



National Library of Canada
Collections Development Branch

Canadian Theses on
Microfiche Service

Bibliothèque nationale du Canada
Direction du développement des collections

Service des thèses canadiennes
sur microfiche

NOTICE

AVIS

The quality of this microfiche is heavily dependent upon the quality of the original thesis submitted for microfilming. Every effort has been made to ensure the highest quality of reproduction possible.

If pages are missing, contact the university which granted the degree.

Some pages may have indistinct print especially if the original pages were typed with a poor typewriter ribbon or if the university sent us a poor photocopy.

Previously copyrighted materials (journal articles, published tests, etc.) are not filmed.

Reproduction in full or in part of this film is governed by the Canadian Copyright Act, R.S.C. 1970, c. C-30. Please read the authorization forms which accompany this thesis.

**THIS DISSERTATION
HAS BEEN MICROFILMED
EXACTLY AS RECEIVED**

La qualité de cette microfiche dépend grandement de la qualité de la thèse soumise au microfilmage. Nous avons tout fait pour assurer une qualité supérieure de reproduction.

S'il manque des pages, veuillez communiquer avec l'université qui a conféré le grade.

La qualité d'impression de certaines pages peut laisser à désirer, surtout si les pages originales ont été dactylographiées à l'aide d'un ruban usé ou si l'université nous a fait parvenir une photocopie de mauvaise qualité.

Les documents qui font déjà l'objet d'un droit d'auteur (articles de revue, examens publiés, etc.) ne sont pas microfilmés.

La reproduction, même partielle, de ce microfilm est soumise à la Loi canadienne sur le droit d'auteur, SRC 1970, c. C-30. Veuillez prendre connaissance des formules d'autorisation qui accompagnent cette thèse.

**LA THÈSE A ÉTÉ
MICROFILMÉE TELLE QUE
NOUS L'AVONS REÇUE**

SEDIMENTOLOGY OF THE CLIFTON FORMATION
(UPPER CARBONIFEROUS)
OF NORTHERN NEW BRUNSWICK:
A SEMI-ARID DEPOSITIONAL SETTING
FOR COAL

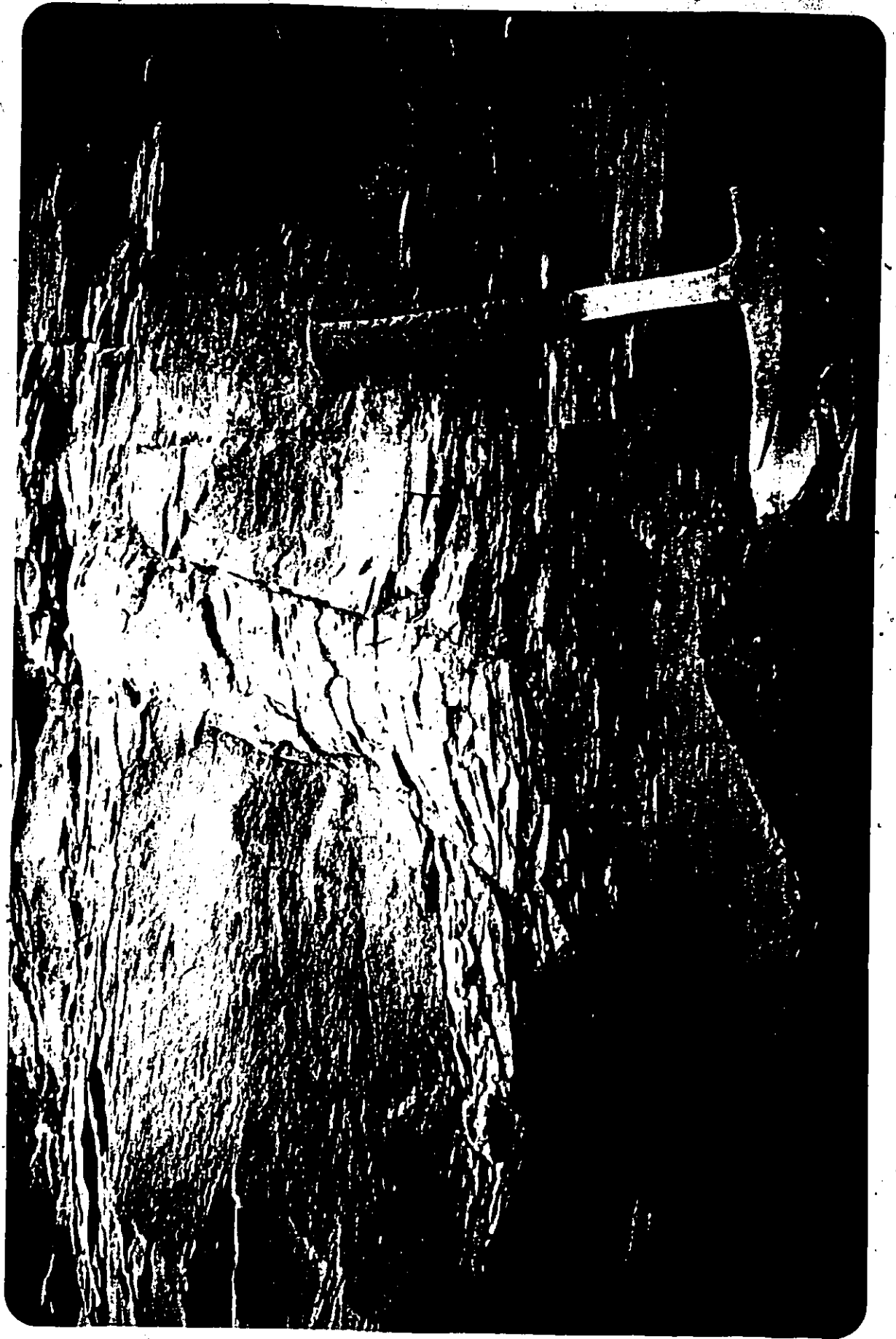
A thesis
presented to the
School of Graduate Studies
in partial fulfillment of the
requirements for the
M.Sc. degree in Geology

BY
ANDREW S. LEGUN

University of Ottawa
Ottawa Canada 1980



UNIVERSITÉ D'OTTAWA
UNIVERSITY OF OTTAWA



FRONTISPIECE.

Tree trunk cast enclosed in crevasse splay sandstone. Note shale at base and top of cast.

7

ABSTRACT

Members A and B of the Clifton Formation (Westphalian C-D age, Pictou Group) exposed along the south Chaleur Bay coast between Clifton and Caraquet, New Brunswick, are interpreted as the deposits of a semi-arid alluvial plain.

The flood basin sediments of Clifton Member A record flood cycles similar to interdistributary bay fills of delta plains, followed by progradation of channel sands (Clifton Member B). However, the plain was alluvial rather than deltaic because:

- 1) there is no evidence of marine influence; and
- 2) it was subjected to long periods of emergence and sediment denial marked by a variety of caliche features in seat earths and other facies.

Eventual subsidence of abandoned crevasse/distributary sandstone lobes of each flood cycle in Clifton Member A is marked by thin carbonaceous laminae or thin coals capping seat earth profiles, many of which reflect a rising water table. Paleocurrents show less variation than might be expected for stratigraphically distinct crevasse splay deposits. Consistency of paleocurrent direction is probably due to low levées and extensive overbank flooding, with sheet floods moving down the regional paleoslope.

Coals in Clifton Member A did not reach commercial thickness because of the semi-arid climate, and because the rate

of water rise during flooding of extensive shallow basins limited the thickness of peat accumulation.

In Clifton Member B, abundant channel shiftings into overbank areas resulted in the dispersal of peat mats and the incorporation of a large quantity of transported plant litter as coal spar in the sandstones.

This style of alluvial sedimentation has not been previously recognised in ancient successions. Possible modern analogues are the extensive floodplain of the Lake Eyre Basin in Central Australia, and the Okavango River in South Central Africa.

TABLE OF CONTENTSPage

LOCATION, ACCESS, PREVIOUS WORK	1
METHODS OF STUDY - OUTLINE OF WORK DONE	6
STRATIGRAPHY	
Chaleur Bay Coast	8
Clifton to New Bandon - Measured Sections	11
FACIES ANALYSIS OF CLIFTON FORMATION MEMBER A	
Facies States	12
Facies Descriptions	13
Geometric Elements	16
Facies Changes (Markov Chain Statistics)	16
PALEOCURRENTS (CLIFTON MEMBERS A AND B)	23
NATURE OF SANDBODIES OF CLIFTON FORMATION MEMBER A	
Thin Sandbodies	26
Lateral Accretion Sandbody	27
Thick Sandbody	27
NATURE OF SEAT EARTHS OF CLIFTON FORMATION MEMBER A	
Introduction	29
Paleosol Caliche	29
Leached Paleosol	32
Lateral Variation in Seat Earths	33
Caliche Features in Other Facies	34

CLIFTON MEMBER B.

Facies States	37
Facies Descriptions	37
Nature of Sandbodies	39
Nature of Intraformational Conglomerate	41

DEPOSITIONAL RELATIONSHIPS OF CLIFTON MEMBER A, B.

Contrasts	43
Depositional Constraints	44
Crevasse Splays and Channels - A Discussion	44
Possible Model for the Depositional Geometry of Clifton Member A	59

COAL.

Prerequisites for Deposition of Peat	62
Prerequisites as Related to Depositional Environment of Member A and B	62

CONCLUSIONS.

69

ACKNOWLEDGEMENTS.

88

REFERENCES CITED.

89

APPENDICES.

93

- I Petrographic Data of Three Sandstones
based on Representative Hand Specimens.
- II Report on the Thin Section Analysis of
Samples from Point Caplin (A.D.I. 1974)

93

94

LIST OF FIGURES.

1. Location of surface and subsurface geological data: Clifton to Caraquet, Chaleur Bay Coast, Northern New Brunswick.	2
2. Age and stratigraphic correlation of Upper Carboniferous sediments in New Brunswick based on plant and miospore data.	5
3. Sandbody stratigraphy of the Clifton Formation along the Chaleur Bay Coast.	9
4. Markov chain statistics of measured sections, upper part of Member A, Clifton Formation: transition count matrix	19
transition probability matrix	19
5. Markov chain statistics of measured sections, upper part of Member A, Clifton Formation: independent trials matrix	20
residual probability matrix	20
6. Path diagram of observed facies relationships, upper part of Member A, Clifton Formation.	21
7. Path diagram of preferred facies relationships, upper part of Member A, Clifton Formation.	21
8. Facies model for upper part of Member A, Clifton Formation, depicting a flood cycle.	22
9. Paleocurrents of the Clifton Formation.	25
10. Single channel crevasse splay in the Brahmaputra River (after Coleman, 1969).	46
11. Multichannel crevasse splay in the Brahmaputra River (after Coleman, 1969).	46
12. Shoal water sub-delta of the Mississippi River (after Gagliano and van Beek, 1970).	46
13. Interdistributary bay sedimentation model (modified after Elliot, 1974).	48
14. Model of crevasse/distributary sedimentation.	55
15. The Okavango Delta (after Johnson and Bannister, 1977).	58
16. A possible model for the depositional geometry of Clifton Member A.	60
17. Late Carboniferous (Westphalian CD) paleogeography (after Scotese et al., 1979).	64
18. Composite Section Clifton Formation Member A.	fold-out in back pocket

LIST OF PHOTOGRAPHS.

1. Clifton Formation. Member A overlain by Member B.	73
2. Large shallow troughs of facies St.	73
3. Bedding plane exposure of coal spar.	73
4a. Facies Sr.	74
4b. Facies Sr: climbing ripples with heavy suspension drape.	74

5. Facies Sr: "rib and furrow" current structure.	74
6. Caliche encrusted vertical fissure in facies Sr.	75
7. Close-up of fissure in photo 6.	75
8. Composite sheet sandstones with tree trunk casts.	76
9. Close-up of tree trunk cast in photo 8.	76
10. Stigmara.	76
11. Mottled seat earth of facies Fr.	77
12. Caliche hardpan; seat earth, coal, sandstone succession.	77
13. Thick sandbody of Clifton Member A.	77
14. Thick sandbody of Clifton Member A: incised channel edge.	78
15a. View of Section I from Section J.	78
15b. Close-up of headland sandbody in photo 15a.	78
16. Clifton Formation, Member B overlying Member A.	79
17-20. Meandering channel deposits.	80
21-23. Lateral variation in the deposits of a crevasse splay or distributary lobe.	81
24. Thick sandbody of Clifton Member A: pinnacle of red shale at base.	82
25. Parting lineation.	82
26. Caliche intraclasts as lag deposit.	82
27. Caliche microstructure: soil peds and crystallaria.	83
28. Caliche hardpan nodule with embedded pebbles indicating sub-aerial exposure.	83
29. Caliche hardpan and adjoining vertical wedge (fallen block).	84
30. Outline of exposed vertical wedge (in situ).	84
31. Facies St of Clifton Member B.	85
32. Outline of large channel in grey sandstones of Member B.	85
33a. Large abandoned channel fill in Clifton B.	85
33b. Close-up of base of channel fill in photo 33a.	85
34. Intraformational conglomerate consisting of caliche fragments.	86
35. Sculptured coastline of Member B.	86
36. Discontinuous thin coals enclosed in Clifton Member B.	86
37. Lepidodendron stem.	87
38. Lepidodendron stem with needle-like foliage.	87
39. Lepidodendron needles; current aligned.	87

LOCATION; ACCESS, PREVIOUS WORK.

The area of study is located in northern New Brunswick, east of the city of Bathurst, along the Chaleur Bay coast between Clifton and Caraquet (refer to map fig. 1). Road access is by Highway 11 which skirts the coast. Short public side roads lead down to the shore (usually to a boat launching area) from communities en route.

The sediments of this study are Westphalian C in age (Barss and Macquebard 1967) and belong to the Pictou Group, which underlies much of eastern New Brunswick and constitutes the top of the New Brunswick "platform". The base of the New Brunswick platform lies on deeply weathered Devonian granite along the Nepisiguit River immediately south of Bathurst. East of Bathurst these Upper Carboniferous rocks are first exposed at Salmon Beach in a 2m bluff. Exposure improves east of Cranberry Cape and is best developed between Clifton and New Bandon where steep bluffs rise to 40m above the sea. At New Bandon vertical cliffs develop (sandstone dominance) and from there to Grande Anse the coastline is sculptured into islets, jutting headlands and undercut coves. Relief diminishes eastward from New Bandon. By Anse Bleu the bluffs rise barely above high tide. Cliffs reappear at Haut Caraquet on the south side of Caraquet Bay.

Chaleur Bay provides the best exposure of the Pictou Group in northern New Brunswick. Nevertheless these coastal

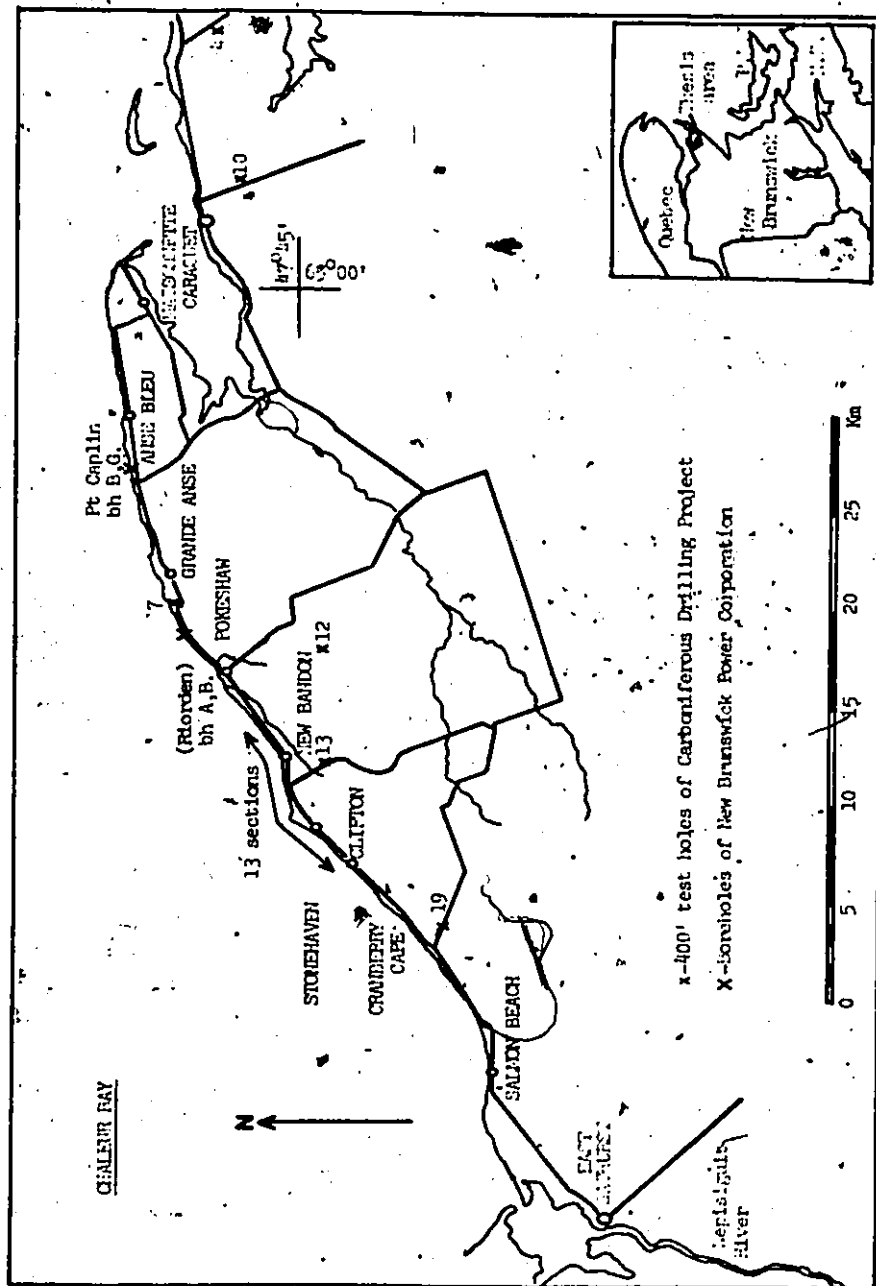


FIG. 1. LOCATION OF SURFACE AND SUBSURFACE GEOLOGICAL DATA: CLIPTON TO CARACET, CHALEUR BAY COAST, NORTHERN NEW BRUNSWICK.

exposures have not been studied in detail. Alcock (1935) divided the coastal sediments east of Bathurst into the Bathurst and Clifton Formations. The grey sandstones of the Clifton gradually succeed the red sandstones and shales of the Bathurst. East of Caraquet the grey beds themselves are gradually succeeded by purple sandstones, shales, and conglomerates. The sediments dip very gently NE along the coast and Alcock estimated a total thickness of about 230m. McAlary (1952) in an unpublished thesis dealt with the same formations inland, south of the coast and east of the Nepisiguit River. He suggested a fresh-water origin for both and the presence of a basin deepening eastward. Barss and Hacquebard (1967); Barss (1979, personal communication) provided dates on the rocks based on spore contents. The Bathurst extends back at least to Namurian C, whereas the overlying Clifton Formation is Westphalian C to Stephanian.

Van de Poll (1973) in a basin analysis of the entire New Brunswick platform divided the Pictou into major fluvial cycles, each hundreds of metres thick, each cycle consisting of a red and grey megafacies. Climate was seen as a major depositional factor, wet periods being responsible for the grey channel dominated facies (sandstones) and dry periods for the overbank dominated red facies (shales). The writer's area of study straddles the change from red megafacies (top of cycle I) to grey megafacies (bottom of cycle II) of van de Poll (1973). Alcock (1935) and

McAlary (1952) commented on calcareous zones within these sediments but Rast of ADI (1974) was the first to identify them as caliche, a pedologic indication of semi-arid conditions. Coastal occurrences of coal are noted in the Carboniferous compilation report of Ball and Gemmell (1975). The best known occurrence is a thin seam at Clifton. In the shales immediately below it are numerous well preserved plant remains. They have been classified and described in detail by Bell (1962).

The New Brunswick Department of Natural Resources is presently completing a geologic compilation of the Pictou Group in northern New Brunswick. Part of the Bathurst Formation has been assigned to the Clifton on the basis of spore dating*. This includes all coastal exposures east of Bathurst up to New Bandon. They constitute Clifton Member A. At New Bandon the succeeding grey sandstones constitute Clifton Member B. The redefined Bathurst rocks, a triangular area adjacent to the Nepisiguit River, are pre-Pictou. The Bathurst Formation has been correlated through a basal conglomeratic outlier near the mouth of Millstream River (12km NNW of Bathurst) with the Bonaventure Formation (Alcock, 1935).

Miospore correlation of these units with others of the Carboniferous in New Brunswick is shown in fig. 2 (Ball, 1979, personal communication).

*This is invalid: a Formation is defined on the basis of mapability and visually discernible upper and lower contacts.

Age	Group	Megaflora Zone	Miospore Zone	Northern N.B.	Central N.B.	Southeastern N.B.
Pennsylvanian	Permian		Vittatina Spore Zone E	C	Richibucto Fm.	Tormentine Fm.
	Stephanian		Potonileisporites Spore Zone D			
	Westphalian D	Pictou Group	Ptychocarpus unitas	Clifton Fm.	Scoudouc Fm.	Scoudouc Fm.
	Westphalian C		Linopteris obliqua	A	Sudbury Creek Fm. Hirley Cr. Fm.	Salisbury Fm.
	Westphalian B	Amberland Group	Lonchopteris		Minto Fm. Upper Lower	Ross Fm.
	Westphalian A	Riversdale Group		Bathurst Fm.	Newcastle Creek Fm.	
	Namurian C					
	Namurian B					
	Namurian A					

FIGURE 2. AGE AND STRATIGRAPHIC CORRELATION OF UPPER CARBONIFEROUS SEDIMENTS IN NEW BRUNSWICK BASED ON PLANT AND MIOSPORE DATA (after Ball, personal communication 1979, *fidé Basse*).

METHODS OF STUDY - OUTLINE OF WORK DONE.

Between Clifton and New Bandon 13 sections within Clifton Member A were measured, sampled, described, photographed and correlated laterally. Vertical sandstone cliffs precluded extending sections more than 10m vertically into Member B. Sedimentary facies were identified and attention paid to their spatial organisation (lateral and vertical) for each facies is exposed for hundreds of metres (much of it inaccessible) before it passes out of section. The low coastal dip also allowed an assessment of sandbody shape, dimensions and internal structure.

Paleocurrent measurements were taken on most of the rocky shelves that are exposed at low tide between Clifton and Caraquet. It was hoped that paleocurrents would reveal how the coastline was sectioning the sandbodies (transversely or longitudinally) as well as constraining their possible mode of origin.

Available drill core and logs were examined in order to extrapolate the known stratigraphy laterally and vertically and to understand the nature of the sandbody transition from Clifton Member A to B. Drill core included solid core from nuclear site investigations at Riorden, Point Caplin, Cape Play (partially intact at Mataquac dam site near St. John's) and core present as chips (10ft. represented by a 5cm vial) for testholes 19, 10, 7 of the Carboniferous drilling project (Fig. 1).

Supplemented by thin section petrographic examination, XRD mineral identification, analysis of paleocurrents and facies (Markov chain statistics) interpretations were made and the environment of deposition deduced for Clifton Members A and B. The relationship between Members A and B was explored in the context of:

- 1) similarities and contrasts
- 2) depositional constraints
- 3) a discussion on crevasse splay - channel associations
- 4) a possible model for the depositional geometry

Member A

The formation of coal was discussed in light of the prerequisites of its formation and the interpreted depositional environment of Clifton Members A and B.

STRATIGRAPHY:

Chaleur Bay Coast

As testholes 7, 10 and 19 are chip samples, which only provide lithological data, Fig. 3 shows the coastal stratigraphy in terms of sand body distribution. In Clifton Member A, carbonaceous laminae and thin coal seams traceable for hundreds of metres (in some cases kilometres) were used to determine the coastal dip. The grey sandstones of Member B provided no markers but the basal contact can be followed to testhole 7 near Grande Anse. Eighty metres of Clifton A section were measured between Clifton and New Bandon (8km). This gives an average dip of about 0.5° . Thirty-eight metres of Clifton Member B are exposed between New Bandon and testhole 7 (7km). Caraquet, well to the east of testhole 7, appears, surprisingly, to be at about the same stratigraphic level as testhole 7. Broadly speaking, Clifton Member A is dominated by reddish and multi-coloured shales (silt-clay size) that can be limey and often bear traces of coal. These alternate with sandstones that are thicker nearing the contact, and perhaps more lithic. The lithic material includes coal stringers and spar.

The contact with Member B is marked by olive-grey stacked sandstone units. Shales intercalate in places above the contact, but are usually thin and grey. Intraformational conglomerates include fragments of coal spar, limestone and

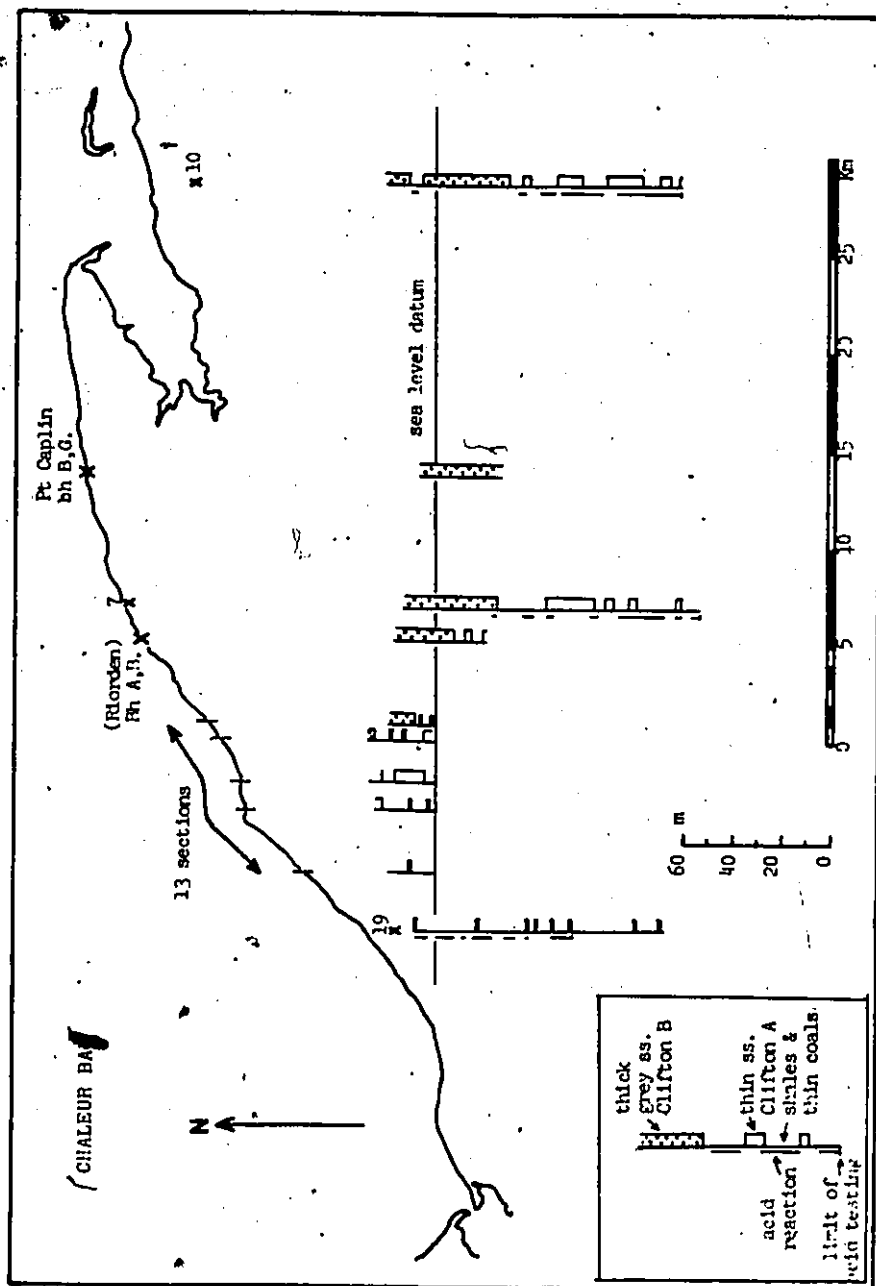


FIG. 3. GEOLOGICAL STRATIGRAPHY OF THE CLIFTON BAY. ALONG THE CHALEUR BAY COAST. STRATIGRAPHY BASED ON CONTACT AND SURFACE DATA. THERE IS A 5-15m RISE IN SECTION PER KM ALONG THE COAST.

shale. The transition is also marked by a decrease in calcareous content. The chip samples were well suited for testing gross changes in calcareous content. A small portion of the chips was placed in a crucible and cold dilute HCl added. Any bubbling was considered a positive reaction. The results are depicted alongside some of the sections in fig. 3.

Although considerably inland (25km SSW of Clifton) a 290m hole drilled to basement by Jowsey Ltd in 1961 at Allardville, New Brunswick, could have provided much stratigraphic detail. Unfortunately, the core has been destroyed and the log is difficult to decipher. Incoherent mottled conglomerates within shales are figured by question marks in the logger's description. They are interpreted here as limey concretionary zones similar to those observed in coastal exposures. These reddish and mottled shales are dominant in the core. Sandstone units are thin (less than 3m) and comprise only about 10-15% of the lithologies. Below 240m, quartz pebble conglomerate is present and sandstone increases. The basement is metamorphic: chloritic schist below a basal breccia.

According to van de Poll's division of the Pictou into megafacies, the grey megafacies of cycle I should be present in the core underlying the red megafacies of cycle I. In the Allardville log, however, fine grained reddish clastics are dominant down to the basement. The grey megafacies is not present. Furthermore, the change from cycle I red to cycle

II grey in drill core along the coast reflects an overall upward coarsening. This contrasts somewhat with van de Poll's basinwide observations that conglomerate at the base of the grey megafacies marks the beginning of each cycle.

Spores from testhole 4 south of Lower Caraquez indicate a Westphalian D age (Thymospora spore zone, Barss 1979, personal communication). The age of the sediments from Clifton to Caraquez thus extends from Late Westphalian to not younger than Westphalian D.

Clifton to New Bandon - Measured Sections.

The 13 measured sections consist of the upper part of Clifton Member A and its transition to Member B. The important stratigraphic elements are as follows: (photo 1)

(upsection)		
	Member B	
New Bandon		grey ss. bodies
		thin ss. bodies, red shales, seat earths
Stonehaven	A	thick ss. body
	Member	thin ss. bodies, red shales, seat earths
Clifton		thin grey ss. bodies, grey shales, coal, seat earths.

These stratigraphic elements can all be understood in terms of varying dominance within a single set of facies types. This bespeaks the continuity of sedimentary processes within the succession. The facies are defined and described below.

FACIES ANALYSIS OF CLIFTON FORMATION MEMBER A.

Facies States.

A facies is a body of rock with specified characteristics, and as such should be readily distinguishable from other rock bodies. It should ideally reflect a particular process or environment of sedimentation (Reading, 1978). Facies at Clifton Member A were readily discerned and include:

- St trough cross-bedded sandstone
- Sr ripple cross-laminated sandstone
- F1 alternating beds of sandstone and shale
- Fsc mudshales

Fsc(r)

Fr seat earths

Fr(C)

C carbonaceous laminae, thin coals

The symbols are after Miall (1978) with addition of subfacies Fsc(r) and Fr(C) that are transitional (Fsc to Fr, and Fr to C, respectively)...

Sandstones less than 1m thick in shales were considered as facies F1. One metre was chosen as it is about the lower boundary for an inchannel deposit (Collinson, 1978). However, this might not be true for very broad shallow streams (Steel, 1978).

Facies Descriptions.

St consists of trough cross-bedded sandstones of medium to coarse sand grade that occasionally react to acid. This facies prevails in the thick sandstone body and is present in the thicker parts of thin sandbodies otherwise dominated by Sr. Exposed troughs are shallow (photo 2). Width/depth ratios vary from a few dm x cm to a maximum measured size of 15m x 1m. Basal contact is shallow erosional scours in the thin sandstone bodies while the thick sandstone body is deeply incised. Set size has a tendency to decrease upwards. Plant material can be present as coal spar littering bedding plane surfaces. In one case this appears to be due to scour erosion into a laterally adjacent coal seam (photo 3).

Sr consists of light bluish grey ripple cross-laminated sandstones of fine grade that effervesce slightly in acid. Low angle climbing ripples are very common (photos 4,5). This facies occurs as single or composite sand sheets up to several metres in thickness. Composite sandsheets are separated by mud drapes. The basal contact is either 1) sharp; 2) planar erosive with chips of underlying muds; or 3) marked by rapid coarsening upwards from climbing-ripple lamination with laminae in-phase. The fine sandstones of this facies are locally penetrated by the calcified remains of ancient root systems with typical downward forking. Calcareous crusts are present on the surfaces of

vertical cracks that can be a metre or more deep (photos 6, 7). Plant debris is not common. It is evidenced by plant impressions rather than by organic remains (carbon films, etc). This facies grades laterally and vertically to:

- Fl, consisting of alternating beds of red and grey mudshale, siltshale and sandstone. The sandstones display climbing ripples and commonly root features. Tree trunk casts as well as stigmata were observed at two different stratigraphic levels (photos 8,9,10). Calcareous concretions are locally abundant.

- Fsc, consisting of laminated red muds and clays. This facies is without current bedding. It is fissile to blocky, highly fractured and easily dislodged from slopes as a shower of fragments. In places, small root traces and isolated plant debris (eg fern pinnules) are present. At Clifton, these shales are vertically dissected by bluish calcareous sheets and wedges. Small scale dessication features such as mudcracks (diligently sought) were not found.

This facies overlies and underlies thin sandstone bodies. Where overlying, it shows vertical development into:

- Fr, consisting of mottled seat earths of many colours (blue, yellow, green, ochre, brown, light grey). Seat earths are crumbly and clayey in texture. The mottling suggests an organic webbing or boxwork (root network?)(photo 11).

Associated with it are calcareous nodular layers with individual nodules up to 8cm in diameter. These nodules are sparse to abundant, can exhibit size grading, rarely form a semi-continuous layer within the seat earth and in one case a hardpan surface. The upper portion of many seat earths is represented by a grey-green stiff clay without boxwork or nodules (subfacies Fr(C)).

The above facies is commonly overlain by:

C consisting of carbonaceous clay laminae and thin coals. Carbonaceous clay laminae are very thin (a centimetre or so) and remarkably continuous. Being rather impermeable they are traceable as seepage lines along the coast until they pass out of section. Occasionally they thicken into thin coals a few centimetres thick.

The thickest coals are found at Clifton (2 coal seams 30cm and 10cm thick). Sediments immediately underlying are grey earths and plant-bearing underclay (subfacies Fr(C)). The lowest coal is 1.5m above the continuous calcareous hardpan (photo 12).

In summary, the thick sandstone body is deeply incised and dominated by facies St. Thin sandstone bodies of shallow erosional to rapidly gradational basal contact dominated by facies Sr and Fl are underlain and overlain by facies Fsc. Overlying facies Fsc grades into calcareous seat earths (Fr) which are commonly capped by carbonaceous laminae or thin coals.

Geometric Elements.

The thick sandstone body (photo 13; see also section F in fold-out) which is up to 12m thick, has a channel edge deeply incised (photo 14). The thinner sandbodies (4m or less) wedge out laterally over hundreds or thousands of metres and pass by intercalation into red mudshales. Where the sandbodies are thickest an internal channel outline may be present, associated with trough cross-bedding and minor basal erosion (photo 15; base of section C, I in fold-out). Adjacent thin sandbodies separated by mudstones have the same base. In some cases it appears sheet sandstones of laterally adjacent sandbodies interfinger. Top surfaces can be undulating and marked by active and inactive channel fills of narrow (10m) to wide (200m) cross-section. One such inactive channel-fill shows a seat earth profile thicker than that outside the channel (photo 16; near base of section B in fold-out).

One sandbody is marked by a channel edge followed by mud-draped internal lateral accretion surfaces. These abruptly end against sandstones that wedge out, intercalating with mudshales and siltstones. This sandbody is much narrower than usual and relatively thick (4m) (photos 17-20; section I in fold-out).

Facies Changes.

A Markov chain analysis* was done on the vertical facies

*method after Miall (1977).

distribution in Member A. Data from borehole A Riorden were included with that of the 13 measured sections. The grey colour of some of the beds at Clifton was ignored in assigning a facies state. As noted before, the division between Sr and Fl is rather arbitrary. Subfacies Fsc(r) is included in the analysis as it is stratigraphically distinct from facies Fsc.

The transition count matrix and the transition probability matrix are presented in fig. 4. Facies relationships are shown in a probability path diagram of observed facies relationships (fig. 6). One can note that the path tends to be one way, ie that the development of one facies is strongly dependent on the deposition of a previous facies. A sandstone body is almost invariably involved in each cycle.

To separate the random element of facies transitions, an independent trials matrix was constructed and subtracted from the transition probability matrix. Residual probabilities greater than 0.1 are underlined in fig. 5, and shown in a path diagram of preferred relationships, fig. 7. The preferred relationships together with average thickness of the facies are used to model a cyclothem (fig. 8).

The cyclothem (ie a repeating vertical package of facies transitions) is interpreted as a flood cycle spanning thousands of years. The cycle begins with quiet water sedimentation followed by the rather sudden incursion of

flood sheet sands. These floods eventually wane, emergence follows and a soil develops. Subsidence overtakes sedimentation (ie submergence) and a thin swamp deposit forms. The cycle repeats itself.

A lateral facies analysis demonstrates few changes along any stratigraphic level. Those that occur are as follows.

Sr (thins or splits) $\rightarrow$ Fl $\rightarrow$ Fsc

Fl $\rightarrow$ Fsc $\rightarrow$ Fl

Fr $\rightarrow$ Fsc(r) $\rightarrow$ Fr

In other words, the sheet sandstones wedge out into red mudshales and the seat earth thins or thickens.

A lateral and vertical facies analysis can serve as a guide for extrapolating between sections and revealing the depositional geometry of Member A.

Such a composite section of Member A is enclosed as a fold-out at the back of this report. The reader is referred to it as a quick key to the essential aspects of this study.

It shows 1) a sequence of cyclothems of low lateral variability, and 2) bounding elements and internal aspects of the sandstone bodies. Together with paleocurrent data, interrelationships of various factors are revealed.

TRANSITION COUNT MATRIX

	Fsc	Sr	Fl	Fsc (r)	Fr	C	St	Totals
Fsc	0	10	8	2	0	0	0	20
Sr	0	0	11	4	0	0	2	17
Fl	4	5	0	13	5	16	2	30
Fsc (r)	1	0	2	0	14	5	1	23
Fr	1	0	2	0	0	16	2	21
C	16	0	3	1	1	0	0	21
St	0	2	2	0	0	0	0	4
Totals	22	17	28	20	20	22	7	

TRANSITION PROBABILITY MATRIX

	Fsc	Sr	Fl	Fsc (r)	Fr	C	St
Fsc	0	0.5	0.4	0.1	0	0	0
Sr	0	0	0.65	0.24	0	0	0.12
Fl	0.13	0.17	0	0.43	0.17	0.03	0.07
Fsc (r)	0.04	0	0.09	0	0.61	0.23	0.04
Fr	0.05	0	0.10	0	0	0.76	0.10
C	0.76	0	0.14	0.09	0.05	0	0
St	0	0.5	0.5	0	0	0	0

FIGURE 4. MARKOV CHAIN STATISTICS OF MEASURED SECTIONS, UPPER PART OF MEMBER A, CLIPTON FM.
(See p.12 for explanation of facies codes.)

INDEPENDENT TRIALS MATRIX

	Psc	Sr	Fl	Fsc (r)	Fr	C	St
Psc		0.15	0.24	0.17	0.17	0.19	0.06
Sr	0.13		0.24	0.17	0.17	0.19	0.06
Fl	0.21	0.16		0.19	0.19	0.21	0.07
Fsc (r)	0.19	0.15	0.25		0.18	0.19	0.06
Fr	0.11	0.15	0.24	0.17		0.19	0.06
C	0.19	0.15	0.24	0.17	0.17		0.06
St	0.17	0.13	0.21	0.15	0.15	0.17	

RESIDUAL PROBABILITY MATRIX

	Psc	Sr	Fl	Fsc (r)	Fr	C	St
Psc		0.35	0.16	0.37	0.17	0.19	0.06
Sr	0.19		0.41	0.37	0.17	0.19	0.06
Fl	0.08	0.01		0.24	0.02	0.18	0.07
Fsc (r)	0.15	0.15	0.16		0.42	0.03	0.02
Fr	0.14	0.15	0.04	0.17		0.57	0.04
C	0.57	0.15	0.10	0.12	0.12		0.06
St	0.17	0.37	0.29	0.15	0.15	0.17	

FIGURE 5. MARKOV CHAIN STATISTICS OF MEASURED SECTIONS, UPPER PART OF MEMBER A, CLIFTON PM.
RESIDUAL PROBABILITIES GREATER THAN 0.1 ARE UNDERLINED.

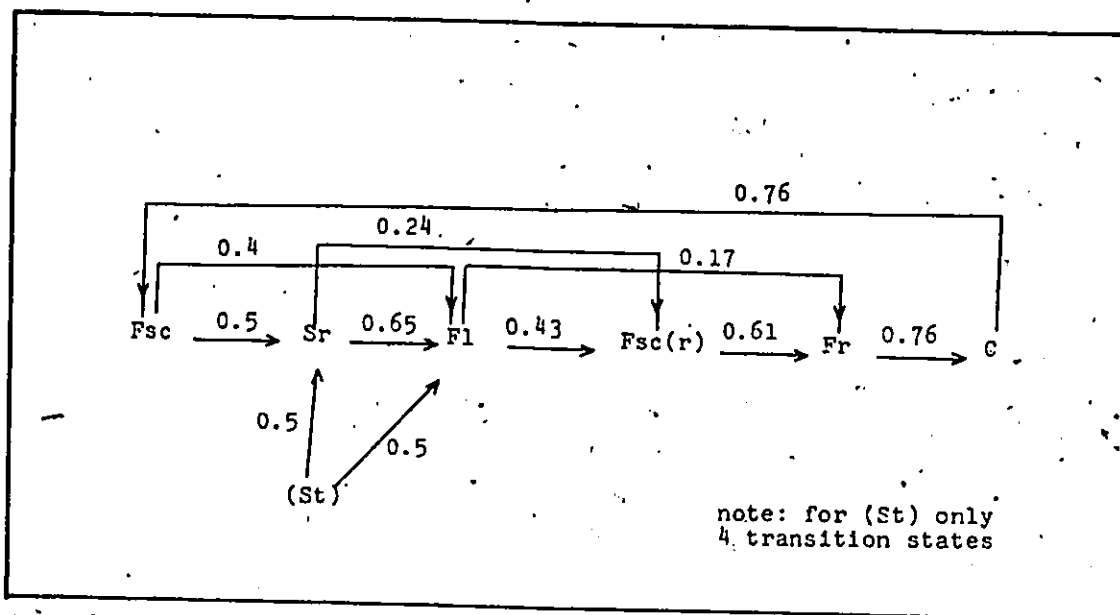


FIG. 6. PATH DIAGRAM OF OBSERVED FACIES RELATIONSHIPS UPPER PART OF MEMBER A, CLIFTON FM. (FROM TRANSITION PROBABILITY MATRIX).

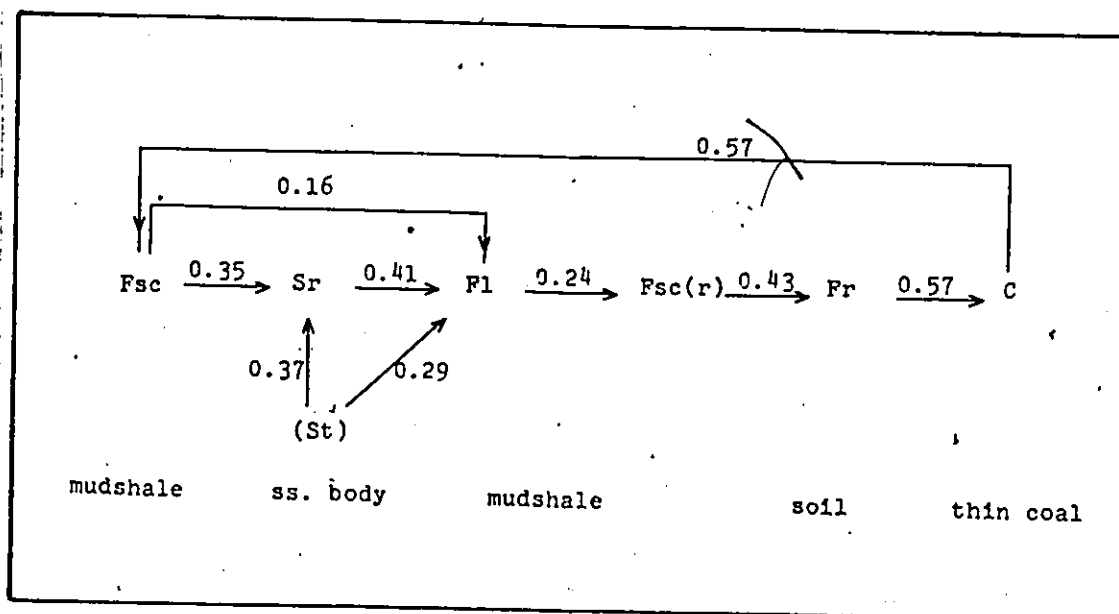


FIG. 7. PATH DIAGRAM OF PREFERRED FACIES RELATIONSHIPS UPPER PART OF MEMBER A, CLIFTON FM. (FROM RESIDUAL PROBABILITY MATRIX).

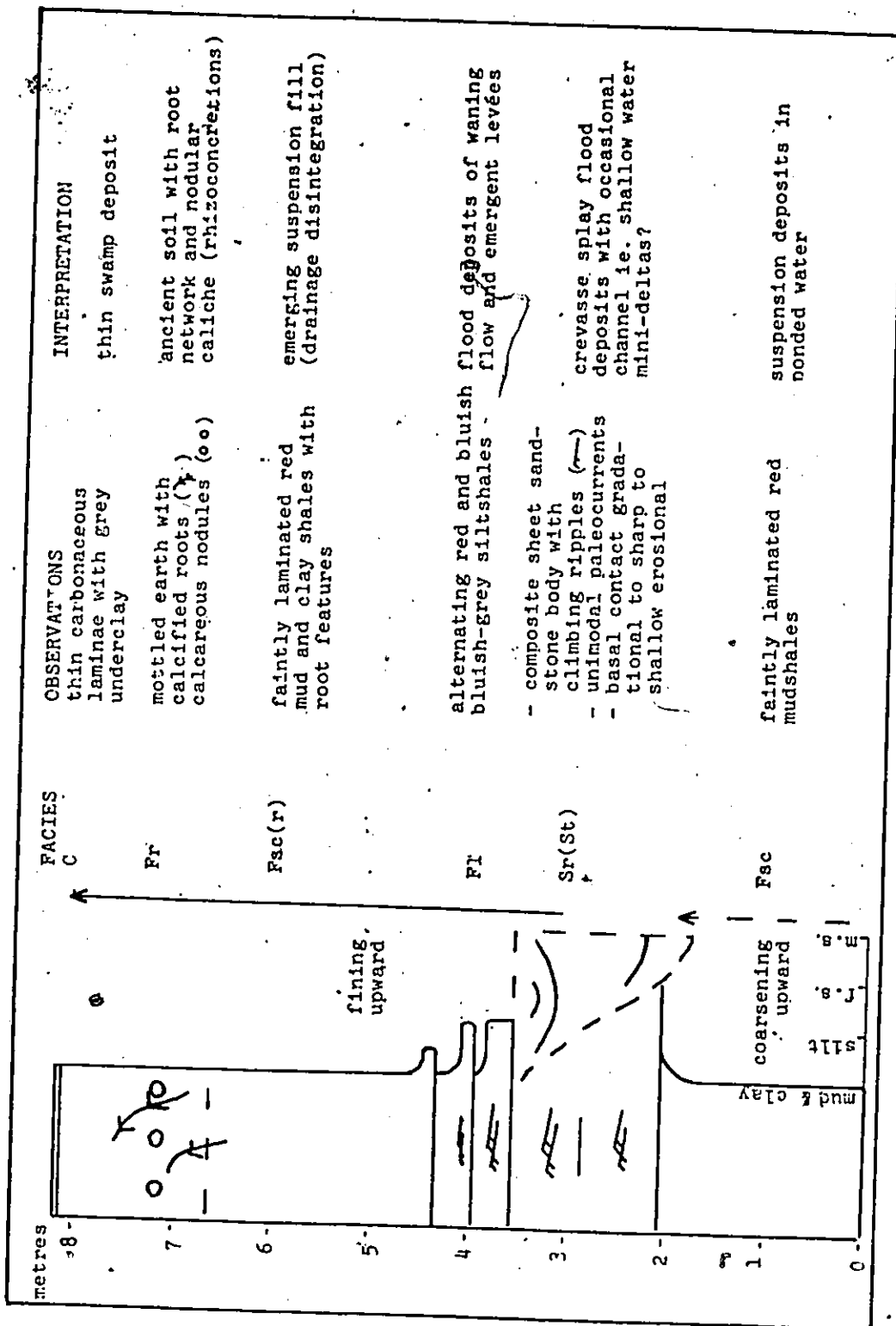


FIG. 8. FACIES MODEL FOR UPPER PART OF MEMBER A, CLIFTON FM. DEPICTING A FLOOD CYCLE: CREVASSE SPILL DEPOSITION IN SHALLOW PONDED WATER FOLLOWED BY EMERGENCE AND PEDOGENESIS.

PALEOCURRENTS (CLIFTON MEMBER A AND B).

Paleocurrents on rocky shelves exposed at low tide represent bedding plane exposures of sandstone bodies. Because of the low coastal dip, a set of paleocurrents measured eastward along the coast represents a slow rise within the sandbody. In Member B a small number of measurements were taken on higher shelves above tide level. Paleocurrent data are depicted in fig. 9.

In Member A, only two sandbodies provided a reasonable set of paleocurrent data. Both showed little angular variance over considerable lateral exposure. Both at Stonehaven (600m exposure) and New Bandon (480m) 90% of the readings fell within a 40° range. Troughs and ripples gave the same trend. The data for Clifton Member A suggests that individual sand bodies have unidirectional paleocurrents of low variance. As a group the sandbodies indicate a pronounced flow direction to the ESE. One small data set of 6 measurements indicates an almost reverse flow on weakly rippled silts (backflow?).

In Member B, 70% of the readings in a 2000m exposure fell within a 40° range. This is surprising for such a length of exposure but it corresponds to only about 10% of section. Mean current flow was to the SE. Furthest to the east at Anse Bleu flow directions are more variable over 400m exposure. Flow appears to swing from SW to NW with a mean at 287° .

A regional analysis of paleocurrent data is hampered

because measurements could not be taken continuously at a given spacing along the coast. Readings were weighted to give a unit weight per unit distance in calculating the regional paleocurrent direction. The result was a mean flow direction of 120° with a vector magnitude of 56%. If the readings were not weighted, the mean flow direction would be essentially unchanged and the vector magnitude increased somewhat. The slight suggestion of bipolar flow would not be evident.

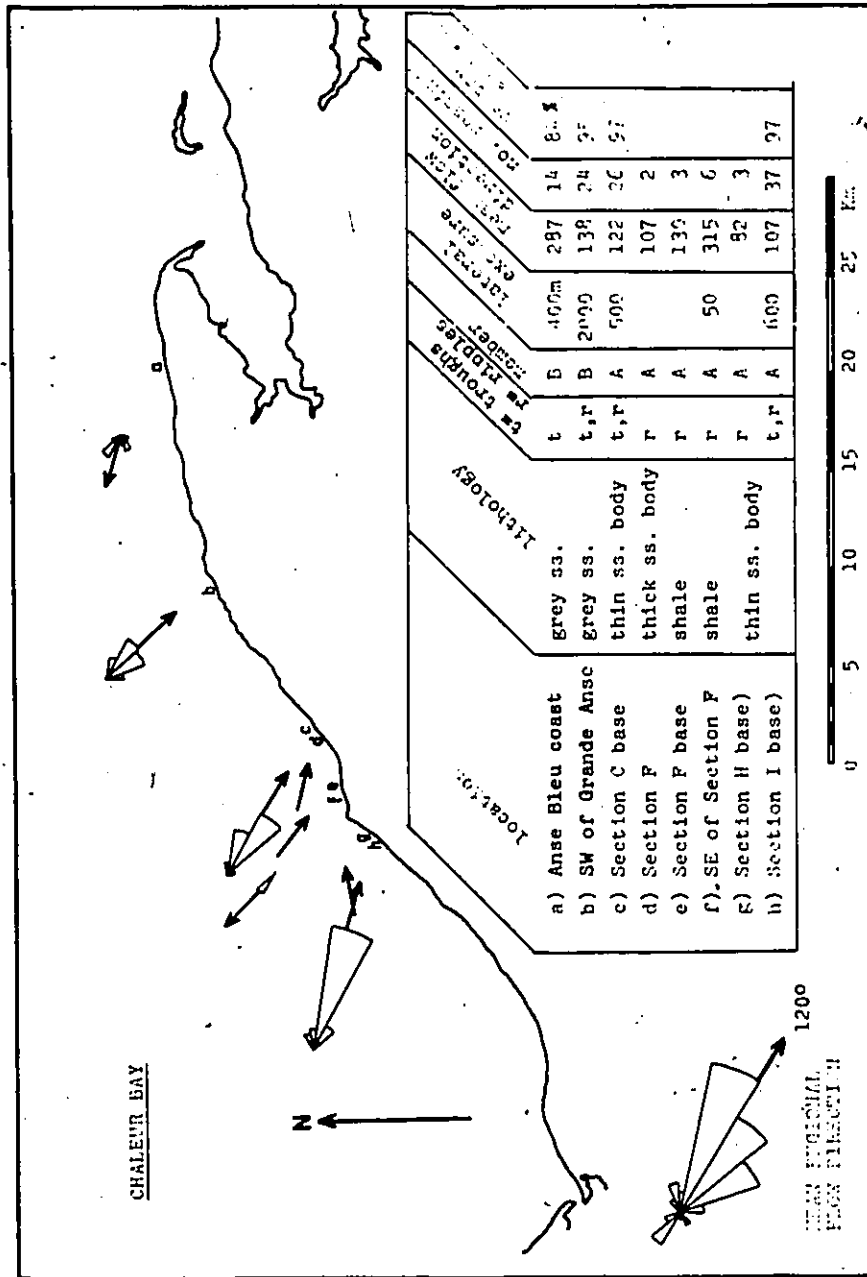


FIGURE 1. PALEOCURRENTS OF THE CLIFTON FM. IN CALCULATING MEAN REGIONAL FLOW DIRECTION, READINGS WERE WEIGHTED TO GIVE A UNIT WEIGHT PER UNIT DISTANCE (60m) OF LATERAL EXPOSURE.

NATURE OF SANDBODIES OF CLIFTON FORMATION MEMBER A.

Thin Sandbodies.

The wedge-like shape, dominance of climbing ripples, and unidirectional paleocurrents of low variance indicate that the thin sandbodies of Member A consist of crevasse splays associated with channels (photos 21-23). Crevasse splay is used here in a rather loose sense for a wedge of sediment rapidly washed out into a flood basin. Mud draped surfaces and shale interbeds with casts of tree trunks indicate significant pauses in the sedimentation of successive splays as well as very shallow waters (photos 8,9). Indicators of waning flow in the sandbodies include an overall fining upwards with flattening of the ripple drift, ripples superimposed on troughs (falling flow regime) and a variety of channel fills.

Three large channel fills were found (section B,K,L: 5,6,10m. above base respectively). The most accessible channel (section B, photo 21) has an asymmetric outline, the deepest portion (2m) adjacent to the left bank. It is about 200m wide. This is a maximum as it is probably cut in oblique section. The alternating beds of shale and sand adjacent to the left bank show inclined bedding away from the channel, strongly suggestive of a levée (photo 22).

Lateral Accretion Sandbody.

The narrow but relatively thick sandbody exposed on the southwest side of Stonehaven wharf is an excellent example of a multiple point bar deposit. It is only about 300m wide but up to 4m thick. It begins with a channel edge followed by distinct lateral accretion surfaces (photos 17-19). These end rather abruptly against sands that thin out interdigitating with shales (photo 20). Trough cross bedding occurs together with the lateral accretion surfaces and comprises the in channel deposits. The thinning sands probably represent levées and overbank deposits.

The height of the lateral bedding is 4m, which can be equated with the maximum depth of water at the bankful discharge. A single accretion surface extends for 50m. Such a surface represents approximately two-thirds of the channel width. Hence the apparent width of the channel was about 75m, giving a width/depth ratio of about 18:1.

Thick Sandbody.

The thick sandbody of Member A is exposed NE of Stonehaven below an abandoned quarry (section F, 8m above base). It ends abruptly against redbeds in a double channel outline (photo 14). Its base is rather massive and inversely graded (?), very irregularly but sharply cut into the underlying red shales, with pinnacles of red shales. This indicates that deposition rapidly followed erosion, otherwise the

pinnacles would have remained (photo 24). The sandstone body is dominated by structures indicative of upper lower to upper flow regime (troughs and primary current lineation: photo 25). The eventual waning of flow (climbing ripples) is not marked by overbank deposition. Paleocurrent measurements at the top match those of the channel edge. The channel is at least 1500m wide but rise of the base before it passes out of section suggests it might not have been much wider. This is a major channel body. It lacks lateral accretion bedding, so formation in a meandering channel is improbable, although possible. Lateral accretion bedding is not often present in meandering channel deposits (Rust, personal communication).

Unimodal paleocurrents, high flow regime (eventually waning) sudden deposition features such as massive sandstones on an irregularly cut base, and probable low width/depth ratio of about 125:1 indicate the thick sandbody represents a major fluvial distributary. According to Collinson (in Reading 1978), fluvial distributaries have low width/depth ratios compared to alluvial channels (range about 1000:1) since they tend to be short lived. This is due to avulsive events in which they seek shorter, steeper paths into a flood basin.

NATURE OF SEAT EARTHS OF CLIFTON FORMATION MEMBER A.

Introduction.

Facies analysis has shown that the red mudshales overlying the sandstones of each cyclothem differ from the underlying mudshales. The overlying redshales show vertical transition into seat earths (photo 11).

The seat earths represent cumulative soils. A cumulative soil is one in which sedimentation accompanies pedogenesis. Its features are partly sedimentologic and partly pedogenic. The seat earths show development from paleocol caliche to underclays to thin coals as sedimentation proceeded. This is represented by the facies change $F_{sc}(r) - Fr - Fr(C)$ which also constitutes the cumulative soil profile.

Paleosol Caliche.

Paleosol caliche is formed by accumulations of carbonate within ancient soils under semi-arid conditions. The ideal environment for their formation is neither excessively arid nor excessively humid (Reeves 1976). The carbonate is considered primary, a product of the original soil-forming process. This process probably involves the presence of high pCO_2 at the top of the soil profile due to organic activity, and low pCO_2 at the base of the roots (Birkeland 1974). Calcium is leached at the top, transported downwards in solution as bicarbonate and precipitated at the base of the

roots as rhizoconcretions. The carbonate occurs in a variety of forms including 1) pseudomorphs after plant roots - such calcified root casts are called pedotubules; 2) nodular horizons; 3) nodular horizons with internodular fillings; and 4) calcareous crusts (Reeves 1976). Together 1, 2, 3 and 4 represent a sequential development from bottom to top in a caliche profile. In simplest terms, pedotubules grade into scattered nodules. These enlarge and coalesce (honeycomb texture) eventually forming a continuous calcareous crust, a "plugged" horizon, impermeable to water. This sequence of progressive calcification also means progressive induration of the soil into a "hardpan". It is important to note that 1) both age and exposure cause induration of the profile; and 2) induration occurs above the water table. Periods of the order of 10^3 - 10^5 years may be involved in the development of mature caliche profiles (Gardner 1972).

The paleosol caliches of the present study correspond mainly to stages 1) and 2) of the caliche profile - pedotubules followed by nodules. Often the pedotubule stage Fsc(r) may end abruptly without vertical gradation into the nodules of facies Fr. An interpretation as paleosol caliche is justifiable on the following grounds:

- 1) Carbonate fragments are found in overlying sands, therefore the carbonate must be primary (photo 26).
- 2) The calcified layers contain root casts and

associated nodules (rhizoconcretions).

3) The nodules consist of calcite and not siderite. (Siderite is typical of calcareous seat earths that underlie some Appalachian coals.)

4) In thin section the nodules exhibit the caliche microstructure called soil peds and crystallaria (photo 27) in which multiple generations of calcite veins bind angular to round areas made of calcite microspar and red mud (Hubert 1978).

5) The calcareous hardpan at Clifton has a thin regolith cover indicating subaerial exposure (photo 28).

Within facies Fr, red colouration passes through mottling (yellow, brown, blue, etc.) into grey and green. Nodules seem to be associated with the mottling. Occasionally however, there is mottling but no nodules. Colour mottling in modern soils is commonly ascribed to a fluctuating water table, the presence of iron in both oxidised and reduced states, and various organic complexes (Birkeland 1974). The repeated wetting and drying due to a fluctuating water table may explain the many generations of calcite veining found in soil peds. With each drying a different set of soil and root associated fractures and voids would become available to carbonate rich groundwaters.

Leached Paleosol.

The question arises as to what the grey-green non-nodular top (subfacies Fr(C)) of the cumulative soil profile represents. Since these paleosols are capped by carbonaceous laminae or thin coals, the water table must have risen between the time of caliche formation and peat deposition. This is particularly clear at Clifton where the caliche hardpan is 1.6m below a 10cm coal seam. Subfacies Fr(C) may represent leached soils. These greyish fine earths may be soft and yielding or stiff and slickensided. In the latter case they are semi-flinty, breaking into irregular polyhedra. Close examination reveals that slickensiding occurs along carbon films. It is probable that with compression, compaction and dewatering, plant remains form carbonaceous films along which sliding occurs (Huddle and Patterson, 1961). The flinty (leached?) nature of some clays is confirmed by X-ray diffraction which revealed no clay mineral peaks, but only those of quartz and perhaps a mica. Carbonate peaks are also absent.

It is worth focusing on the paleosol-coal association at Clifton to confirm the nature of the cumulative soil profile. Several square metres of caliche hardpan surface are exposed at Clifton. The surface is abruptly overlain by fine grey earth which is devoid of calcification features, but does have plant carbon compressions. As mentioned previously, there is evidence that the hardpan was subaerially

exposed. This is evident in an examination of the surface of the crust, which is bumpy and nodular (photo 28), with the nodules partly wrapped in mud shale. Imbedded in mud-rich matrix are rounded pebbles of micritic limestone - obviously derived from the weathering of the hardpan crust. This thin regolith means that the hardpan must have been a surface feature, an air-exposed crust of limestone that was part of the local topography. This topography (perhaps a shallow depression) was flooded for a period of time sufficient to form a poorly drained soil facies Fr(C) and a peat swamp.

Lateral Variation in Seat Earths.

There is some thickening and thinning of seat earths laterally (sections A-E, fold-out). This is most pronounced in the large channel fill previously described (photos 16, 21). Within this channel the soil profile is:

Few cm	C
	↑
30cm	Fr(C)
	↑
60cm	Fr (mottled but no nodules)

while outside C with a thin underclay Fr(C) abruptly overlies Fsc(r), ie:

few cm	C
	↑
few cm	Fr(C)
	↑
	Fsc(r)

The difference in thickness outside and within the channel

is probably a function of sedimentation rate. The higher rate within the channel resulted in a thicker profile, as well as preventing formation of caliche nodules. The reader is referred to Leeder (1975) who has tried to quantify the relationship between sedimentation rate, thickness of paleosol caliche profile and the type of profile that develops. With eventual flooding and the growth of vegetation, more poorly drained conditions would prevail in the abandoned channel; hence the presence of subfacies Fr(C) at the top of the channel fill profile. The soil profile at other stratigraphic levels also varies laterally but its relationship to underlying sandstone bodies or structures is uncertain (particularly as many profiles need to be dug out with a shovel from under scree). Overlying carbonaceous laminae do not seem to be particularly influenced by the local changes in underlying soil profile thickness.

Caliche Features in Other Facies.

Features attributable to caliche are found in most other facies. They include calcified root networks and rhizonecretions in the sandbodies underlying the paleosol. In one case a sandbody is hardly recognisable as induration and soil development extends through it, destroying original textures and sedimentary structures.

The hardpan caliche at Clifton is a key for interpreting calcareous crusts on fissure walls. These fissures cut through

various facies. Photo 29 shows part of a vertical wedge of calcrete extending from the hardpan. This is in a fallen block. Photo 30 shows clearly the outline of a wedge against the exposed fissure wall. The bedding of the hardpan to which it extends and connects is clearly visible. Similar vertical wedges are abundant in the red and greenish mudshales between Clifton and Stonehaven and in the shore sandbody between Sections A and B (photo 6). The wedges in mudshales are undulating and smooth surfaces, like the folds of a drape. The crusts on sandbody fissures are rough and pisolithic (photo 7). Pisoliths (ie small calcareous nodules $\leq$ 1cm) show concentric growth and vague radial fabric, as observed through a binocular microscope. Shaley material wraps about the pisoliths. Some calcite veins cut across occasionally. This is all reminiscent of soil peds and crystallaria. These wedges or caliche "roof pendants" bear testimony to exposure and deep desiccation, with precipitation of carbonate groundwaters. Similar structures are briefly mentioned by Reeves (1976) who refers to caliche "stalactics" hanging down into soil (ibid. p109).

The base of some sheet sands has abundant calcareous chips. This is the case for the sandstone overlying the upper coal seam at sections K and K' (Clifton: photo 26) and the thick sandstone body at section G, as well as others. These chips are interpreted as originating from the erosion of floodplain caliche. Certainly their angularity suggests

an intraformational origin. Occasionally thin sand sheets (dm or so) are full of caliche fragments. This suggests a sheet flood advancing over a dry surface.

Thin sections of various sandstones show that carbonate is present in the matrix rarely to abundantly. It is present as: (see appendices)

- solitary interstitial patches bounded by detrital grains;
- connected interstitial patches;
- continuous areas of carbonate with "floating" grains enclosed within.

CLIFTON MEMBER BFacies States.

Facies of Clifton Member B include:

St, Sp	trough and planar crossbedded sands
Sr	ripple cross-laminated sands
Sh	horizontally laminated sands and siltshales
rare Fsc	mudshales
Se	intraformational conglomerate in erosional scours

Facies Descriptions.

St, Sp consists of trough and planar cross-bedded sandstones. This facies is similar to that found in Member A but it forms much thicker sandbodies (up to 10m) (photo 31). Planar cross-bedding is slightly more in evidence. The sandstones are darker toned, coarser (medium grade) and more poorly cemented compared with Member A counterparts. Coal spar litter is common. Calcite cement is rare. Trough set thickness appears to decrease upward from a maximum of about 2m. Troughs can be up to 15m wide.

Sr consists of ripple cross-laminated sandstones of fine grade. This facies is minor relative to St, and less than a metre thick where observed overlying (and underlying) St. It includes some good exposures of lunate ripples, but is more commonly represented by low angle climbing ripples.

It is occasionally top truncated.

Sh consists of grey horizontally laminated sandstones, and siltshales. This facies shows a progressive fining upward from fine sand to silt. Fissile throughout, it is similar to facies Fl of Member A but it lacks the alternations, and the mudshales. It is up to a metre thick. Plant litter is again common. Against this facies, broad erosive channel outlines of the overlying facies St are made distinct by cutting down (photo 32). These channel outlines can be hundreds of metres thick.

Fsc consists of mudshales. Isolated clay seams a few centimetres thick within sandstones are mentioned in the logs from Riorden and Cape Play. A red mudshale unit - actually a channel fill - is present at the mouth of the Little Pokeshaw River (photo 33). Several metres of reddish mudshale are also logged in testhole 10 at Caraquet well above the estimated base of Member B.

Se consists of intraformational conglomerate in erosional scours. Fragments include coalspar, shale, calcareous shale, micritic limestone and the local sandstone. The matrix is rich in recrystallised calcite, in which grains and fragments float. Several exposures are present between New Bandon and Caraquet; a bedding plane exposure of conglomerate can be seen at the rocky tidal flats below Maisonette lighthouse (photo 34). The conglomerate forms a surface patch, enclosed by trough cross-bedded sands, and consists of

angular carbonate chips, closely spaced. XRD analysis of the chips revealed diffraction peaks matching calcite.

Nature of Sandbodies.

Markovian facies analysis of the sandbodies was not possible since very few sections suitable for measuring were found (vertical undercut cliffs with no beach are common)(photo 35). However, some examples of vertical change are:

				<u>channel fill</u> (photo 33)
↑	St	St	St	Fm
	Se	Se	Se	Sh
	Sh	Sr		Sp(Sr) decreasing set size upward
	St	St(Sp)	St	St

Top truncated, channel outlined, fining upward sandstone units suggest deposits of a fluvial system. The thick channel member consisting of St, Sp, Sr, Sh? is preserved while the overbank deposits are not. This is probably due to channel shifts, for many channel outlines (requiring sharp eyes!) are present.

The following features suggest a braided rather than meandering origin for these deposits - based largely on the comparative summary of Miall (1977):

- lenticular rather than rectangular channel outlines;

- channel bases are erosive scour surfaces in lower parts of sandstone sequence;
- presence of Sp facies (advancing sand bars) which is rare in meandering rivers (this was disputed by Jackson, 1976);
- thin overbank member relative to channel member (ratio is 1:5 or less);
- lack of lateral accretion surfaces (not very diagnostic);
- low variance in paleocurrents.

An appropriate braided model is, possibly Facies Assemblage S_{III}: Distal Braided Rivers and Alluvial Plains (Rust 1978a).

The channel fill at the mouth of Little Pokeshaw River (photo 33) is probably about 5m above the base of Clifton B. It is 120m wide and 4.5m deep. The nature of the fill lies somewhere between a fining upward cycle (progressive abandonment of braided channel) and an abrupt fine-grained fill characteristic of neck cut-offs in meandering systems. A mixed braided-meandering origin thus cannot be ruled out for this sandbody sequence.

The presence of disrupted coal seams enclosed in sandstone at Haut Caraquet wharf is enigmatic (photo 36). Such coal cannot be in situ. It is surrounded by coalified plant litter. Coal seams of several metres length terminate abruptly, without wedging. In some cases they are strung together, suggesting a stratigraphic horizon; in others they

41

are pivoted at odd angles to local cross-bedding. Abrupt terminations at first sight suggest tree trunks, but this is not tenable for the following reasons:

- the coal appears to consist of a variety of matted plant spar rather than a single phase;
- it is improbable that most trunks are exposed in longitudinal section.

A better explanation is that these are peat rafts, which floated, degassed, and finally sank during transport. Some may not have remained coherent but had their contents dispersed by the currents. More difficult to explain is the inclined attitude of some against the current. The writer would suggest that this is a form of imbrication, in which a semi-buoyant mat was flipped by the current so it dipped upstream. The process is analogous to that affecting flat pebbles in stream beds (Rust 1972).

Nature of Intraformational Conglomerates.

The nature of the unfossiliferous micritic limestone fragments in the intraformational conglomerates (photo 34) is problematic. A straightforward interpretation is that they were derived from overbank caliche, eroded and deposited as channel lag. However, microstructure soil peds and crystallaria are not apparent. Furthermore, would channel shiftings of a braided system allow sufficient exposure in interfluvies for caliche formation? It would seem so, given their presence in some

modern day alluvial fans (eg Williams 1973).

If the micritic limestone fragments are caliche there is little need to invoke climatic change as responsible for the change in deposition from red to grey megafacies (Clifton A to B) as proposed by van de Poll (1973). Alternatively, the caliche which is always fragmented could be interpreted as a reworked fossil caliche. The importance of climatic lag in fluvial systems has been noted (Rust 1979).

The micritic limestone fragments might also represent marls. Marls include algal, nodular, pseudobrecciated forms (Pettijohn 1975) that are not unlike caliche. In fact, marl and caliche may be found together (Wheeler and Textoris 1978). In the absence of faunal remains (eg ostracods) or of other sediments of possibly lacustrine origin, it seems unlikely that this is marl.

DEPOSITIONAL RELATIONSHIPS OF CLIFTON MEMBERS A, B.

Contrasts.

To demonstrate the relationships between the sediments of the lower (Member A) and upper (Member B) sequence, their contrasts are listed below:

Lower Sequence (Member A)

dominated by red muds
shallow ponded water
deposition
sandbodies thin - dominated
by climbing ripples (crevasse
splay deposits)
plants as impressions except
where beds grey
calcareous cement in
sandstones
caliche in situ within paleosol
seat earth (paleosol) common
coal in situ
fine grained sandstones
deposition from suspension
and mixed load
base of sandstones gradational
or planar erosive

Upper Sequence (Member B)

dominated by olive-grey
cross-bedded sands
fluvial deposition
sandbodies thick - dominated
by trough cross-bedding
(channel deposits)
plants as coal spar
calcareous cement uncommon
in sandstones
caliche fragmented - present
as intraformational
conglomerate
seat earths not observed
transported coal spar,
disrupted coal seams enclosed
in sandstone
medium to coarse grained
sandstones
deposition mainly from
bedload
irregular erosive base to
sandstones

Depositional Constraints.

The constraints on a model to integrate depositional features of Members A and B are as follows:

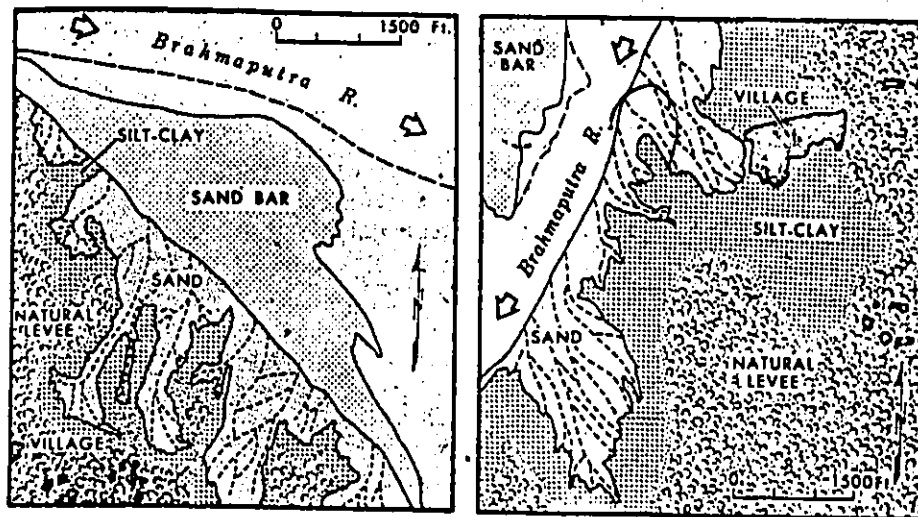
- 1) Both thin sandbodies of A and thick sandbodies of B derived their sediment from the same source. Petrographically the sands are similar, consisting mostly of grains of quartz, quartzite (micaceous) and volcanics (see appendix). However the composite sheet sands of A show more evidence of diagenesis as they are better cemented.
- 2) In Member A, large portions of the flood basin received virtually no sediment for long periods of time. During such times (lasting thousands of years?) emergence and pedogenesis occurred.
- 3) Flood events dominate both sequences. Sedimentary structures indicate repeated waning flow conditions. However, the lithic content, grain size and structures of the upper sequence suggest that it had greater transporting and erosive power.
- 4) Relatively late in the deposition of Member A there was a period at which major fluvial distributaries briefly encroached into the flood basin.

Crevasse Splays and Channels - A Discussion.

We may distinguish two types of major overbank flood sheets: those that represent wedges of sediment washed out through the sides of channel bodies and those that represent

outwash from the ends of channels. An example of the former is crevassing of levées in raised channels such as that of the Brahmaputra River (Coleman 1969; figs. 10,11). An example of the latter is the channel itself splitting into distributaries, eg the shoal water deltas of Fisk (1961) (fig. 12). The flood basin that receives these sediment wedges may be represented by the alluvial plain of a river, an interdistributary bay of a delta, a coastal lagoon, an inland swamp, etc.

In the first case it is the height of the levée that determines the type of splay deposits. Extensive levée build-up depends on repeated bankful discharge. As a result the channel may become elevated with respect to the flood plain. With major flooding the flood waters tend to leave the main river system via a single channel, down a steep levée gradient and terminate in a radiating delta-like fan consisting of multiple channels (fig. 10). Proximally the crevasse channels scour a few feet into underlying sediment, distally they do not. Such is the case for the Brahmaputra River as described by Coleman (1969). Downstream, where levée gradients are low, the water leaves the main river system through a multi-channeled system characterised by anastomosing pattern (fig. 11). Basal erosion is lacking; the splay is thinner and cut and fill structures are present besides ripple drift.



LEFT: FIGURE 10. SINGLE CHANNEL CREVASSE SPLAY IN THE BRAHMAPUTRA RIVER.

RIGHT: FIGURE 11. MULTICHANNEL CREVASSE SPLAY IN THE BRAHMAPUTRA RIVER. THIS TYPE IS MORE COMMON IN THE LOWER REACHES OF THE RIVER.

(AFTER COLEMAN 1969).

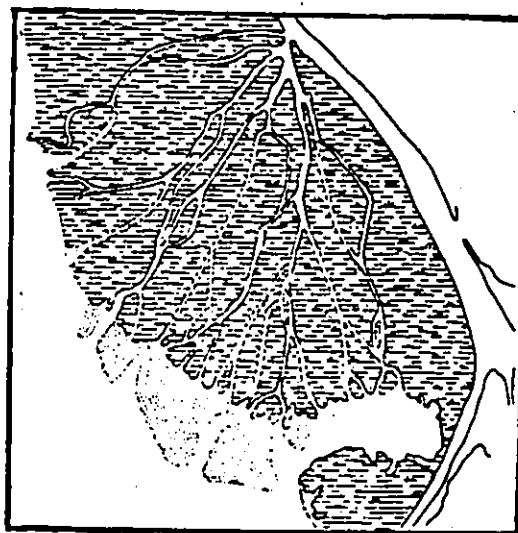


FIGURE 12. SHOAL WATER DELTA OF MISSISSIPPI RIVER WITH A DISTRIBUTIVE NETWORK OF CREVASSE CHANNELS DEPOSITING MINOR MOUTH BAR SANDS (STIPPLED).

AFTER GAGLIANO AND VAN BEEK, 1970.

"Therefore, in a section cut parallel to main channel, the levée deposits appear as a series of overlapping and interfingering lenses of coarse, well-sorted sands which are separated by finer grained deposits. The lateral extent of the lenses varies considerably, from a few hundred feet to over 3,000ft. In a transverse section sands predominate near the channel. From these sandbodies long, thin stringers extend into the finer grained basin deposits. These thin sand units represent the maximum extent of the crevasse splay deposits into the adjacent basin."

(Coleman, 1969, p232)

Elliot (1974) has used the principle of levée or alluvial ridge build-up followed by crevassing to develop a model of interdistributary bay sedimentation. In this case, the channel is a distributary within the lower deltaic plain adjacent to an interdistributary bay. Elliot envisages the following sedimentation events:

- levée prograding (Phase I, fig. 13)
- levée breached by crevasse splay lobes (Phase II)
- channel migration over crevasse splay (Phase III)
- avulsion of distributary channel (Phase IV)

The resulting vertical sequence (fig. 13: compare with cyclothem in fig. 8) begins with alternating sandstones and mudstones coarsening upwards (levée progradation; Phase I). This is followed by a sheet erosive contact (proximally) and cross-stratified sandstones of the crevasse splay with an internal channel outline(s). According to Elliot, the net effect of the crevasse splay was to divert flood waters into the flood basin and to lessen the local gradient. Subsequent floodings can be discharged through

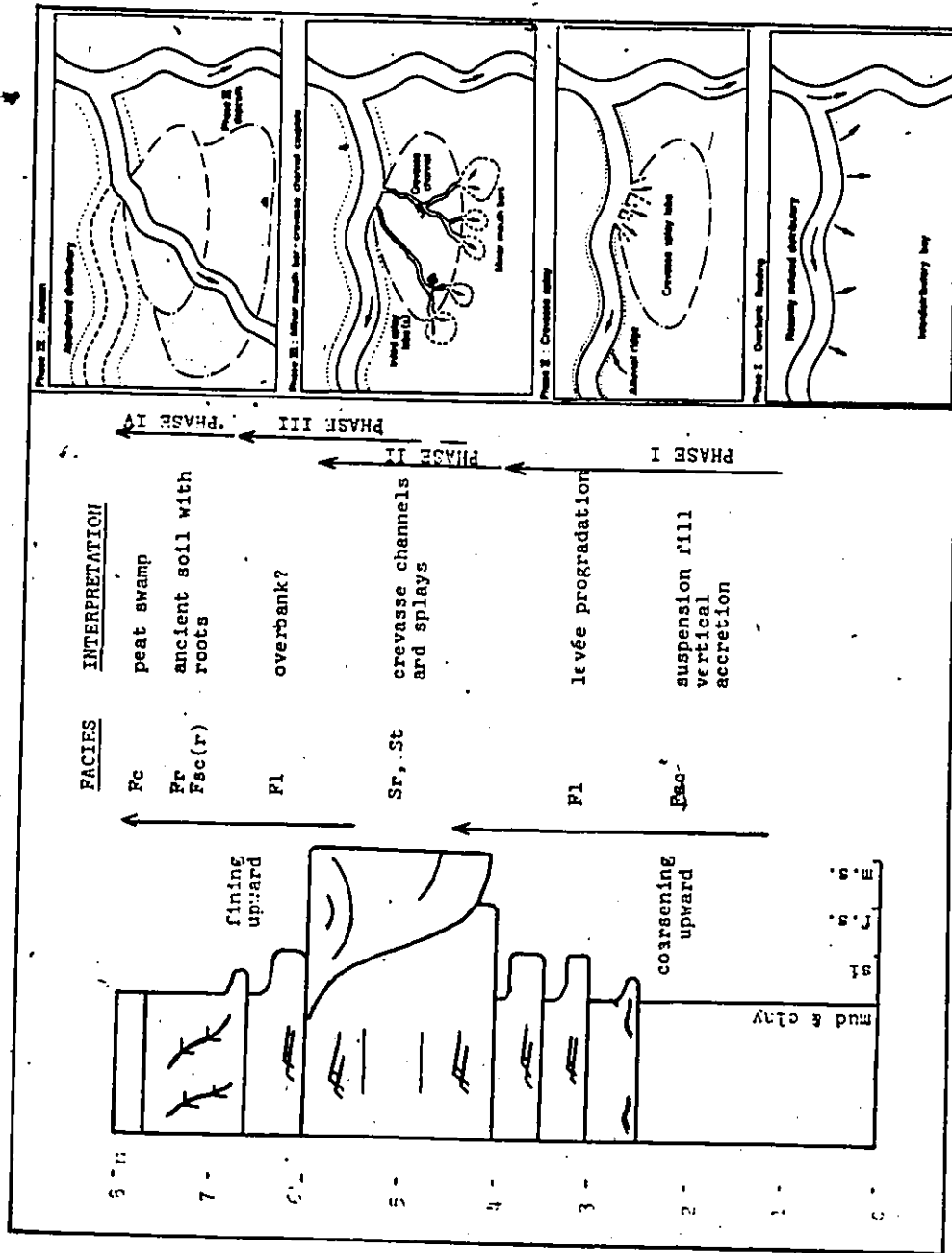


FIGURE 12. MODEL OF INTERTRIBUTARY BAY SEDIMENTATION (MODIFIED AFTER ELLIOTT, 1974). FACIES MODEL AT LEFT CORRESPONDS TO PHASES OF SEDIMENTATION SHOWN AT RIGHT.

a channel network on top of the splay.

Comparison of Elliott's vertical sequences (fig. 13) with the facies model of Clifton Formation Member A (fig. 8) reveals the following contrasts:

1. There is a lack of evidence of levée progradation in the cyclothems of Member A. Facies analysis shows that the vertical transition Fl-Sr does not show more than a random probability. This does not mean, however, that the transition Fl-Sr where observed is necessarily coincidental.
2. With respect to the base of the cyclothem, red muds, coarsen abruptly into sandstones but this is followed by either no change in grain size or a gradual fining upward within the sandstone body itself. This suggests that the emergent phase (channels) is dominant with respect to the initial subaqueous (shallow?) outbuilding phase. It should be remembered that some flood water appears to have advanced over dry surfaces (thin sands rich in caliche; lithic fragments).
3. The laminated red muds are not interdistributary bay sediments. There is no burrowing, and no evidence of marine organisms.

However, the cyclothems of Member A do seem to represent filling of a portion of the flood basin, with gradient lessening and eventual abandonment.

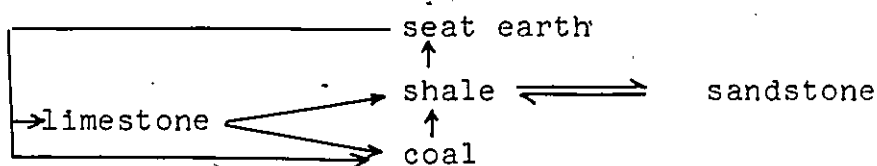
Duff and Walton (1973) used observed relationships between channel and sheet sands in the Joggins section of Nova Scotia to suggest an overall situation of a basin

affected by sedimentation from a major channel. They observed sheet sandstones passing laterally into lenticular channel bodies. The sheet sandstones occasionally formed a single unit but more commonly were composite (termed multileaf by Duff and Walton, 1973). The multileaf bodies consisted of a series of ± 50 cm thick sandstones separated by shale or mudstone partings. The basal contact of this single or multileaf body was usually conformable but sharp. Thickness was maintained from the body laterally into the channel; however, the channel sand on occasion protruded below the level of the associated sheet sand. Channel sands seemed to affect the number of adjacent sheets. More "leaves" were present in the vicinity of the channel. In the succession as a whole the sandstones with channels had an average thickness of 4m whereas those without averaged 2m.

Channels reported by Duff and Walton were up to 36m wide and 3m deep. Fill included occasional conglomerate (intraformational?) at the base followed by sandstone $\pm$ siltstone, shale, mudstone. Trough cross-bedding was common in channels. Ripple drift (in sheet sands was minor relative to a larger ~~current~~ structure called mounds and troughs (present also in channels) interpreted as consisting of suspension lamina draped over dunes. Directional structures were highly variable in orientation. They include ripples superimposed on larger structures (dunes) indicating

a secondary flow that at times was opposite to the primary ("counter" ripples):

The sandstone bodies were related to the other facies as part of the following facies sequence:



Duff and Walton (1973) interpret these cycles as

"due to major channel migrations in an area undergoing overall and continuous subsidence".

The channel sandstones were formed in association with crevassing of the major distributaries and bedload sediment was carried periodically and only during high-water stages. Mixed sediment fills are therefore common. Sheet sands were spread from the channels. As the distributary moved away (avulsion?), sediment supply decreased and the general subsidence of the area produced waterlogged ground on which peat formation was possible. Continued subsidence allowed marine flooding, in which bivalve-bearing limestones were formed. With the eventual return of a major distributary channel, the sequence was repeated.

The description of the single to multi-leaf sandbodies fits well with the composite sand sheets of Member A consisting of facies St(Sp), Sr and Fl. The two sandbodies

with channel sandstone (base of sections C, I in fold-out; photo 15) happen to be the thickest of the cyclothem sandbodies. Basal contacts and lateral variations are similar to those described by Duff and Walton (1973). Compared with Joggins, these are the significant differences in the sandbodies:

- the two potential major active channels mentioned above are much wider (several hundred metres) compared with a maximum of 36m for Joggins;

- directional structures are much less variable than at Joggins. Where ripples are superimposed on a larger structure (troughs) they show the same paleocurrent direction;

- lack of trough and mound structure.*

Comparison of the facies cycles shows a basic similarity except for the lack of bivalve limestones at New Brunswick. Evidently no brackish or marine waters ever reached the flood basin of Member A during maximum subsidence.

Duff and Walton (1973) and Elliott (1974) in their models consider the channels associated with splays to be crevasse channels originating from a major distributary. Duff and Walton do not give direct evidence of such a distributary's existence (eg the presence of a very thick

*Similar structures are interpreted as representing the interaction between river discharge, waves, and bay sedimentation in distributary mouth bars (Elliott, 1974).

sandbody). The channels of Member A associated with splays are too wide to be considered crevasse channels; more probably they are distributaries. The crevasse channel/distributary distinction is one of scale - a crevasse channel that remains open is in effect a small distributary.

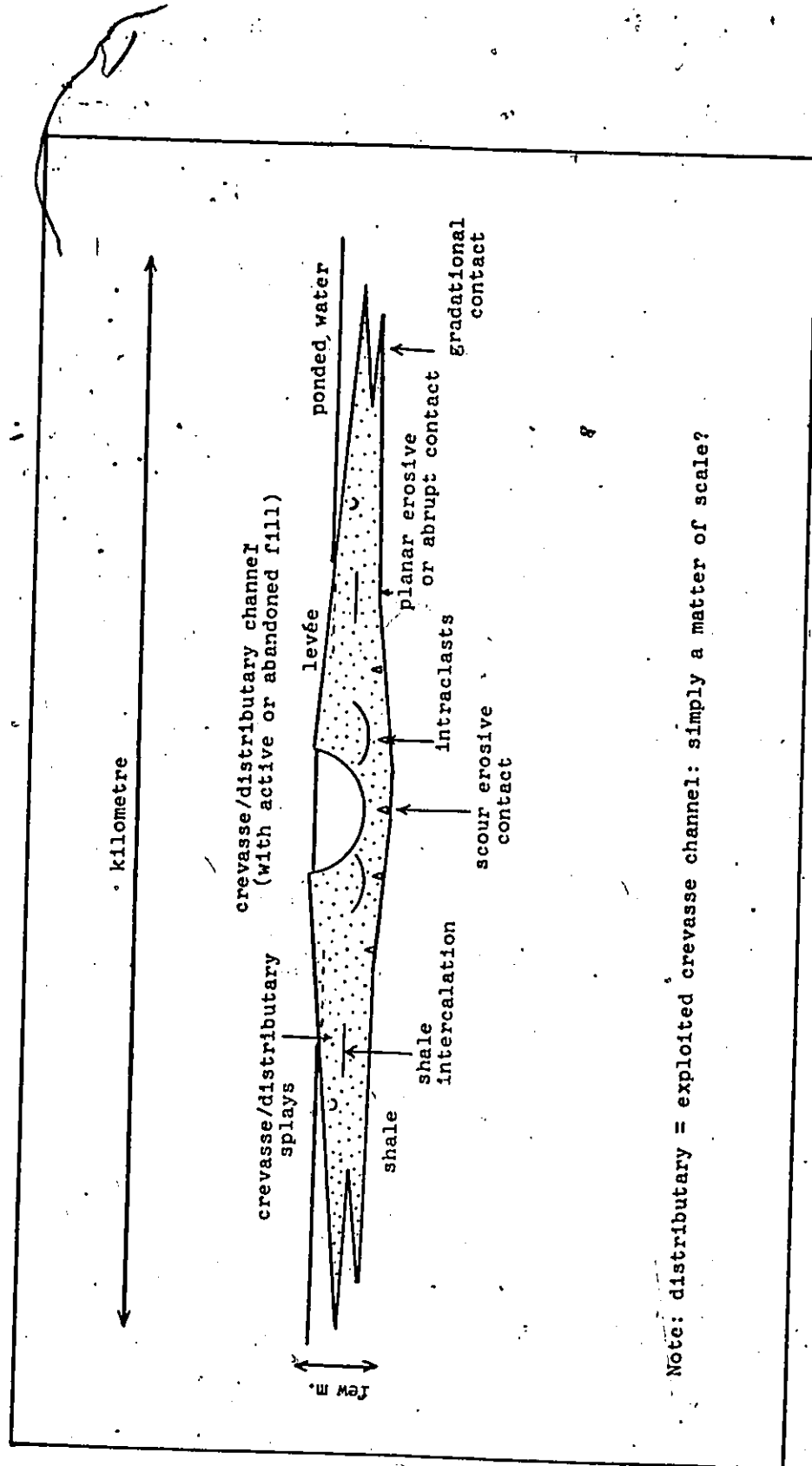
Considering the overall stratigraphy and changes in sandstone body thickness as indicating and changes in channels and as sources of crevasse sediment, it is apparent that the significant thickness change in the stratigraphy is not lateral but vertical. A proximal-distal relationship is suggested, with eventual progradation of channel sands of B over the flood plain of A.

In this context the writer would like to consider the second case of channel-crevasse splay association - that of crevasse splays as outwash (or sheet floods) from the ends of fluvial systems where they assume a distributive pattern. In this case crevasse splays need not be related to some large but non-evidenced distributary sandstone. The fluvial distributary splits and resplits into smaller channels. Depending on which "order" of distributive network we focus upon, we look at smaller to larger channel-crevasse splay systems. Successive distributary networks are common on delta platforms, coastal plains and semi-arid

flood basins. On delta platforms they are called shoal water deltas (fig. 12), and are formed when sand, carried to the mouth of an enlarging pass, forms a bar that divides the stream into branches. Figure 14 depicts a model of a hypothetical distributary lobe.

Examples of distributary networks in semi-dry flood basins include the Kosi of India, the Okavango of Botswana and the channel country of Australia. In many cases the distributaries fork and rejoin, and include some meandering segments. The distributive network is more properly termed anastomosing (Schumm 1968; Rust 1978b). A good example of a dry interior and locally distributive network is the flood plain of Cooper Creek in Central Australia, which consists of a channelised zone and marginal or intervening backplains. It has been studied by Mabbutt (1967); Rust (1979); and Veevers and Rundle (1979).

The channelised zone is anastomosing; channels locally exceeding 60m in width fork and rejoin. Migration of any meandering segments is unimportant. The channels have short stretches of levée, up to 100m wide that rise very little above the plain. The backplains consist of a variety of depressions that are connected with the channelled zone, fill up during major floods and act as lateral storage basins. With low water they slowly drain out. The depressions consist of clay pans with limestone crusts that are strongly cracked or "gilgaid" during drought (Mabbutt 1967). With shallow



Note: distributary = exploited crevasse channel: simply a matter of scale?

FIGURE 14. MODEL OF CREVASSE/DISTRIBUTARY SEDIMENTATION. Model shows wedge shaped crevasse splay deposit formed by crevassing of a distributary which is elevated with respect to its flood basin. Scour erosion occurs proximally (intraclasts) while distally, contacts are gradational (upwards coarsening). The crevasse channel may remain open and act as a secondary distributary forming its own levees. Note thickening of crevasse splay deposit in vicinity of channel.

inundation they form sump basins of disintegrated drainage. Distributary channels feeding into such sumps show reticulate anastomosing patterns. The largest of the sumps, Yamma Yamma (at the confluence of the Wilson and Cooper), has in the past been a lake (Mabbutt 1967).

In Member A the association of crevasse splays, small and large active and abandoned channel fills, meandering segments, and extensive rooting may be compatible with an anastomosing system. Rust (1978b) has noted that anastomosing channel sediments should be distinctive in the ancient record on account of abundant suspended load deposits and evidence of intense plant activity. However, paleocurrents show less dispersion than might be expected in Clifton Member A in such a proposed high sinuosity system. Persistence of paleocurrent direction might be expected with extensive overbank flooding during major floods. Floodplains would fill, and low levées be submerged. Sheet sands would be deposited under a continuous expanse of flowing water.

The calcareous pans of the channel country of Central Australia, with cracked reticulate surfaces that undergo long-term flooding or draining seem analogous to the hardpan overlain by seat earth and coal at Clifton. If major avulsion occurred in the channel country such that backplains developed over a previous channelised zone, one might expect a vertical sequence of sheet and scour route sands overlain by calcareous rooted seat earths, hard pans and loess.

However, local stratigraphy in the Lake Eyre basin

suggests a more arid situation than that which prevailed for Clifton Member A and B. Lake Eyre basin sediments include gypsite, dolomitic clays and aeolian sands that are lacking in the Clifton Formation. Also, facies Fsc at the base of each flood cycle in Clifton A, indicating sedimentation in quiet, shallow ponded waters, does not seem to have an equivalent in the channel country of Australia. Nevertheless, vegetated inland distributive networks such as the Cooper in Central Australia, the Okavango in S. Central Africa (fig. 15) and the Ili in Kazakhstan USSR, demonstrate that peat can develop in a semi-arid climate.

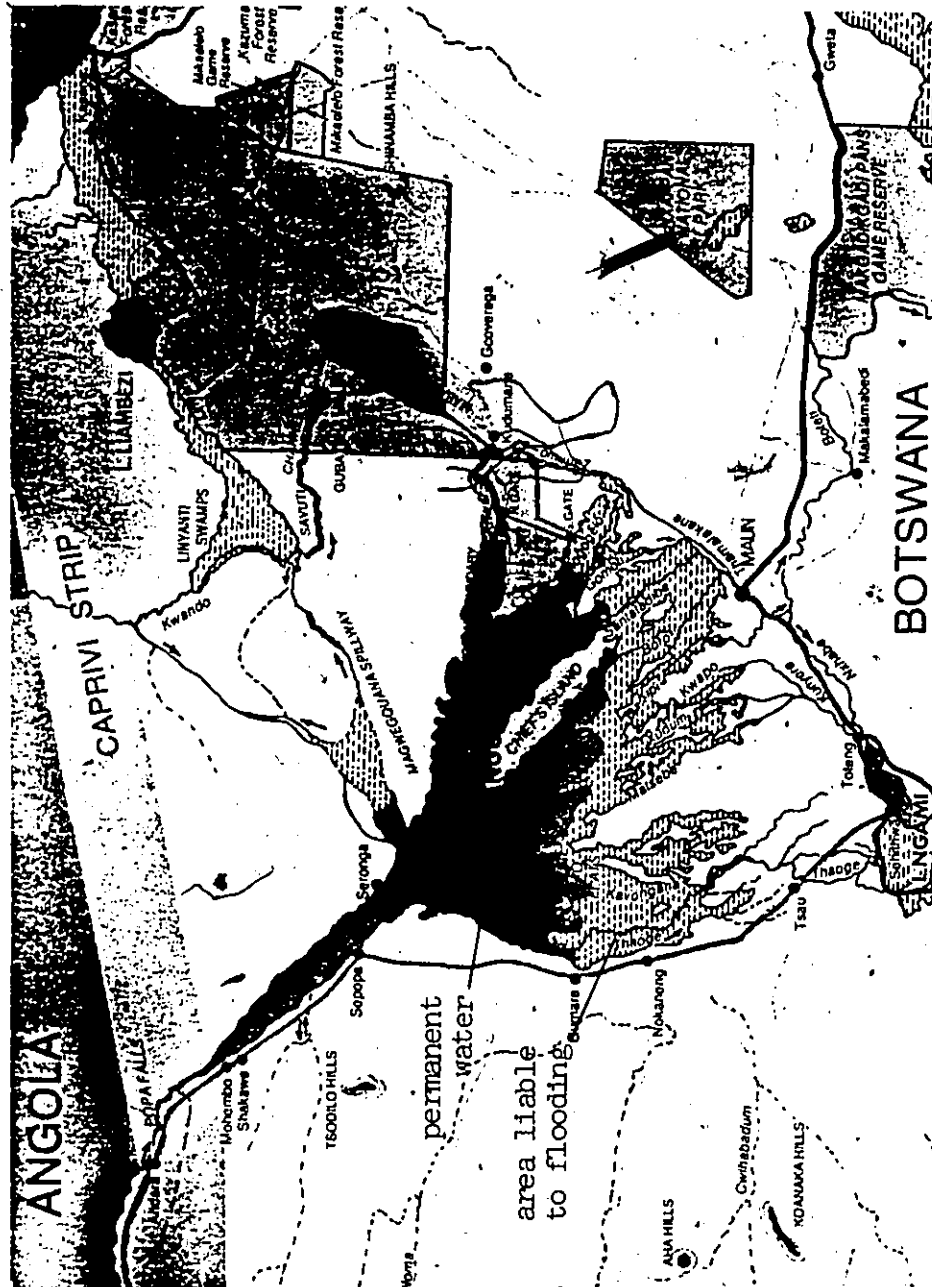
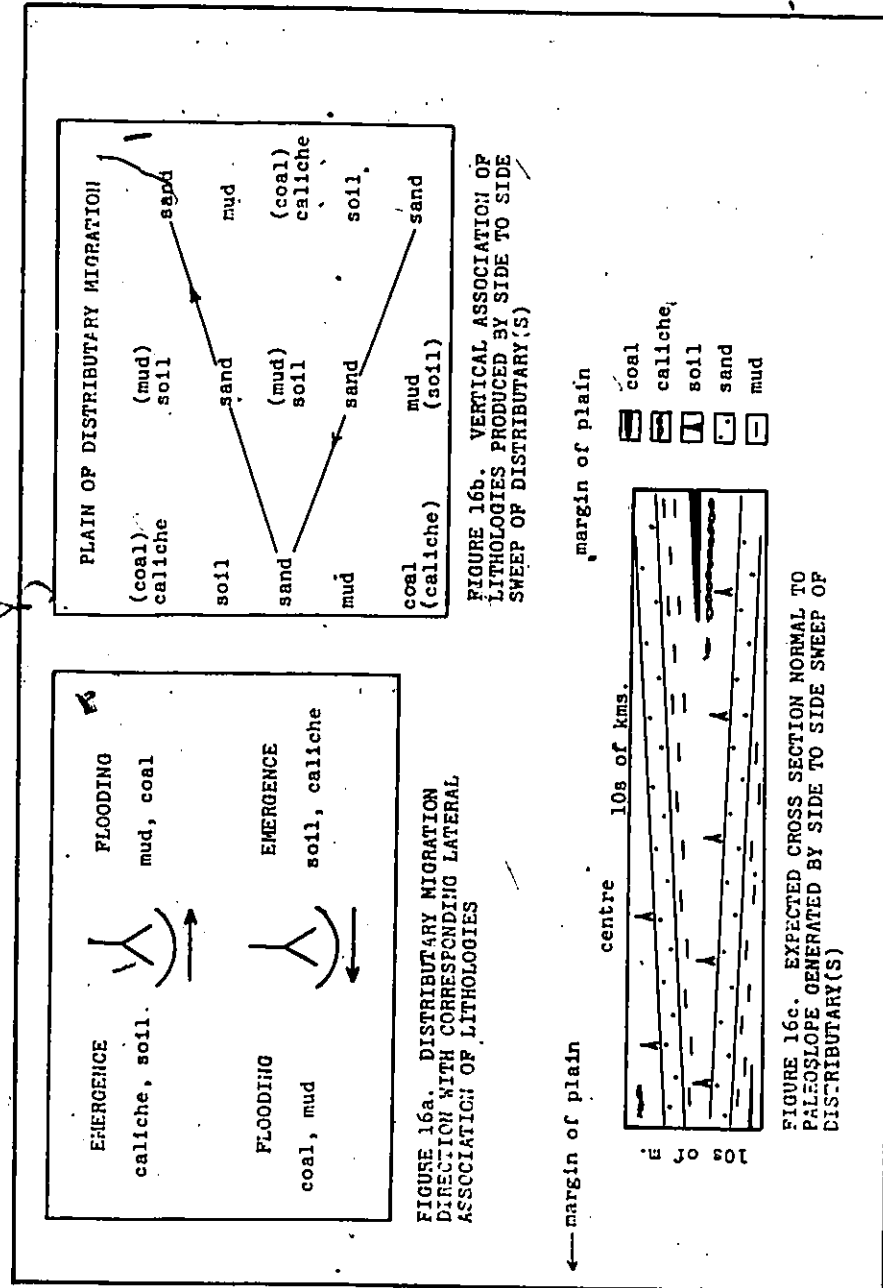


FIGURE 15. THE OKAVANGO DELTA: A VEGETATED DISTRIBUTIVE CHANNEL NETWORK WITHIN AN ISLAND SEMI-ARID SETTING. (AFTER JOHNSON AND BANISTER 1977)

A Possible Model for the Depositional Geometry of Clifton
Member A.

In the light of the above discussion, a model can be presented to explain the cross-sectional depositional geometry of Member A (Fig. 16). This model is based on a migrating distributary lobe that sweeps from side to side of the distal, shallow-flooded portion of an alluvial plain. Migration would probably not be continuous (as illustrated in the figure) but in short avulsive steps. The distributary avulses because it fills its local basin with sediment. The distributary migrates to the area which has been subsiding (ie sediment starved) for a long period of time. The area it is migrating towards undergoes flooding, while the area it leaves undergoes emergence. The lateral distribution of lithologies is thus coal-mud-sand-soil-caliche.* Note that coal and caliche preferentially form at the edge of the plain where distance from sediment sources is maximised. Coal can follow caliche at one edge as a result of subsidence to base level (rising water table) when the distributary is at the other edge of the plain. Neither coal nor caliche is preferentially developed in the midportion of the plain, which is never far from sedimentation input.

*Allen (1974) has commented that known migration rates over an alluvial plain are rather high for a paleosol caliche to form.



A variety of factors, including balance between sedimentation and subsidence, rate of distributary migration, climate, slope and position on the alluvial plain will determine whether coal and caliche will form.

COAL.Prerequisites for Deposition of Peat.

Prerequisites for the development of a peat deposit and consequently for the formation of coal include:

- 1) fresh clear water (marine influx would kill the vegetation);
- 2) protection of swamp from clastic input (barriers, low regional relief);
- 3) a slow continuous rise of the water table to match the growth of peat (ie subsidence): if the water table rises too quickly the swamp will drown; if it rises too slowly, plant material on the surface will rot and peat already formed will be eroded;
- 4) favourable climate;
- 5) persistence of conditions in time and space.

Prerequisites as Related to Depositional Environment of Members A and B.

A. The climate was not favourable. Paleosol caliche indicates a climate in which the annual evaporation exceeded rainfall. The 500mm isohyet is commonly cited in the literature as an approximate upper boundary of caliche formation. However, in low latitudes (eg Tanzania) caliche occurs up to 750mm

isohyet (Goudie 1973). Higher rainfall is compensated by even higher evaporative losses. During the Carboniferous, New Brunswick lay on the equator, according to the reconstruction of Scotese et al. (1979: fig. 17). It is thus possible that though the climate was effectively semi-arid, the rainfall was significant.

One might expect that a semi-arid climate would restrict the number and type of plant species as well as their characteristics (eg narrow leaves, thick cuticles to reduce evaporative losses. Bell (1962) painstakingly described the flora from the Clifton Formation and the Pictou group of New Brunswick. The flora included tree ferns such as Lepidodendron and Calamites and their various components (whorled leaves, branchlets, roots) which are given separate "form" genus names as well as a variety of smaller fern-like herbaceous and arborescent vegetation. Some of the larger Lepidodendron remains found during the course of this study are illustrated in photos 37-39. Nowhere does Bell suggest any variation in form due to possible environmental differences between the Pictou in New Brunswick and Nova Scotia. Swamp vegetation of course can create its own shady microclimate, conserving moisture, in contrast to a much earlier, exposed surrounding. This may have been a factor.

Alkaline groundwaters from underlying or adjacent caliche zones flowing into swampy areas would reduce the acidity of the peat, hence accelerating bacterial activity

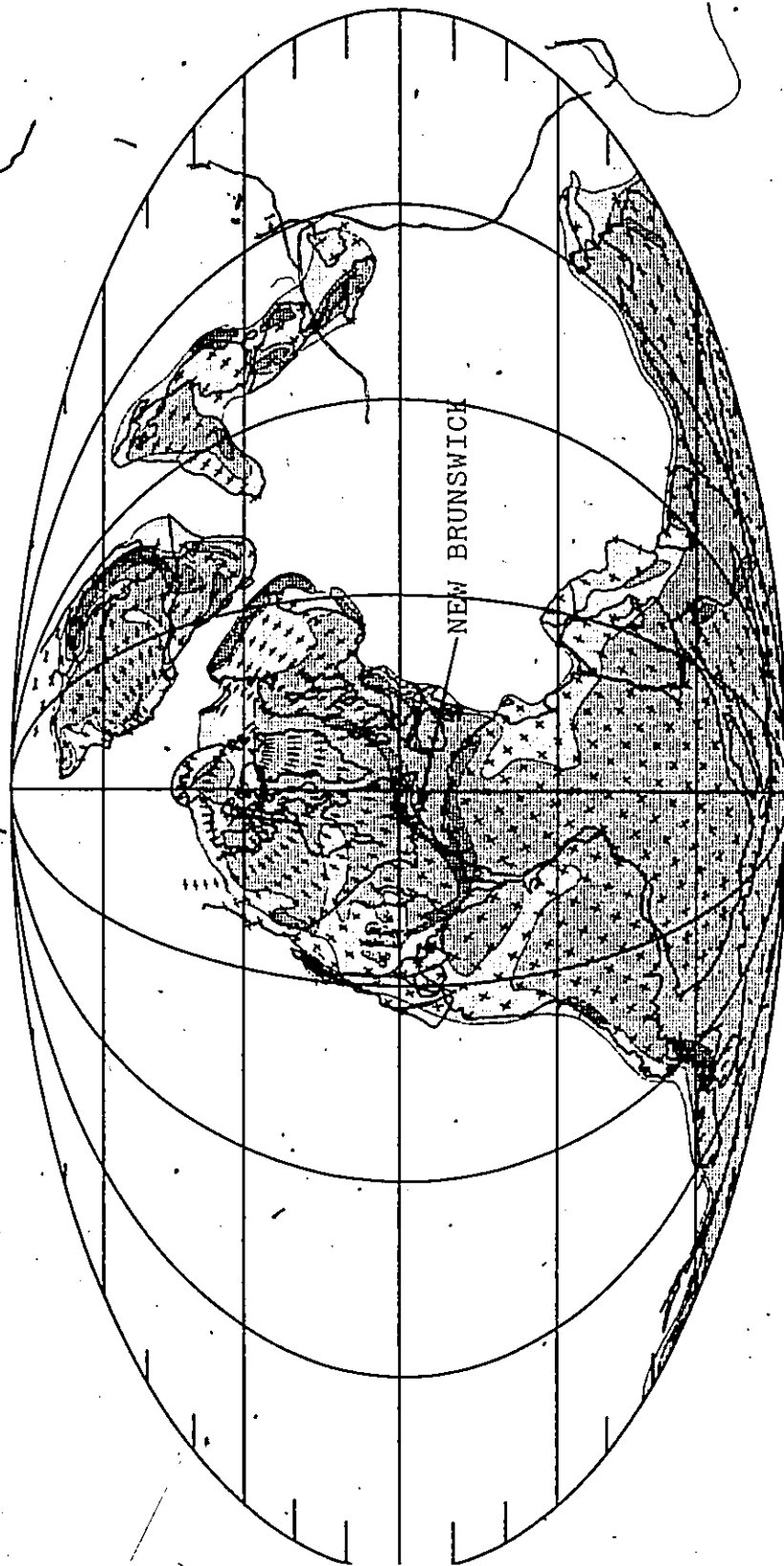


FIGURE 17. LATE CARBONIFEROUS (WESTPHALIAN CD) PALEOGEOGRAPHY. MOLLWEIDE PROJECTION "FRONT VIEW". Deep oceans, unshaded; shallow seas, light shading; low land, intermediate shading; mountains, dense shading. (After Scotese et al, 1979)

and the destruction of peat.

Stack et al. (1975) note that peat may occasionally form even in a steppe climate if the groundwater table remains sufficiently high over a long period.

"A condition for the formation of such a peat is a depression in the ground surface."

(Stack et al. 1975)

B. The basins in which peat deposition did occur were very shallow. The water level could only rise very slowly and peat could not form to any appreciable thickness.

It is worth explaining in some detail how the shape of an inland basin controls the thickness of coal that can form in it, for this applies to all coal seams in the Pictou Group of New Brunswick.

Falini (1965) in a most illuminating paper determined the rate of water rise for various shapes of limnic basins, for it is the rate of water rise that controls the growth of peat, its thickness and the nature of its constituents (arborescent or herbaceous). This is clear from the following:

- if peat growth rate cannot match the rate of water rise then the peat drowns;

- if peat growth can match the rate of water rise then the peat is maintained;

- if the water rise is very slow or stops, surface degradation of the peat will occur.

In simplest terms the rate of water rise for a limnic basin equals:

$$\frac{\text{volume inflow} - \text{volume evaporated}}{\text{surface area}}$$

As the water level rises the surface area of the lake will increase, therefore the rate of rise of the water will decrease with time. The shape of all lacustrine basins is between two extremes - a graben or rift with vertical walls; and a blocked, extremely flat valley which widens. In the first case the rate of water rise does not change with time unless a spillway is reached. In the second case, evaporation losses balance out inflow for even a small increment in the water level (since the surface area increases so rapidly). The height at which this balance occurs is called the equilibrium height. In all intermediate cases the water first rapidly rises, then the rate diminishes till the final equilibrium height is reached.

In a graben or rift, the thickness of coal that can be deposited is equal to the depth of the basin provided that the water rise is sufficiently slow - a rate that the peat can match. In an extremely flat valley the water level may rise only a few centimetres before equilibrium (between evaporation and inflow) is reached. A swamp develops but does not persist, for silting raises the basin floor.

"Only occasional accumulations of vegetable matter may form, always of limited thickness and extent, in the ponds left here and there between alluvial cones

formed at the mouth of the tributaries."

(Falini 1965)

In intermediate cases there is a limited range within which the rate of rise of the water level can be matched by the growth of the bog. The thickness of peat that can form lies between the two extremes of graben and flat valley (and can be calculated if the geographic characteristics, shape, inflow, specific evaporative loss, etc. of the basin are known).

Falini derived several "laws" relevant to prerequisites of climate and water rise and coal thicknesses in New Brunswick (particularly the Minto seam).

1) Total peat thickness is proportional to inflow (basins supplied by larger rivers can produce thicker peat).

2) For a given inflow the thickness of peat deposited is smaller, the lower the inclination of the sides of the basin.

3) For a given inflow and any basin shape the thickness is inversely proportional to the specific yearly evaporation.

C. Peats were not protected from clastic input. Abundant coal spar and even disrupted coal seams in Member B suggest that overbank peat swamps did develop. However, shifting channels dispersed any accumulation of plant remains before they were sufficiently buried.*

*A non-commercial coal seam, presumably of autochthonous origin (ie in situ peat) is present in the Caraquet area in Clifton Member B. (Ball et al, personal communication)

CONCLUSIONS.

The depositional environment of ~~Member~~ A is interpreted to be that of a major semi-arid flood basin fed by the distal waters of a braided fluvial system. Cycles in the flood basin represent periodic progradation and abandonment of distributary lobes. During progradation, flow was channelized proximally, but distally spread as sheet flow as successive distributaries bifurcated. Time breaks in flooding were of sufficient length that trees grew in emergent levées adjacent to channels. Abundant mudshale partings and intercalations in crevasse splay sands attest to the variability in discharge and climbing ripples to the spreading of sediment-charged flood water flow.

In each cycle, the local gradient decreased as a result of distributary sedimentation and water was ponded between emergent crevasse splays. An avulsion switched sedimentation to an adjacent subsided portion of the flood basin. In the abandoned distributary lobe, the drainage disintegrated, followed by extensive rooting and caliche soil formation. Thicker soil profiles developed in abandoned channels where the sedimentation rate was a little higher and there was greater variation in the groundwater table. Given sufficient exposure during abandonment, calcareous hardpans formed in depressions. Deep desiccation led to caliche soil roof pendants extending several metres downward. These penetrated underlying channel and crevasse splay sands.

As the sedimentation rate during pedogenesis was very low, eventual net subsidence occurred. This had two effects: the water table rose and the fluvial system migrated back to the subsiding lobe. The rise in water table was marked by the top of the soil profile being leached and capped by thin peat deposits. A calcareous hardpan with thin regolith overlain by soil and 30 cms of coal is the best documented evidence of long term exposure being followed by long term submergence.

Renewed sedimentation began as flood waters of the fluvial system once again encroached into this part of the flood basin, distally depositing red mud shales that buried thin peats. This marked the beginning of the next flood cycle.

Over a period of many flood cycles the fluvial system prograded over the flood basin. Thick fluvial distributary channel units near the top of Member A mark this change. The massive sandstone at the base of Member B probably marks an avulsive event in which a primary distributary began deposition.

The presence of paleosol caliche in each distributary flood cycle of Clifton Member A indicates that pedogenesis occurred over a period of thousands of years under a climate where yearly evaporation exceeded rainfall. Due to New Brunswick's position on the paleo-equator during Pennsylvanian times (ie high evaporation rates), caliche may have formed under a significant rainfall, of as much as 750mm per year. The superimposition of distributary flood cycles might be

explained by a model based on side to side sweep of distributaries on a shallowly flooded alluvial plain. This model predicts an association of coal and caliche on the margins of the plain where sedimentation is potentially the least.

Coal did not form commercial seams in Member A since:

- a) the climate was not favourable (semi-arid);
- b) the basins of deposition were very shallow. (With flooding, the surface area increased rapidly and the water level rose only a few centimetres before reaching evaporation equilibrium. Any peat growth during water rise thus underwent surface degradation during stillstand).

Coal did not form commercial seams in Member B due to abundant channel shiftings and erosion of overbank sediments.

Coal is mostly present as transported plant debris and peat mats in various stages of dispersal by current activities.

PHOTOGRAPHS.

Photos 1-30 pertain mainly to Clifton A

Photos 31-39 pertain mainly to Clifton B

The reader will find it worthwhile to examine photos 1-30 in conjunction with the composite section fold-out of Member A found in the back pocket. Photos of measured sections and various features can be matched with their diagrammatic representation in the fold-out as well as be put in proper locational perspective.

PHOTO 1.

Clifton Formation, Member A (shales, seat earths and thin sandstones)

overlain by Member B (thick grey ss.s).

Rod at lower right 2.4m long.

Carbonaceous clay laminae used as

marker horizon sharply delineated

as a line of seepage to left of rod.

LOCATION: Section A, near New Bandon.

PHOTO 2.

Large shallow troughs of facies St.
Flow direction to left.

LOCATION: Stonehaven, near Section I.

PHOTO 3.

Bedding plane exposure of coal spar.

plant litter derived from sand washout

of adjacent peat. Hammer 32cms.

LOCATION: Stonehaven, near Section I.



PHOTO 4a.

Facies Sr: climbing ripples with accentuation of low angle of climb by fractures.

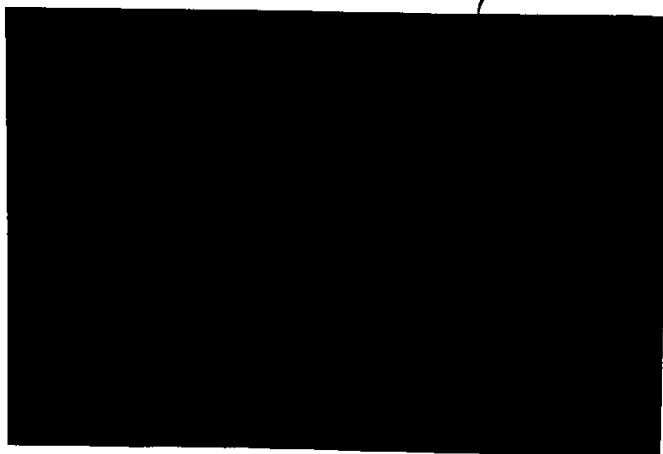
PHOTO 4b.

Climbing ripples with anomalous heavy suspension drape.
Hammer 32cms long.

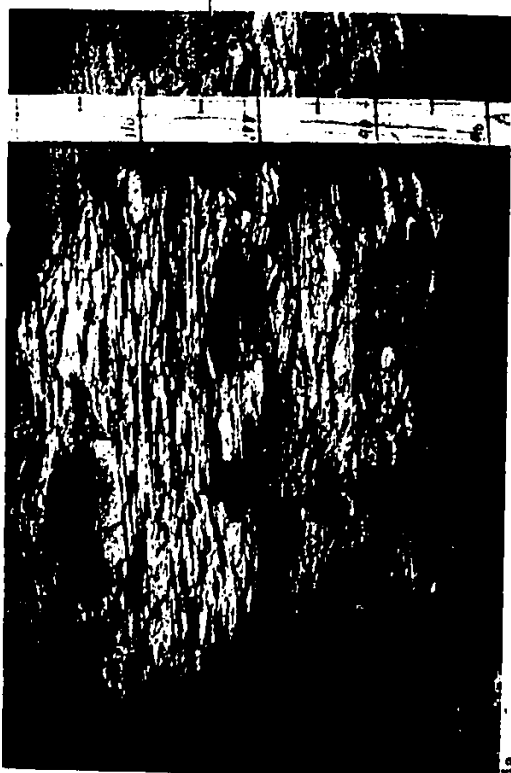
PHOTO 5.

Facies Sr: rib and furrow current structure - bedding plane exposure of facies Sr. Flow direction bottom to top. Pen is 15cms long.

LOCATION: base of Section C, New Bandon.



5



4a



4b

PHOTO 6.

Caliche encrusted vertical fissure in facies Sr.
Note contrast in appearance of joint surface
behind 2.4m rod and fissure wall to right of rod.
(See also photos 29,30)

LOCATION: between Section A and Section B, New
Bandon.

PHOTO 7.

Close up of fissure wall in photo 6, with pisolithic
caliche crust.



6



7

PHOTO 8.

Composite sheet sandstones with shale intercalations. Note tree trunk cast adjacent to 32cm long hammer, at extreme right. Other casts faintly visible to left.

LOCATION: near base of Section C.

PHOTO 9.

Close-up of tree trunk cast in photo 8 enclosed by crevasse splay sandstone.

PHOTO 10.

Stigmara (root) in facies Fl.



10



8.



9.

PHOTO 11.

Mottled seat earth of facies Fr

Pen is 15cms long.

PHOTO 12.

Caliche hardpan abruptly overlain
by seat earth (near rod top)
followed by thin coals immediately
underlying sandstone body. 2.4m
rod towards bottom left. (See also
photos 29, 30).

LOCATION: near Section K, Clifton

PHOTO 13.

Thick sandbody of Clifton Formation

Member A, interpreted as a primary
fluvial distributary deposit. Cliffs
15-20m high.

LOCATION: near Section F, between New
Bandon and Stonehaven.



12



11



13

PHOTO 14.

Thick sand body of Clifton Member A: incised channel edge. Cliffs 25m high. Sharp horizontal line 0.8cm above channel top in photo is a carbonaceous clay marker horizon. Compare photo with Section F in fold-out.

LOCATION: immediately to left of Section F.

PHOTO 15a.

View of Section I from Section J. Thickening of sandbody results in formation of a resistant headland. Thickened sandbody may represent deposits of an active distributary channel. Cliffs about 15m high.

PHOTO 15b.

Close-up of headland sandbody in photo 15a showing trough cross-bedding. Rod 2.4m long.

LOCATION: near Section I.

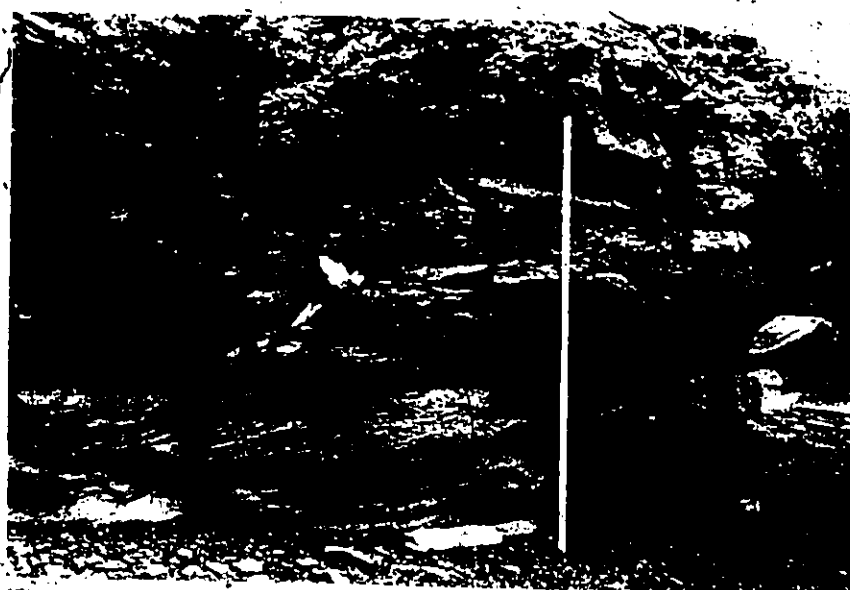


PHOTO 16.

Clifton Member B overlying
Clifton Member A.

Note channel fill in sandbody
to right and above 2.4m rod.

Carbonaceous clay marker
horizon distinct as seepage

line above sandbody. (See
photo 21 for close-up; see
also Section B in fold-out.)

LOCATION: Section B, New Bandon.



PHOTOS 17-20.

Meandering channel deposits.

Channel edge (extreme top left) is followed by in-channel lateral accretion surfaces (point bar deposits) in photos 18, 19 (top right, bottom left). Overbank deposits in photo 20 (bottom right). Note three distinct units above sandbody:

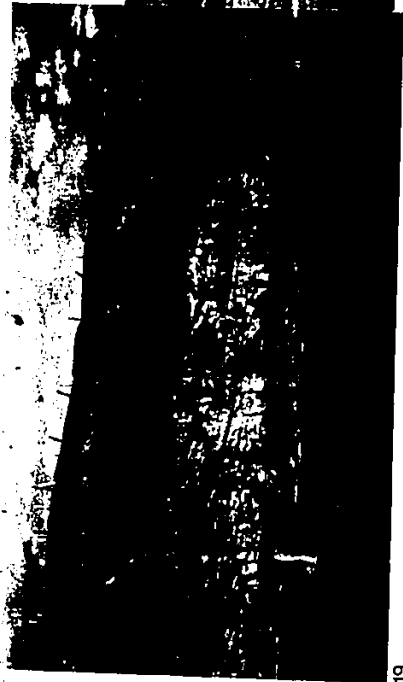
↑ red mudshales
mottled seat earth
nodular caliche layer



18



17



19



20

PHOTOS 21-23 (top to bottom)

Lateral variation in the deposits of a crevasse splay or distributary lobe.

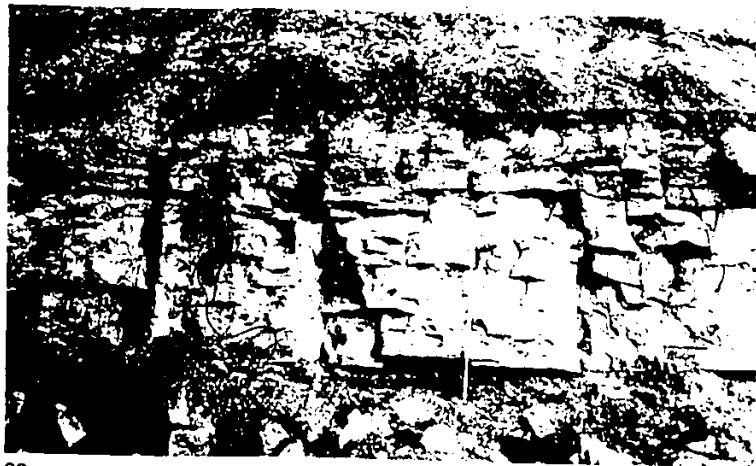
The sandstones of the lobe thin and split laterally. Where thickest (photo 21) an abandoned channel is present with adjacent levée. Note the persistent seepage line of carbonaceous clay above the lobe.

LOCATION: between Sections A and B.

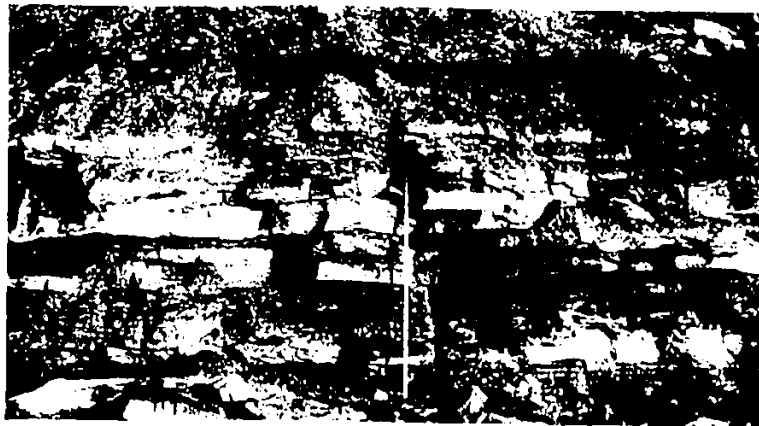
(approx. 100m between sections)



21



22



23

PHOTO 24.

Thick sand body of Clifton Member A:
pinnacle of red shale at base.

LOCATION: near Section F.

PHOTO 25.

Parting lineation: indicator of upper
flow regime deposition.

LOCATION: as above.

PHOTO 26

Caliche interclasts as lag deposit at base
of sheet sandstone. Sheet sandstone in
sharp contact with underlying grey
carbonaceous shale.

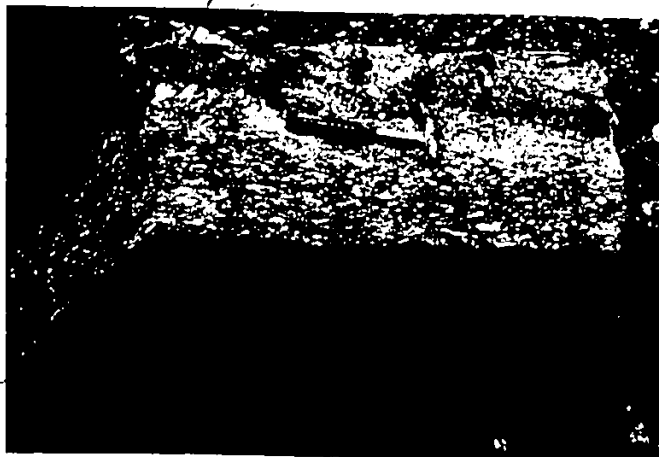
LOCATION: Clifton.



24



25



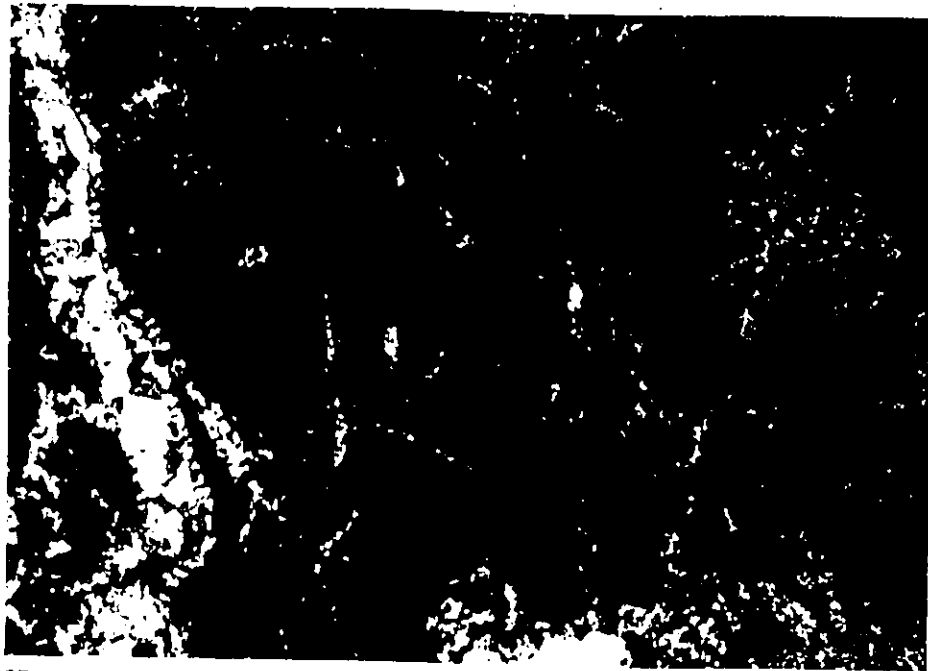
26

PHOTO 27.

Caliche microstructure, soil peds and crystallaria: multiple generations of calcite veins bind angular to round areas made of calcite microspar and red mud. Note radial fabric of calcite microspar surrounding mud cores. Photo taken under crossed nicols. Scale under photo = 1mm.

PHOTO 28.

Caliche hardpan nodule with embedded pebbles (regolithic). The pebbles demonstrate that the caliche hardpan was subaerially exposed. Scale in cm.



27.



28

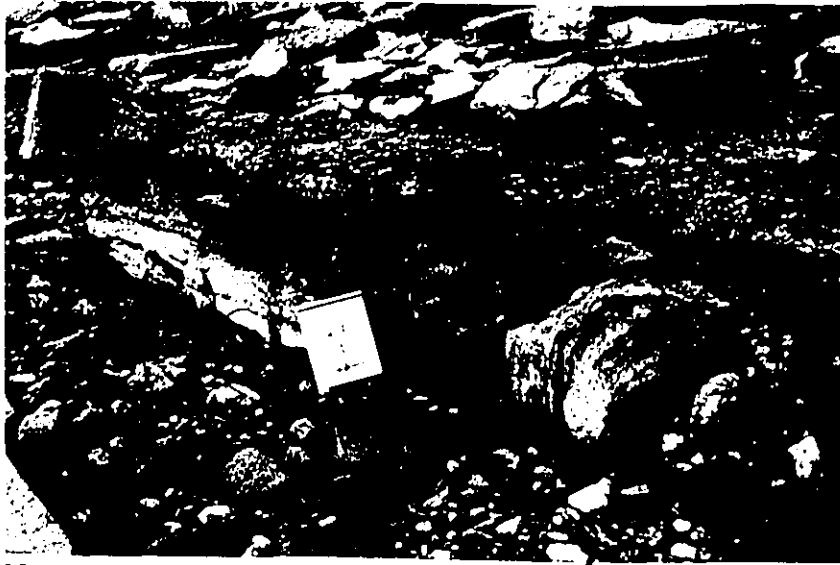
PHOTO 29.

Caliche hardpan and adjoining vertical wedge exposed in fallen block at Clifton. Scale (32cm x 25cm) clipboard leans against vertical wedge.

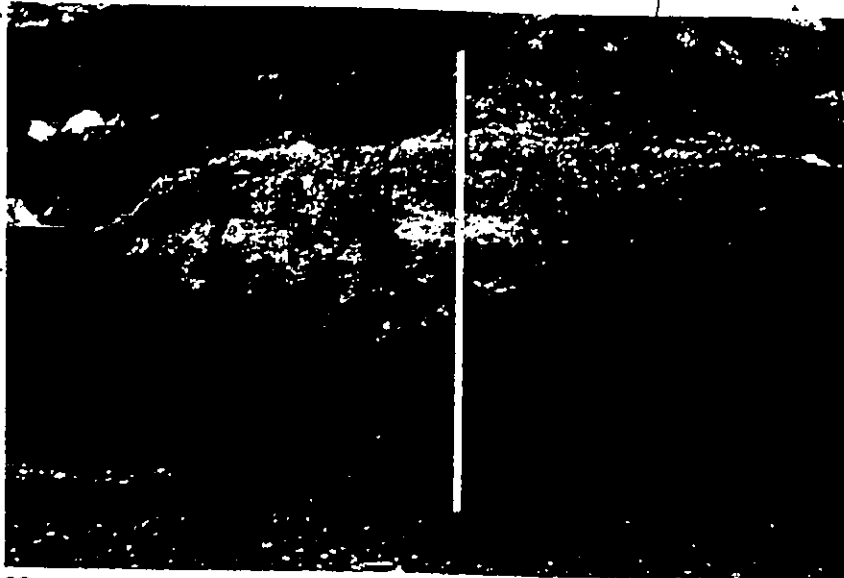
PHOTO 30.

Outline of exposed vertical wedge (parallel to plane of photo) to right of rod with connection to hardpan surface above. Hardpan forms a ledge in the photo.

LOCATION: Clifton.



29



30

PHOTO 31.

Facies St of Clifton Member B showing unidirectional trough cross-bedding.

2.4m rod at lower right.

LOCATION: mouth of Little Pokeshaw River.

PHOTO 32.

Outline of large channel in grey

sandstones of Clifton Member B.

15m cliffs.

LOCATION: Pokeshaw beach.

PHOTO 33a.

Large abandoned channel fill in Clifton

Member B. Top of 2.4m rod at left

of centre marks base of fill. Fill is

lens-like in shape with the top planar

and the base concave up. Approx. width

of exposure is 120m.

LOCATION: mouth of Little Pokeshaw River.

PHOTO 33b.

Close-up of base of channel fill in photo 33a.

Note upward fining, decreasing cross-bedding set size, and progressive change in current structures (St→Sp(Sr)→Sh) indicative of waning flow.

(see text p.37)



33a



33b



31



32

PHOTO 34

Intraformational conglomerate consisting of caliche fragments. Bedding plane exposure near Maisonette lighthouse.

PHOTO 35

Sculptured coastline of Clifton Member B between Grande Anse and Pokeshaw.

PHOTO 36

Discontinuous thin coals enclosed in Clifton Member B sandstone with associated abundant plant litter and wood trash on bedding and cross-bed surfaces. Thin coals interpreted as rafted peat mats. Dipping coal may represent an imbricate peat mat. Cross-bedding suggests flow from left to right.

LOCATION: cliffs by Lower Caraqueet Wharf.



34



35



36

PHOTO 37.

Lepidodendron stem.

LOCATION: Clifton.

PHOTO 38.

Lepidodendron stem

with needle-like foliage.

LOCATION: Clifton.

PHOTO 39.

Current aligned Lepidodendron?.

leaf needles.

LOCATION: Clifton



37



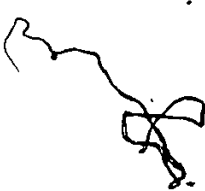
38



39

ACKNOWLEDGEMENTS.

First of all, I would like to thank my supervisor, Dr Brian Rust, who provided the opportunity and freedom to pursue this research topic and whose door was always open for consultation. Equal appreciation goes to my wife who typed the manuscript and was patient with me as I juggled words and phrases moments before they were to be typed.



This thesis benefited from the kind listening ear of Brian Zaitlin and the terse, to the point comments on technique of the departmental photographer and draughtsman, Edward Hearn. My thanks to Dr Owen Dixon for making me aware of the importance of a clear format in a thesis, and its overall organisation.

A special thanks to Mike Jackson for logistic support and for loosening the purse strings when necessary.

Last but not least, I would like to thank all the members of the Geology Department at the University of Ottawa, staff and students alike and in particular Hamid Majid for making this the convivial work place that it was during my stay, September 1978 - September 1980.

REFERENCES CITED.

- A.D.I. Ltd. 1974. New Brunswick Electric Power Commission, Site Investigation in Report on the Investigation of Pennsylvanian Strata in Northeastern New Brunswick by D.O. Downing, Resource Associates Ltd, Fredericton, New Brunswick.
- ALCOCK, F.J. 1935. Geology of Chaleur Bay Region, Geol. Surv. Can. Mem. 183, 146 p.
- ALLÉN, J.R.L. 1974. Studies in fluvial sedimentation: Implications of pedogenic carbonate units, Lower Old Red Sandstone, Anglo-Welsh outcrop, Geol. J., Vol. 9, Pt. 2, pp. 181-208.
- BALL, F.D. and GEMMELL, D.E. 1975. Carboniferous Compilation, Vol. II, Coal, Topical Report 75-20, Mineral Resources Br., Dept. of Natural Resources, Prov. of New Brunswick.
- BARSS, M.S. and HACQUEBARD, P.A. 1967. Age and stratigraphy of the Pictou group in the Maritime Provinces as revealed by fossil spores, Geol. Assoc. Can. Spec. Paper no. 4, pp. 267-283.
- BELL, W.A. 1962. Flora of Pennsylvanian Pictou group of New Brunswick. G.S.C. Bulletin 87, 71 p.
- BIRKELAND, P.W. 1974. Pedology, Weathering and Geomorphological Research, 258 p., Oxford University Press, New York.
- COLEMAN, J.M. 1969. Brahmaputra River channel processes and sedimentation, Sedimentary Geology 3, pp. 129-239.
- COLLINSON, J.D. 1978. Vertical sequence and sandbody shape in alluvial sequences, Fluvial Sedimentology, ed. Andrew D. Miall, C.S.P.G. Memoir 5, pp. 577-586.
- DUFF, P.M. and WALTON, E.K. 1973. Carboniferous Sediments at Joggins, Nova Scotia, Septième Congrès International de Stratigraphie et de Géologie du Carbonifère, Compte Rendu Band II, pp. 365-379.
- ELLIOTT, T. 1974. Intertributary bay sequences and their genesis, Sedimentology V, 21, pp. 611-622.
- FALINI, F. 1965. On the formation of coal deposits of Lacustrine origin, G.S.A. Bulletin, V. 76, pp. 1317-1346.

- FISK, H.N. 1961. Bar-finger sands of the Mississippi Delta. In: Geometry of Sandstone Bodies: Am. Assoc. Petroleum Geologists, pp. 29-52.
- GAGLIANO, S.M. and van BEEK, J.L. 1970. Geologic and geomorphic aspects of deltaic processes, Mississippi delta system, In: Hydrologic and Geologic Studies of Coastal Louisiana, Report No. 1, pp. 140. Centre for Wetland Resources, Louisiana State Univ.
- GARDNER, L.R. 1972. Origin of the Mormon Mesa Caliche, Clark County, Nevada, Bull. Geol. Soc. Am., 83, pp. 143-156.
- GOUDIE, A. 1973. Duricrusts in Tropical and Subtropical Landscapes, 175 p, Clarendon Press, Oxford.
- HUBERT, J.F. 1978. Paleosol caliche in the New Haven Arkose, Newark Group, Connecticut. Paleogeogr., Paleoclimatol., Paleoecol., 24, pp. 151-168.
- HUDDLE, J.W. and PATTERSON, S.H. 1961. Origin of Pennsylvanian Underclay and Related Seat Rocks, G.S.A. Bulletin, V. 72, pp. 1643-1660.
- JACKSON II, R.G. 1976. Large scale ripples of the lower Wabash river, Sedimentology, V. 23, pp. 593-623.
- JOHNSON, P. and BANNISTER, A. 1977. Okavango: Sea of land, Land of water, 201 p., C. Struik, Cape Town.
- LEEDER, M.R. 1975. Pedogenic carbonate and flood sediment accretion rates: a quantitative model for alluvial, arid-zone lithofacies. Geological Magazine V. 112, pp. 257-270.
- MABBUTT, J.A. 1967. Geomorphology of the area, App. 4, In: Gregory, C.M., Senior, B.R. & Galloway, M.C., Bur. Min. Res., Geol. Geophys. Rec. 1967/16: The geology of the Connemara, Jundah, Canterbury, Windorah and Adavale 1:250,000 sheet areas.
- McALARY, J.D. 1952. Marginal Phase of the Pennsylvanian sediments in Northern New Brunswick, Univ. Toronto, unpubl. M.Sc. thesis.
- MIALL, A.D. 1977. Fluvial Sedimentology, Short Course Notes, Stacs Data Service Ltd, Calgary.
- MIALL, A.D. 1978. Lithofacies types and vertical profile models in braided river deposits: a summary. In: Fluvial Sedimentology, ed. A.D. Miall, C.S.P.G. Memoir 5, pp. 597-604.

- PETTIJOHN, F.J. 1975. Sedimentary Rocks, 3rd edition. Harper and Row, New York. 628 p.
- READING, H.G. (editor) 1978. Sedimentary Environments and Facies, 557 p. Elsevier, New York.
- REEVES, C.C. Jr., 1976. Caliche. 233 p. Estacado Books, Lubbock, Texas.
- RUST, B.R. 1972. Pebble orientation in fluvial sediments, J. Sediment. Petrol., V. 42, pp. 284-288.
- RUST, B.R. 1978a. Depositional models for braided alluvium. In: Fluvial Sedimentology, ed. A.D. Miall, C.S.P.G. Memoir 5, pp. 605-626.
- RUST, B.R. 1978b. A classification of alluvial channel systems. In: Fluvial Sedimentology, ed. A.D. Miall, C.S.P.G. Memoir 5, pp. 187-198.
- RUST, B.R. 1979. Sedimentology and Channel Morphology in Cooper's Creek, Central Australia: an example of climatic lag in an arid fluvial system. G.A.C. Prog. Abs., Annual Meeting, 1979 vol. 4, p. 76.
- SCHUMM, S.A. 1968. River adjustment to altered hydrologic régime - Murrumbidgee River and paleochannels, Australia. Prof. Paper U.S.G.S., 568, 65 p.
- SCOTSESE et al., 1979. Paleozoic Base Maps, Journal of Geology, V. 87, pp. 217-277.
- STACH, E. et al., 1975. Coal Petrology, Gebruder Borntraeger, Berlin.
- STEEL, R.J. and AASHEIM, S.M. 1978. Alluvial sand deposition in a rapidly subsiding basin (Devonian, Norway). In: Fluvial Sedimentology, ed. A.D. Miall, C.S.P.G. Memoir 5, pp. 385-412.
- van de POLL, H.W. 1978. Stratigraphy, sediment dispersal and facies analysis of the Pennsylvanian Pictou group in New Brunswick, Maritime Sediments, Vol. 9, No. 3, pp. 72-77.
- VEEVERS, J.J. and RUNDLE, A.S. 1979. Channel Country fluvial sands and associated facies of central eastern Australia: modern analogues of Mesozoic desert sands of South America, Paleogeogr., Paleoclimatol., Paleoecol., V. 26, pp. 1-16.

WHEELER, W.H. and TEXTORIS, D.A. 1978. Triassic limestone and chert of playa origin in North Carolina, Journal of Sed. Pet., V.48, no. 3. pp765-776.

WILLIAMS, G.E. 1973. Late Quaternary piedmont sedimentation, soil formation and paleoclimates in arid South Australia. Zeit. Geomorph. 17, pp102-125.

APPENDIX I

	Clifton B		Clifton A		Clifton A	
	Grey Sandbody		Thick Sandbody		Thin Sandbody	
Roundness	subangular		subrounded		subrounded?	
size range	0.1 - 1.0mm		0.2 - 0.7mm		0.1 - 0.2mm	
mean size	0.5mm		0.4mm			
sorting	4 classes (v.f.s.-c.s.)		3 classes (f.s.-c.s.)		2 classes (v.f.s.-f.s.)	
cementation	fair-poor		fair		good	
Grain types						
quartz	38		39		50	
quartzitic	19		21			
volcanic	11		12		35	
other (micaceous)	7		3			
Groundmass	20		21			
feldspar	3		1		1	
opals	3		1		1	
carbonate (interstitial)	0		1		2	
Total	101%		99%		99%	
Sandstone type	lithic arenite		lithic arenite		lithic arenite	
Comments	chloritic and micaceous material in groundmass (squeezed interstitially)		chalcodony in groundmass (recrystallised volcanics?)		quartz overgrowths poor grain distinction (recrystallisation and leaching?)	

PETROGRAPHIC DATA OF THREE SANDSTONES BASED ON REPRESENTATIVE HAND SPECIMENS.

APPENDIX IIREPORT ON THE THIN SECTION ANALYSIS OF
SAMPLES FROM POINT CAPLIN A.D.I. Ltd. 1974.PURPOSE OF EXAMINATION

Specimens of sandstone have been selected to consider their permeability and porosity, to examine their matrix and to suggest possible variations in the properties of these rocks when subjected to diverse conditions of loading and weathering.

GENERAL PETROGRAPHY OF SPECIMENS FROM POINT CAPLIN

The Point Caplin sandstones are medium to coarse grain with the major part of the sediment grains being quartz and feldspar with a substantial proportion consisting of chips of volcanic rock. The average grain size of the sandstone varies from diameter 0.2 mm to diameter 0.4 mm. Occasional coarser grains, chips and fragments are present. The sandstones are normally well-sorted and the grains vary from distinctly angular to sub-rounded.

In general there are two principal types of sandstone in the cores: (1) the fine grained buff uniform sandstone, (2) coarse reddish sandstone with white patches and fragments of carbonate bearing shales. As an example of the first series the specimen from Point Caplin borehole A taken at the depth of 73.5', while Point Caplin borehole B at the depth of 66'6" has furnished an example of the second type.

Point Caplin BH A 73.5'

Fragments: quartz (50%), fragments of lava, (15%), granite

fragments (10%), feldspar, both potassic and sodic (8%), quartzite (2%). The fragments of lava are highly altered and chloritized. They represent the weak constituent grains in the aggregate.

Matrix: only 5% of matrix is present; it is in part shaley and in part calcareous. The implication is that the grains are well packed and the rock is relatively strong with respect to normal weathering and in position of loads. However, the presence of larger proportions of altered lavas would render it much weaker with respect to freeze and thaw. The porosity is so low that it is unlikely that the rock would have any pore-space ground water and only joint space water is expected.

Point Caplin BH B 66.5'

Fragments: quartz (50%), microcline (10%), plagioclase (12%), volcanic and chloritised fragments (20%), fine grained quartzite (6%). The quartz fragments are angular, some are broken into sharp fragments with calcite crystallized in between.

The matrix as a whole, is recrystallized into a coarse mosaic of calcite with 10 to 12 grains of fragments often being included in the recrystallized limestone. The recrystallized matrix is abundant forming up to 20% of the rock. The grains of quartz and other fragments look "suspended" in the matrix and do not touch each other (the wacke texture). There is not much obvious porosity; but since the calcite (CaCO_3) is highly soluble in acid solutions (e.g. rainwater) it is certain that calcareous sandstones of this type owing to internal solubility will be porous or will soon become porous under near-surface conditions. Rocks of this type are susceptible to rapid weathering and under prolonged, unconfined loading are likely to yield plastically, since calcite easily develops

glide twins. The origin of this rock is assessed to be due to development of caliche at the time of deposition and therefore for constructional purposes it should be avoided. By caliche one means a calcareous crust of weathering formed during the deposition of the sandstone.

Point Caplin BH A 35'5"

For comparison with other rock types a random specimen of pale buff sandstones from Point Caplin was selected at the depth of 35'5". It turned out to be composed of highly packed grains of quartz (50%), feldspars (20%) and miscellaneous rock fragments including acid and basic lavas (30%) with some shaley and calcareous cement, which does not form more than 2 to 4% of the bulk of the rock.

Point Caplin - BH A 44', BH B 46', BH B 56'

From Point Caplin the samples of reddish buff sandstone (depth 44'.0, Borehole A and depth 46'.0, Borehole B). The sandstones are coarse with grains of up to 1/2 mm across. The sample from 44' has been analysed in detail and yielded the following results:

Fragments and grains - quartz 50% subangular grains
feldspar 15% both potassic
plagioclase
rock fragments 15% quartzite
and slate
lava fragments 10-15% mainly acid
matrix - rare calcite.

There are some quartz fragments which are deformed and there are some muscovite flakes. The sediment is sorted as to the grain size, but it is very immature. Although this rock is formally a sandstone, because of the presence of large number of rock fragments etc., it will weather relatively easily.

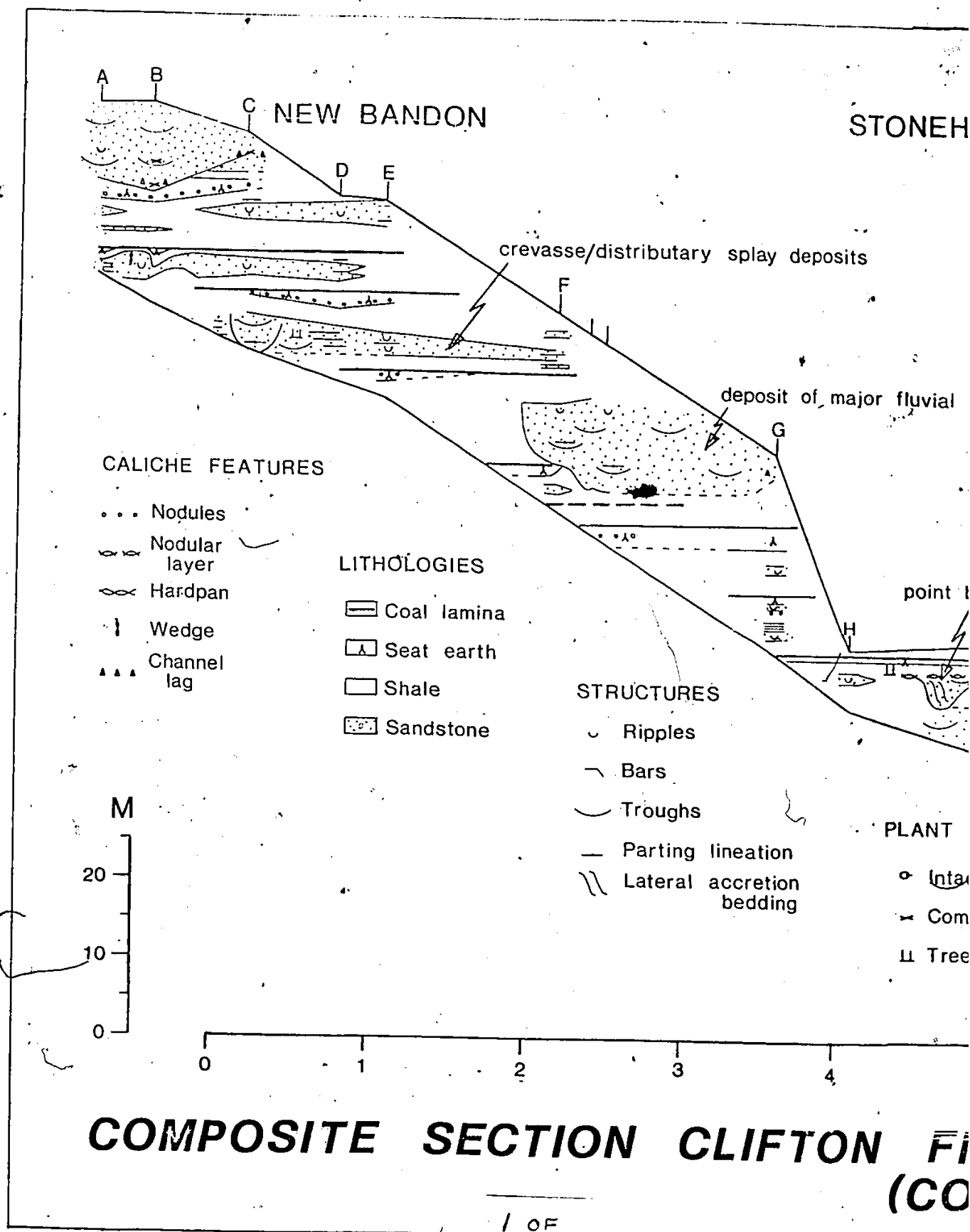
Under construction conditions it will behave as a competent rock. The texture is packite and the rock has a relatively low porosity (less than 10%).

The 46'.0 sample is compositionally similar, but the rock fragments are flatter and have an overall dimensional orientation. Again the rock will be competent.

The 56'.0 sample from Point Caplin on the other hand is a calcareous sandstone of wackite texture with large fragments and nodules. It is a typical caliche type sediment. It will weather and crumble easily and is basically incompetent. Its bearing capacity will be low since some of the fractures in the rock have undergone solution. The permeability of the rock is quite high.

FIGURE 18.

COMPOSITE SECTION CLIFTON FORMATION
UPPER PART OF MEMBER A.



STONEHAVEN

CLIFTON

tributary splay deposits

coal lamina
DISTRIBUTARY FLOOD CYCLE

deposit of major fluvial distributary

point bar deposits

sump basin deposits

STRUCTURES

Ripples

Bars

Troughs

Parting lineation

Lateral accretion
bedding

PLANT REMAINS

○ Intact, leafy

✕ Comminuted

⌌ Tree trunk casts



3 4 5 KM

N CLIFTON FM. MEMBER A
(COASTAL DIP REMOVED)

20F2