributed to the progradation of a single crevasse splay channel from a breached levee, which fans out into more distal finer crevasse splay and overbank deposits. The second cell with the rippled sandstones is attributed to anastomosing crevasse splay channels, levee and flood plain deposits. The matrices for this analysis are in table A3. These two units can be connected into one large cycle or overlapped in a variety of forms (figure A3 and table A4). This is typical of overbank deposits which consist of interfingering and overlapping of a variety of sediment types and styles (Allen, 1965).

Table A1: Markov Chain Analysis for the Total Succession

Transition Count Matrix

	St	Sp	Sr	Sh	Fl	Fm	C	D	E	Total
St	0.000	0.000	7.000	12.000	2.000	2.000	0.000	0.000	0.000	23.000
Sp	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
Sr	2.000	0.000	0.000	8.000	29.000	19.000	2.000	1.000	0.000	61.000
Sh	2.000	0.000	18.000	0.000	16.000	20.000	1.000	0.000	1.000	58.000
Fl	3.000	0.000	14.000	9.000	0.000	45.000	16.000	1.000	3.000	91.000
Fm	0.000	0.000	20.000	28.000	29.000	0.000	15.000	1.000	11.000	104.000
C	1.000	0.000	1.000	2.000	14.000	11.000	0.000	0.000	3.000	32.000
D	0.000	0.000	0.000	1.000	1.000	1.000	0.000	0.000	0.000	3.000
E	14.000	0.000	2.000	0.000	2.000	0.000	0.000	0.000	0.000	18.000
										391.000

Transition Probability Matrix

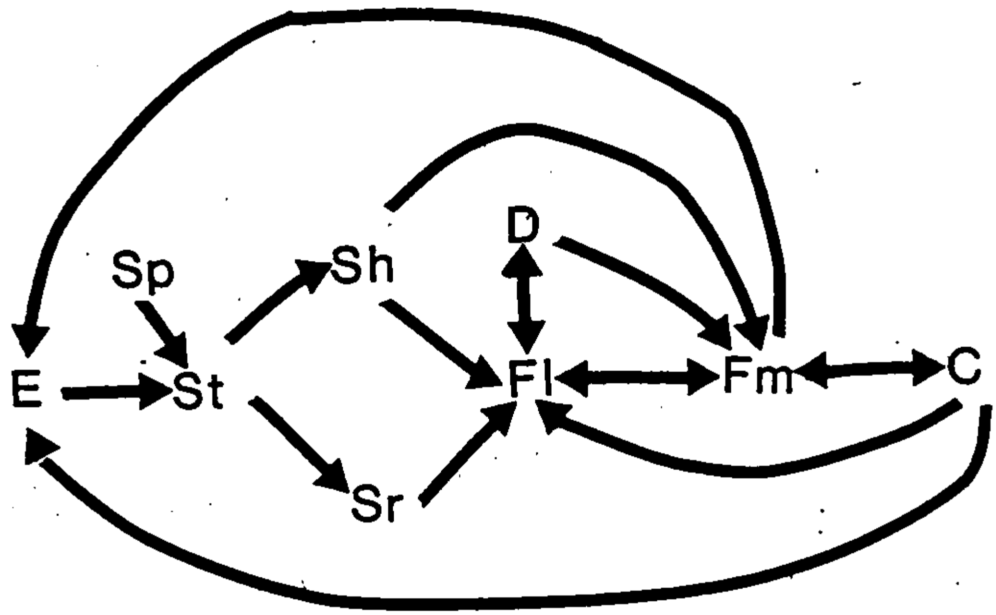
	St	Sp	Sr	Sh	Fl	Fm	C	D	E
St	0.000	0.000	0.304	0.522	0.087	0.087	0.000	0.000	0.000
Sp	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sr	0.033	0.000	0.000	0.131	0.475	0.311	0.033	0.016	0.000
Sh	0.034	0.000	0.310	0.000	0.276	0.345	0.017	0.000	0.017
Fl	0.033	0.000	0.154	0.099	0.000	0.495	0.176	0.011	0.033
Fm	0.000	0.000	0.192	0.269	0.279	0.000	0.144	0.010	0.106
C	0.031	0.000	0.031	0.063	0.438	0.344	0.000	0.000	0.094
D	0.000	0.000	0.000	0.333	0.333	0.333	0.000	0.000	0.000
E	0.778	0.000	0.111	0.000	0.111	0.000	0.000	0.000	0.000

Independent Trials Probability Matrix

	St	Sp	Sr	Sh	Fl	Fm	C	D	E
St	0.000	0.003	0.166	0.158	0.247	0.283	0.087	0.008	0.049
Sp	0.059	0.000	0.156	0.149	0.233	0.267	0.082	0.008	0.046
Sr	0.070	0.003	0.000	0.176	0.276	0.315	0.097	0.009	0.055
Sh	0.069	0.003	0.183	0.000	0.273	0.312	0.096	0.009	0.054
Fl	0.077	0.003	0.203	0.193	0.000	0.347	0.107	0.010	0.060
Fm	0.080	0.003	0.213	0.202	0.317	0.000	0.111	0.010	0.063
C	0.064	0.003	0.170	0.162	0.253	0.290	0.000	0.008	0.050
D	0.059	0.003	0.157	0.149	0.235	0.268	0.082	0.000	0.046
E	0.062	0.003	0.164	0.155	0.244	0.279	0.086	0.008	0.000

Difference Matrix

	St	Sp	Sr	Sh	Fl	Fm	C	D	E
St	0.000	-0.003	0.139	0.364	-0.160	-0.196	-0.087	-0.008	-0.049
Sp	0.941	0.000	-0.156	-0.149	-0.233	-0.267	-0.082	-0.008	-0.046
Sr	-0.037	-0.003	0.000	-0.045	0.200	-0.004	-0.064	0.007	-0.055
Sh	-0.035	-0.003	0.127	0.000	0.003	0.033	-0.079	-0.009	-0.037
Fl	-0.044	-0.003	-0.049	-0.094	0.000	0.148	0.069	0.001	-0.027
Fm	-0.080	-0.003	-0.020	0.067	-0.038	0.000	0.033	-0.001	0.043
C	-0.033	-0.003	-0.139	-0.099	0.184	0.054	0.000	-0.008	0.044
D	-0.059	-0.003	-0.157	0.184	0.099	0.065	-0.082	0.000	-0.046
E	0.716	-0.003	-0.052	-0.155	-0.133	-0.279	-0.086	-0.008	0.000



A1:Total succession preferred sequence

Table A2: Markov Chain Analysis for the Channel Sandstone Deposits.

Transition Count Matrix

	St	Sr	Sh	Fl	E	Total
St	0.000	8.000	10.000	0.000	0.000	18.000
Sr	4.000	0.000	1.000	5.000	0.000	10.000
Sh	1.000	5.000	0.000	0.000	0.000	6.000
Fl	0.000	1.000	0.000	0.000	0.000	1.000
E	11.000	0.000	0.000	0.000	0.000	11.000
						46.000

Transition Probability Matrix

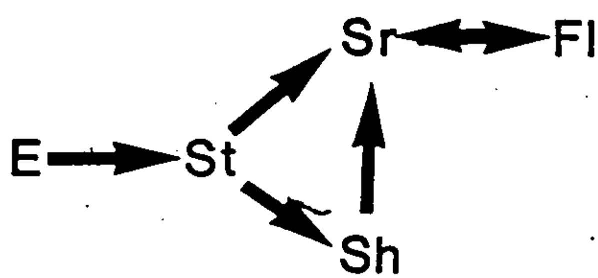
St	0.000	0.444	0.556	0.000	0.000
Sr	0.400	0.000	0.100	0.500	0.000
Sh	0.167	0.833	0.000	0.000	0.000
Fl	0.000	1.000	0.000	0.000	0.000
E	1.000	0.000	0.000	0.000	0.000

Independent Trials Probability Matrix

St	0.000	0.357	0.214	0.036	0.383
Sr	0.500	0.000	0.167	0.028	0.306
Sh	0.450	0.250	0.000	0.025	0.275
Fl	0.400	0.222	0.133	0.000	0.244
E	0.514	0.286	0.171	0.029	0.000

Difference Matrix

St	0.000	0.087	0.341	-0.036	-0.393
Sr	-0.100	0.000	-0.067	0.472	-0.306
Sh	-0.283	0.583	0.000	-0.025	-0.275
Fl	-0.400	0.778	-0.133	0.000	-0.244
E	0.486	-0.286	-0.171	-0.029	0.000



A2:Sandstone facies assemblage preferred sequence.

Table A3; Markov Chain Analysis for the Overbank Deposits.

Transition Count Matrix

	St	Sr	Sh			C	D	E	Total
St	0.000	2.000	4.000	0.000	1.000	0.000	0.000	0.000	7.000
Sr	0.000	0.000	7.000	20.000	21.000	2.000	1.000	0.000	51.000
Sh	3.000	13.000	0.000	23.000	16.000	0.000	0.000	1.000	56.000
Fm	0.000	18.000	26.000	0.000	32.000	14.000	1.000	11.000	102.000
Fl	0.000	12.000	12.000	44.000	0.000	21.000	1.000	2.000	92.000
C	0.000	1.000	2.000	10.000	19.000	0.000	0.000	3.000	35.000
D	0.000	0.000	1.000	1.000	1.000	0.000	0.000	0.000	3.000
E	4.000	2.000	0.000	0.000	1.000	0.000	0.000	0.000	7.000
									353.000

Transition Probability Matrix

St	0.000	0.286	0.571	0.000	0.143	0.000	0.000	0.000
Sr	0.000	0.000	0.137	0.392	0.412	0.039	0.020	0.000
Sh	0.054	0.232	0.000	0.411	0.286	0.000	0.000	0.018
Fm	0.000	0.176	0.255	0.000	0.314	0.137	0.010	0.108
Fl	0.000	0.130	0.130	0.478	0.000	0.228	0.011	0.022
C	0.000	0.029	0.057	0.286	0.543	0.000	0.000	0.086
D	0.000	0.000	0.333	0.333	0.333	0.000	0.000	0.000
E	0.571	0.286	0.000	0.000	0.143	0.000	0.000	0.000

Independant Trials Probability Matrix

	St	Sr	Sh	Fm	Fl	C	D	E
St	0.000	0.147	0.162	0.295	0.266	0.101	0.009	0.020
Sr	0.023	0.000	0.185	0.338	0.305	0.116	0.010	0.023
Sh	0.024	0.172	0.000	0.343	0.310	0.118	0.010	0.024
Fm	0.028	0.203	0.223	0.000	0.367	0.139	0.012	0.028
Fl	0.027	0.195	0.215	0.391	0.000	0.134	0.011	0.027
C	0.022	0.160	0.176	0.321	0.289	0.000	0.009	0.022
D	0.020	0.146	0.160	0.291	0.263	0.100	0.000	0.020
E	0.020	0.147	0.162	0.295	0.266	0.101	0.009	0.000

Difference Matrix

	St	Sr	Sh	Fm	Fl	C	D	E
St	0.000	0.138	0.410	-0.295	-0.123	-0.101	-0.009	-0.020
Sr	-0.023	0.000	-0.048	0.054	0.107	-0.077	0.010	-0.023
Sh	0.030	0.60	0.000	0.067	-0.024	-0.118	-0.010	-0.006
Fm	-0.028	-0.027	0.032	0.000	-0.053	-0.002	-0.002	0.080
Fl	-0.027	-0.065	-0.084	0.087	0.000	0.094	-0.001	-0.005
C	-0.022	-0.132	-0.119	-0.035	0.254	0.000	-0.009	0.064
D	-0.020	-0.146	0.173	0.042	0.070	-0.100	0.000	-0.020
E	0.551	0.138	-0.162	-0.295	-0.123	-0.101	-0.009	0.000

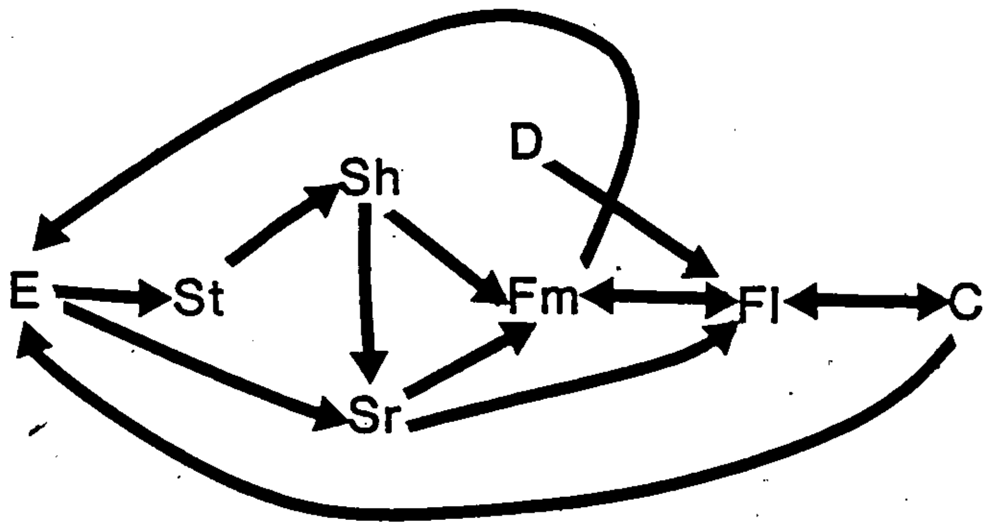
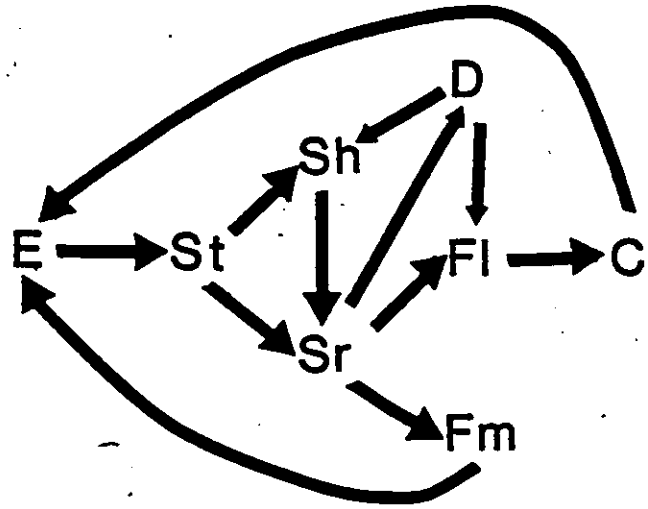
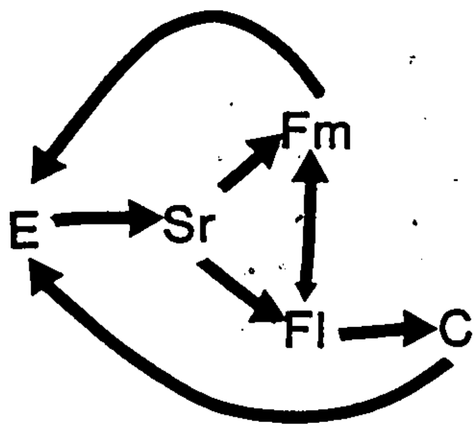


Figure A3:Overbank preferred sequence

Figure A4:



Alternating facies assemblage preferred sequence



Mudstone facies assemblage preferred sequence

Table A4: Tests of Significance (Gingerich, 1969; Harbaugh and Bonham-Carter, 1970).

Total Succession	Gingerich					Harbaugh and Bonham-Carter				
Degrees of Freedom			63					55		
Confidence Limits	90.0	95.0	99.0	99.5	96.9	90.0	95.0	99.0	99.5	96.9
Chi Squared	77.744	82.527	92.021	95.681	103.509	68.794	73.309	82.304	85.783	93.239
Channel Sandstone Deposits										
Degrees of Freedom			15					11		
Confidence Limits	90.0	95.9	99.0	99.5	96.9	90.0	95.0	99.0	99.5	96.9
Chi Squared	22.295	24.986	30.602	32.858	37.839	17.259	19.662	24.752	26.820	31.429
Overbank Deposits										
Degrees of Freedom			48					41		
Confidence Limits	90.0	95.9	99.0	99.5	96.9	90.0	95.0	99.0	99.5	96.9
Chi Squared	60.904	65.168	73.696	77.005	84.114	52.945	56.939	64.964	68.091	74.829

Appendix B

APPENDIX B

Appendix B: Paleocurrent Data Based on Curray's (1956) Analysis of Two-Dimensional Orientation Data.

Calculations:

$$\text{N-S component} = \Sigma n \cos \theta$$

$$\text{E-W component} = \Sigma n \sin \theta$$

$$\tan \bar{\theta} = \frac{\Sigma n \sin \theta}{\Sigma n \cos \theta}$$

$$r = \sqrt{(n \sin \theta)^2 - (n \cos \theta)^2}$$

$$L\% = \frac{r}{\Sigma n} 100$$

$$P = e^{-(L^2 n \times 10^{-4})}$$

where:

θ - azimuth from 0 to 360 of each observation or group of observations.

$\bar{\theta}$ - azimuth of resultant vector.

n - observation vector magnitude or in the case of grouped data of unit vectors, it is the number of observations in each group.

r - magnitude of resultant vector.

L - magnitude of resultant vector in terms of per cent.

P - probability of obtaining a greater amplitude by pure chance combination of random phases.

St facies

	n	$\bar{\theta}$	vector magnitude	probability
a	18	071.8	78.7%	1.4×10^{-5}
b	16	019.5	84.4%	1.1×10^{-5}
c	17	040.5	76.8%	4.4×10^{-5}
d	17	065.8	96.1%	1.5×10^{-7}
e	12	175.5	97.9%	1.0×10^{-5}
f	19	024.3	95.6%	2.9×10^{-8}
g	9	108.2	92.9%	4.2×10^{-4}
h	3	090.5	100.0%	5.0×10^{-2}
i	18	074.0	96.5%	5.3×10^{-8}
j	8	010.5	95.5%	6.8×10^{-4}
k	3	030.5	96.0%	9.7×10^{-1}
l	28	305.6	97.6%	2.6×10^{-12}

channel lineations

m	6	264.4	76.6	9.1×10^{-1}
n	1	170.5	100.0	3.7×10^{-1}
o	1	270.5	100.0	3.7×10^{-1}

channel flute casts

p	5	087.5	71.4	7.8×10^{-2}
q	1	150.5	100.0	3.7×10^{-1}

Sr facies

upper point bar

	n	$\bar{\theta}$	vector magnitude	probability
a	20	015.3	31.1	1.5×10^{-1}
b	4	070.5	33.7	6.4×10^{-1}
c	13	264.2	97.8	4.0×10^{-6}
d	5	310.5	100.0	6.7×10^{-3}

overbank

e	8	270.5	48.5	1.5×10^{-1}
f	6	124.0	94.7	4.6×10^{-3}
g	4	325.7	89.9	3.9×10^{-2}
h	10	209.2	89.7	3.2×10^{-4}
i	1	050.5	100.0	3.7×10^{-1}
j	4	110.5	88.3	4.4×10^{-2}

lineations (primary current)

overbank

k	2	028.5	98.5	1.4×10^{-1}

flute casts

upper point bar

l	1	150.5	100.0	3.7×10^{-1}

overbank

m	2	140.5	98.5	1.4×10^{-1}

Appendix C

APPENDIX C

Appendix C : Petrology

Channel Sandstones

Sample #	A001	A034	A056	A075	A096	A110	A118	A128	K001
biotite	1 %	1 %	2 %	1 %	---	2 %	---	3 %	2 %
muscovite-phlogopite	2 %	1 %	9 %	1 %	1 %	2 %	2 %	5 %	2 %
polycrystalline quartz	2 %	18 %	5 %	10 %	13 %	6 %	11 %	10 %	15 %
monocrystalline quartz	53 %	25 %	48 %	34 %	40 %	32 %	35 %	41 %	38 %
potassium feldspar	---	1 %	2 %	2 %	11 %	6 %	12 %	14 %	9 %
plagioclase	---	---	---	---	---	---	1 %	---	---
calcite	1 %	---	---	---	1 %	6 %	---	2 %	1 %
lithic fragments	20 %	33 %	12 %	20 %	21 %	8 %	24 %	2 %	11 %
clay	24 %	21 %	21 %	31 %	14 %	36 %	14 %	22 %	21 %
accessories	2 %	---	1 %	1 %	---	2 %	1 %	1 %	1 %

Channel Sandstones Continued

Sample #	E010	E013
biotite	4 %	---
muscovite-phlogopite	5 %	11 %
polycrystalline quartz	5 %	3 %
monocrystalline quartz	34 %	37 %
potassium feldspar	15 %	11 %
plagioclase	1 %	1 %
calcite	3 %	10 %
lithic fragments	5 %	1 %
clay	23 %	26 %
accessories	5 %	---

Comments: grains are sub-angular to sub-rounded;
sub-parallelism of elongate grains corresponding to bedding planes;
poor sorting;
grain size is less than .75 mm;
mean grain size .5 mm;

Overbank Deposits

Sample #	A004	A004A	A014	A015	A021	A044	A044A	A053
clay - calcitic	10-15 %	10-15 %	---	5 %	5 %	25 %	30 %	20 %
micritic	30 %	30 %	---	30-40 %	20 %	15 %	5 %	20 %
organics and opaques	10-15 %	20 %	20 %	13 %	20%	5 %	3-5 %	15 %
potassium feldspar	5 %	5 %	10-15 %	5 %	10-15 %	10 %	5 %	---
polycrystalline quartz	---	---	---	5 %	---	5 %	---	5 %
monocrystalline quartz	30 %	30 %	30 %	30 %	35 %	30 %	30 %	30 %
muscovite-phlogopite	5-10 %	10 %	---	5 %	5 %	5 %	---	5 %
biotite	x---	---	---	---	*		---	3 %
chlorite	1 %	3 %	---	2 %	*	5 %	---	2 %
phosphate	---	---	---	---	---	*	---	---
accessories	1 %	*	---	*	---	*	---	*

* denotes presence

(N.B. all are visual estimates)

Overbank Deposits Continued

Sample #	A056	A087	A097	A105	A130	A131	A139	B010
clay - calcitic	20 %	12 %	20 %	30 %	---	5 %	10 %	20 %
sericitic	10 %	20 %	15 %	10 %	40 %	5 %	20 %	5-10 %
organics and opaques	12 %	8 %	*	12 %	20-30 %	15 %	5 %	10 %
potassium feldspar	5 %	5 %	10 %	5 %	5 %	30 %	20 %	10 %
polycrystalline quartz	---	---	---	---	---	---	*	---
monocrystalline quartz	30 %	35 %	40 %	30 %	25 %	30 %	30 %	30 %
muscovite-phlogopite	15 %	10 %	10 %	10 %	5-10 %	15 %	5 %	20 %
biotite	5 %	5 %	3 %			---	3 %	---
chlorite	3 %	5 %	*	2 %	2 %	---	3 %	---
phosphate	---	---	3 %	*	---	---	3 %	---
accessories	*	*	*	*	*	*	*	*

Overbank Deposits Continued

Sample #	B015	B016	C001
clay - calcitic	10 %	10 %	10 %
sericitic	20 %	15 %	25 %
organics and opaques	13 %	10 %	10 %
potassium feldspar	5 %	10 %	5 %
polycrystalline quartz	---	---	5 %
monocrystalline quartz	35 %	35 %	35 %
muscovite-phlogopite	15 %	20 %	10 %
biotite	---	*	*
chlorite	2 %	*	*
phosphate	---	2 %	---
accessories	*	*	*

Comments: grains are sub-angular to sub-rounded, occasionally rounded;
sub-parallelism of elongate grains corresponding to bedding/lamination planes;
moderate sorting;
grain size is less than .075 mm to clay size;
mean grain size .02 mm;

Source Rocks

S001 - Cambrian granodiorite

quartz	35 %
potassium feldspar	10 %
pyroxene	20 %
plagioclase	15 %
sericite	5 %
accessories (zircon)	1 %

pegmatitic grains

S002 - McAdam Lake Formation

quartz	30 %
biotite	25 %
chlorite	10 %
sericite	5 %
muscovite	5 %
chert	
plagioclase	5 %
calcite	
ground mass	20 %

fine grained

arkose

S003 - McAdam Lake Formation

quartz	30 %
biotite	10 %
chlorite	5 %
sericite	15 %
muscovite	5 %
plagioclase	5 %
clasts- chert, sandstone, calcite	30 %

very coarse grained

conglomerate

S004 - George River Group

chalcedony	20 %
calcite grains	10 %
calcite cement	65 %
opaques	5 %

medium to coarse grained

calc-silicate

S005 - Bourinot Group

ground mass	65 %
plagioclase	10 %
potassium feldspar	5 %
quartz	5 %
glass shards	5 %
pyroxene (?)	5 %
accessories	5 %

fine to coarse grains in a very fine groundmass

rhyolite

S007 - Windsor Group

clay	20 %
oolites	60 %
calcite	20 %

lime mudstone

Source Rocks Continued

S008 - Windsor Group

calcitic clay	70 %
calcite	20 %
fossil fragments	5 %
oolites	5 %

limestone

S009 - PreCambrian granite

quartz	45 %
pyroxene	15 %
plagioclase	15 %
potassium feldspar	10 %
chlorite	5 %
sericite	10 %

pegmatitic grains

S010 - Cambrian diabase

plagioclase	45 %
pyroxene	35 %
alteration sericite chlorite	20 %

medium grained
diabasic texture

S011 - Cambrian granitoid

plagioclase	20 %
quartz	35 %
muscovite	5 %
chlorite	5 %
sericite	15 %
potassium feldspar	25 %

coarse to fine grained

S012 - George River Group

extremely fine grained
clay-size

slate

S013 - George River Group

quartz	20 %
calcite	70 %
chlorite biotite	10 %

coarse grained
homogeneous

marble

S014 - Fisset Brook Formation

quartz	20 %
potassium feldspar	15 %
clay	40 %
muscovite	15 %
biotite	5 %
clay clasts	5 %

very fine grained to
silt size

siltstone

S015 - Forchu Group

quartz	20 %
plagioclase	45 %
pyroxene	25 %
biotite chlorite	10 %

parallelism of elongate
grains

schist

Source Rocks Continued

S016 - Fisset Brook Formation

quartz	90 %
sericite	10 %

very fine grained
massive

siltstone

S017 - Cambrian Irish Cove Pluton

quartz	35 %
pyroxene (altered)	40 %
plagioclase (altered)	15 %
chlorite	5 %
accessories	5 %

very coarse grained

granite

S018 - Cambrian Loch Lomond Pluton

see Irish Cove Pluton

S019 - Loch Lomond Rhyolite Porphyry

ground mass	70 %
coarse grains	
potassium feldspar	
quartz	
pyroxene	
plagioclase	30 %

coarse grains in a very fine ground mass

S020 - Riversdale Group

clay	70 %
potassium feldspar	20 %
quartz	10 %

very fine grained
massive

siltstone

S021 - Horton Group

quartz	65 %
potassium feldspar	15 %
plagioclase	10 %
accessories	10 %
altered pyroxene	
apatite	
zircon	
hematite coatings	

coarse grains in a fine grained matrix

conglomerate

Source Rocks Continued

S022 - PreCambrian Basement Complex

quartz	40-50 %
biotite	20 %
chlorite	10 %
plagioclase	10-15 %
potassium feldspar	0-10 %
sericite	5-10 %

medium grained (fine to coarse)
banded

schist to gneiss