TRIASSIC SEDIMENTOLOGY, ST. MARTINS AND LEPREAU, N.B.

THE STRATIGRAPHY AND SEDIMENTOLOGY OF THE TRIASSIC AT ST. MARTINS AND LEPREAU, NEW BRUNSWICK

By

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Abstract

Two small Triassic basins in southern New Brunswick were examined. The eastern basin, centered approximately 30 km east of Saint John, consists of three formations. The lower unit, renamed the Honeycomb Point Formation, resting unconformably on Carboniferous sediments, consists of redbeds and sandstones and was deposited on a semi-arid alluvial fan with flow predominently eastward. Some of the sands were reworked into small dune fields migrating to the southwest.

The lower redbeds are unconformably overlain by the roundstone conglomerates and coarse-grained, gray-green, trough crossbedded sandstones of the Quaco Formation. These sediments were deposited by a large braided river which initially flowed northward but which was later deflected toward the northeast by the growth of alluvial fans.

In the western end of the basin the Echo Cove Formation overlies the Quaco conglomerate. It can be divided into four members, all of which represent alluvial fan deposition. The members are partially time transgressive but are characterized by different facies, paleocurrent directions and climates.

Pollen analysis of sandstones from the upper portion of the Fownes Head Member indicates a mid-Late Carnian age for the sediments.

The Lepreau Formation outcrops along the coast approximately 70 km west of Saint John. It was subdivided into three members. The lower member consists of breccias (predominantly granite) which laterally interfinger with fine to medium grained massive sandstones

deposited on a semi-arid alluvial fan. These are unconformably overlain by a complex series of conglomerates, medium and coarse-grained sandstones and red shales. This unit is gradationally overlain by breccias forming a thickening and coarsening upward sequence.

Regional plate tectonic studies of the initial rifting of the Atlantic show graben formation controlled by four major transform fault systems. The postulated presence of a mantle hot spot along the Kelvin Fracture Zone and the associated doming of the region may have been in part responsible for the northward dipping paleoslope indicated by the Quaco Formation. Palynological studies of the Triassic basins on the continental United States and Eastern Canada show that while the grabens formed along more or less the same zone of structural weakness, they did so as two separate systems. Those in the United States began in South Carolina in the Mid to Late Carnian and gradually opened northwards. Those in Canada also began in the Mid to Late Carnian, however, because of structural weaknesses in the crust caused by the closing of the Proto-Atlantic, the basins opened toward the northeast.

Acknowledgements

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Chapter 1

Introduction

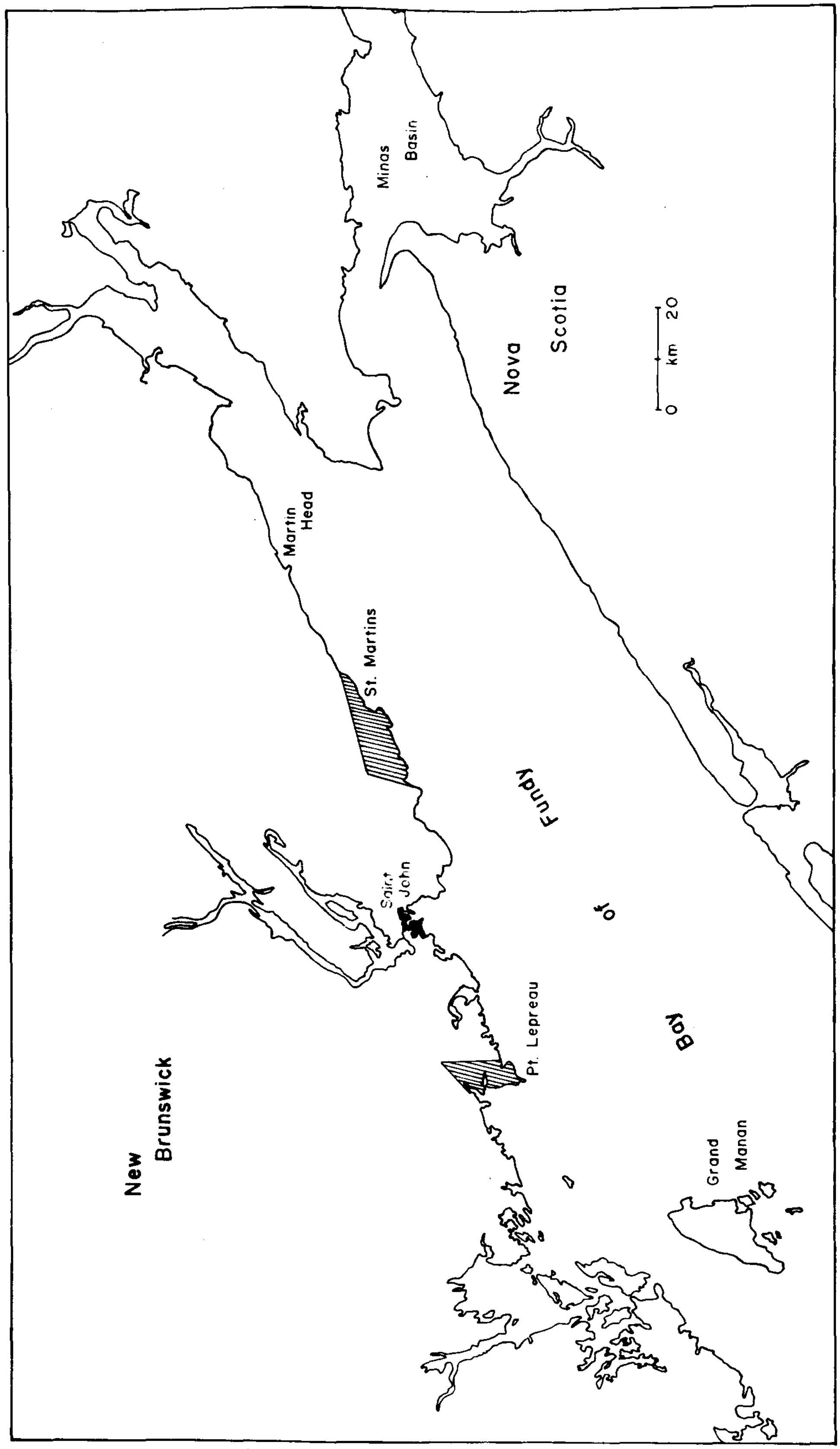
1.1 Purpose and Scope

The original intent of this study was to work out the detailed sedimentology and reconstruct the paleo-environment of two separate blocks of Triassic sediments on the southern coast of New Brunswick (Figure 1.1). Detailed work on one of the areas, the Lepreau penninsula, was severely curtailed when it was discovered the areal extent of the Triassic in and around St. Martins was much greater than previously supposed. Detailed work was restricted to part of the St. Martins area. A geologic map of the Triassic in both regions was constructed. Paleocurrents were measured and the depositional environment was determined for both areas through a generalized facies analysis of the rocks.

1.2 Geographical Setting

The St. Martins group of formations lies approximately 30 km east of Saint John. The extent of the exposures ranges from 65° 42' 30" to 65° 27' 45" W longitude and 45° 24" to 45° 16' 30" N latitude. This is covered by the NTS 1:50,000 series maps 21 H/5 (Loch Lomand) and 21 H/6 (Salmon River). Further detail was provided by the New Brunswick Department of Natural Resources 1/4 mile map series which cover this area on maps R-27, R-28 and Q-28.

Figure 1.1 General location map of study areas. Lepreau is to the west of Saint John, St. Martins to the east.


Minas Basin
Nova Scotia
0 km 20
Martin Head
St. Martins
Bay of Fundy
Saint John
Pt. Lepreau
New Brunswick
Grand Manan

The outcrops are exposed in a small sedimentary basin bounded on three sides by fault contacts with Precambrian to Devonian volcanics and intrusives (Figure 1.2). The latter form the highlands from which numerous streams and creeks flow down to and across the basin. Inland, outcrop is limited to these stream cuts and major roads because of the extensive cover of glacial sediments in the region. The best exposures occur along the coast where they form bluffs 30 to 50 m high.

The Lepreau area is 50 km west of Saint John ranging from 66° 30' to 66° 25' W longitude and 45° 03' 20" to 45° 10' 20" N latitude. This is covered by the 1:50,000 map 21 G/1W (Musquash) and M-30, N-30 of the New Brunswick 1/4 mile map series. Here too the sediments are bounded to the north, east and west by faults in the Precambrian to Pennsylvanian volcanics, intrusives and sediments (Figure 1.3). The amount of relief in this area is much smaller with the result that the few streams which are present do not expose the bedrock. The combination of swamp, scrub forest and glacial till limits exposure to the coast or man-made roadcuts. The best exposures occur on the Lepreau penninsula from the Little Lepreau Basin to Dipper Harbour although there are also outcrops along a thin belt cut by the Lepreau River (Figure 1.3). The cliffs in this region are much smaller than around St. Martins making access to the outcrop much easier but the number of roads is reduced providing only limited entry points.

Both areas have large tides which limit the amount of work which can be done at any one time on the coast. The spring tides are up to

Figure 1.2 Geologic map of the St. Martins area based on the 21 H/5 E and 21 H/6 W maps of Ruitenberg et al. (1975). Contacts between units are normal faults.

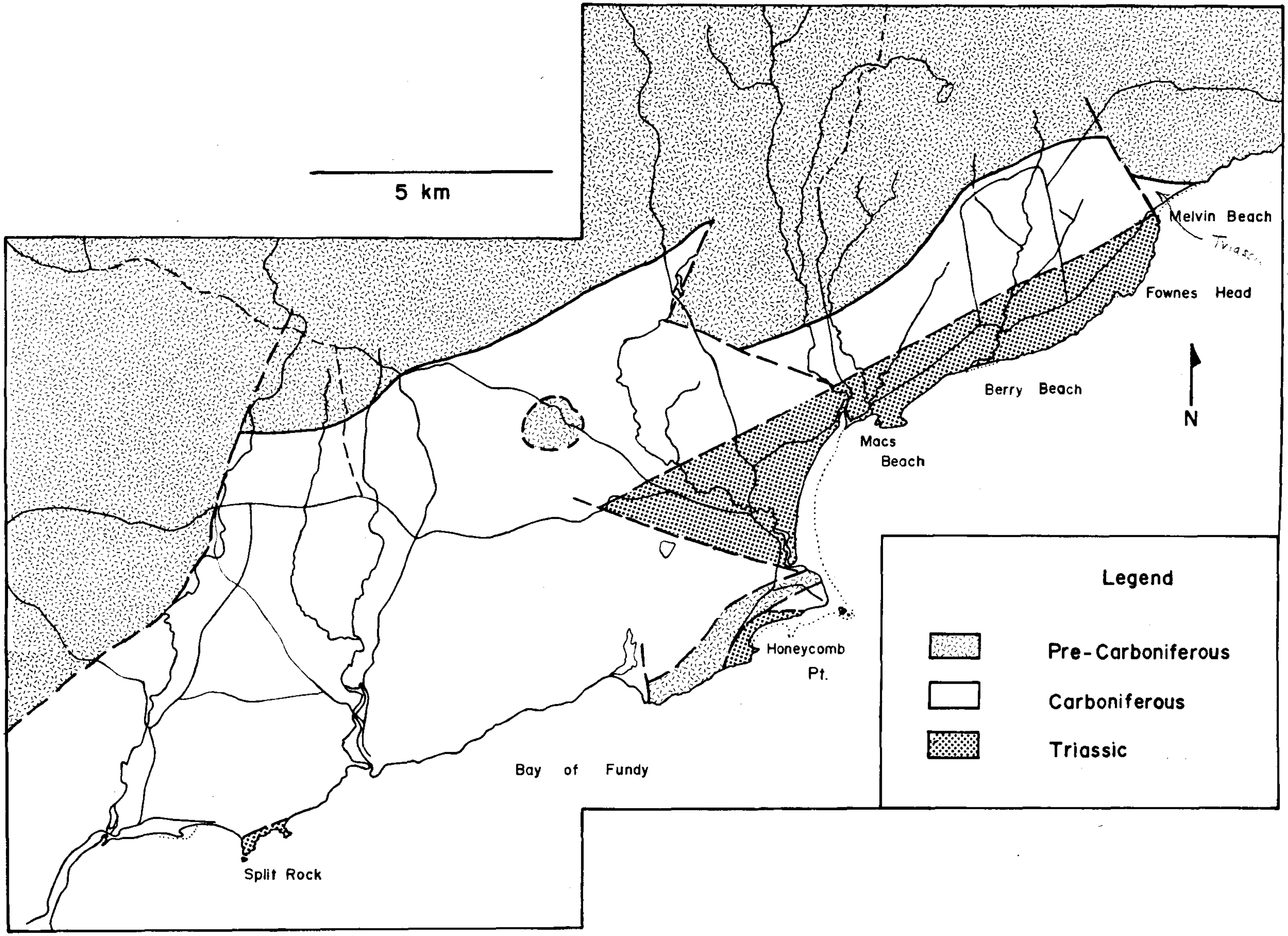
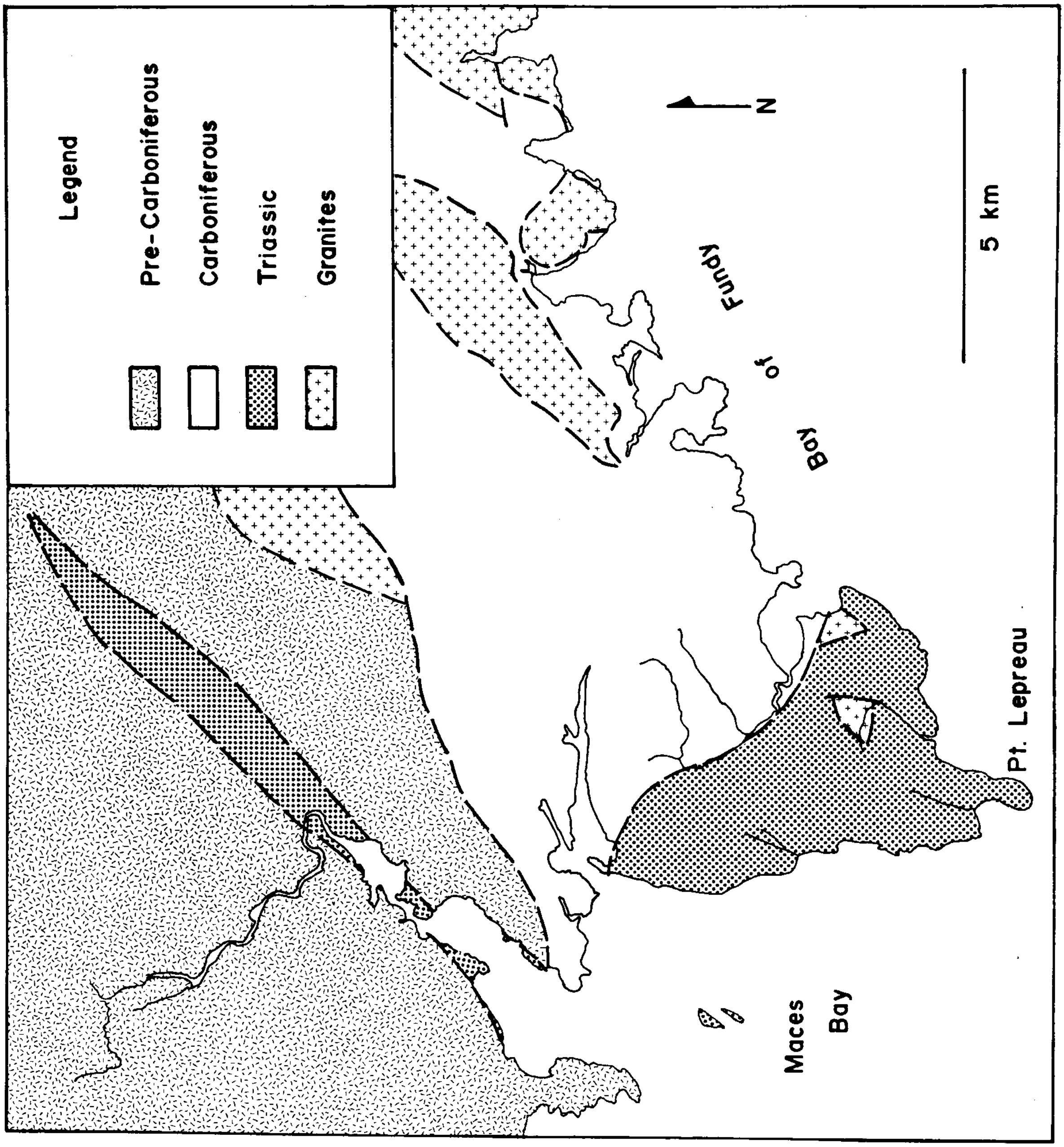

5 km
Melvin Beach
Fownes Head
Berry Beach
Macs Beach
N
Honeycomb Pt.
Bay of Fundy
Split Rock
Legend
Pre-Carboniferous
Carboniferous
Triassic

Figure 1.3 Geologic map of the Lepreau area. Based on the 21 G/1 W map of Ruitenberg et al. (1975).


Legend
Pre-Carboniferous
Carboniferous
Triassic
Granites
N
5 km
Bay of Fundy
Pt. Lepreau
Maces Bay

11 m at St. Martins, and up to 8 m at Lepreau. Caution should be exercised in working the coast, especially in the St. Martins region, where cliffs prevent easy escape from the tides as the water temperature, generally less than 10°C even in summer, and the strong currents, greater than 10 knots along parts of the coast, make swimming impossible. Tide Tables are available in Saint John from commercial fish outfitters and are recommended although both daily papers publish the high and low water times for each day.

1.3 Methods

Geologic mapping of both areas was done on copies of the 1/4 mile map sheets and on 1:10,000 air photos. Outcrop locations were recorded by giving each a number which was noted on the map sheet and in the field book. Where possible the location of any paleocurrent data was pinpointed on the air photos.

Chapter 2

Regional and Structural Geology

2.1 Introduction

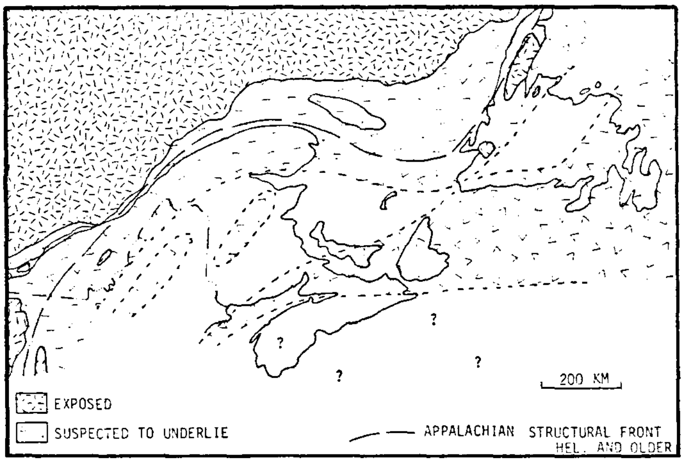
The geology of southern New Brunswick is complex both in terms of structure and lithologies. The region was definitely affected by both the Taconic and Acadian orogenies with a possible Precambrian structural event as well (Ruitenberg et al., 1979). The Triassic sediments are faulted against the Caledonia Highlands which consist of a variety of sedimentary, igneous and volcanic rocks along with their metamorphosed equivalents. These rocks form the source for much of the sediment entering the graben(s). Because the structure of the basin is tied with the evolution of the region and provenance studies are based on the lithologies bordering the graben a brief review of the structural and geological history of the area will be presented in this chapter.

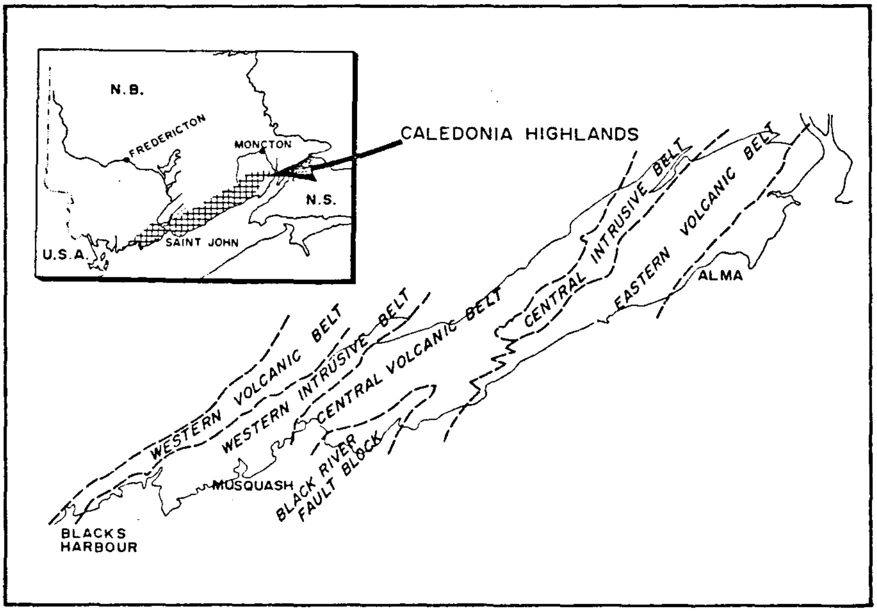
2.2 Precambrian to Carboniferous

The oldest units in the region belong to the Green Head Group in and around the area of Saint John. They consist of metamorphosed and polydeformed clastic and carbonate sediments and intrusives. The former are considered to have been deposited in a platformal sequence on the unfractured Hadrynian crust as shown in Figure 2.1 (Poole, 1976; Ruitenberg et al., 1977, 1979). The carbonates have been dated as

Figure 2.1 Helikian and older rocks in the Maritimes (from Poole, 1976).

Figure 2.2 General geologic map of the Caledonia Highlands showing the Upper Precambrian volcanic belts and the Paleozoic intrusives (from Ruitenberg et al., 1979).

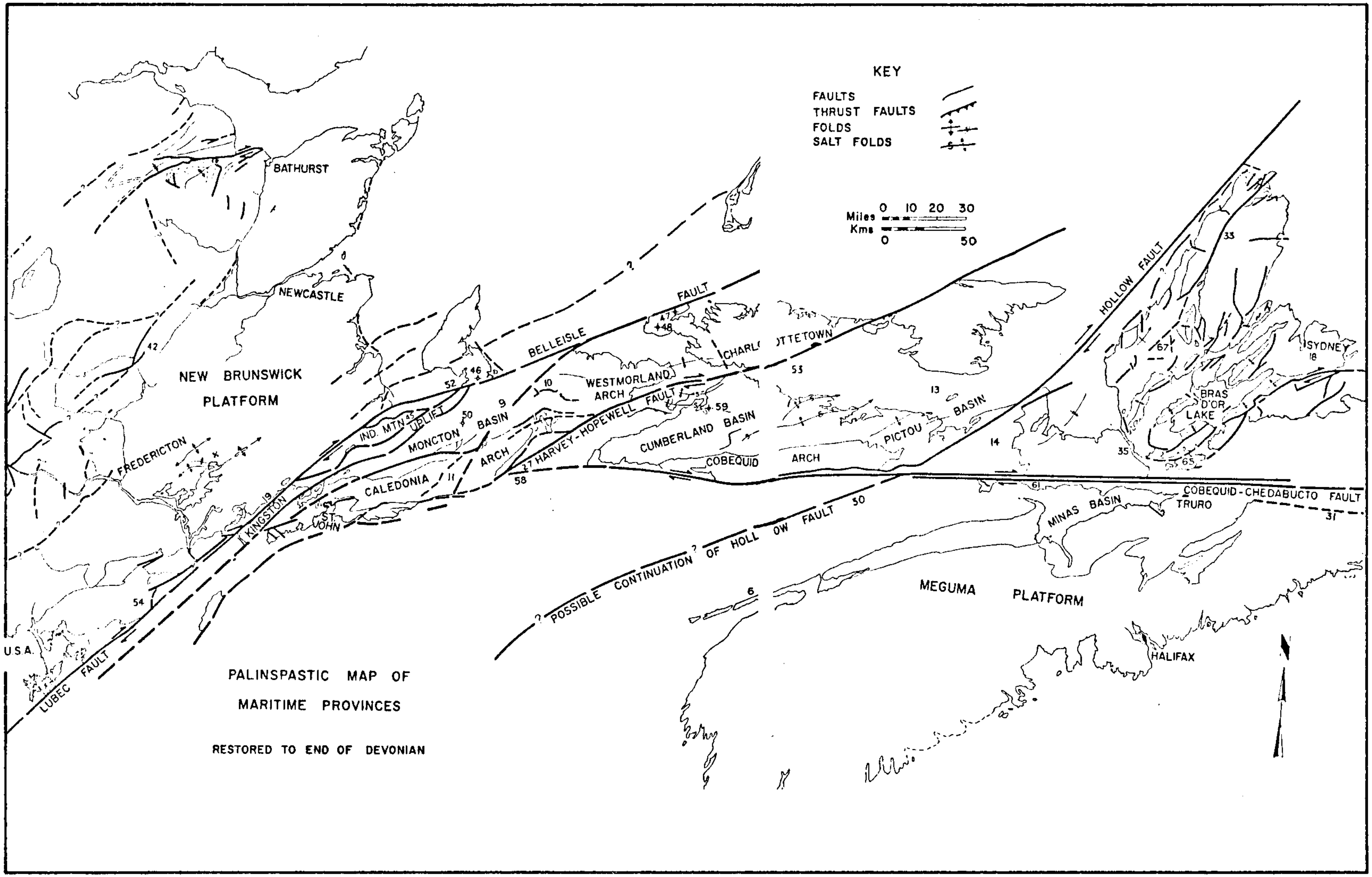

EXPOSED
SUSPECTED TO UNDERLIE
APPALACHIAN STRUCTURAL FRONT
HEL. AND OLDER
200 KM


N.B.
FREDERICTON
MONCTON
N.S.
U.S.A.
SAINT JOHN
CALEDONIA HIGHLANDS
WESTERN VOLCANIC BELT
WESTERN INTRUSIVE BELT
CENTRAL VOLCANIC BELT
CENTRAL INTRUSIVE BELT
EASTERN VOLCANIC BELT
ALMA
MUSQUASH
BLACK RIVER FAULT BLOCK
BLACKS HARBOUR

Hadrynian by Hofmann (1974) on the basis of morphology of the stromatolites present in the group. They are overlain by Hadrynian volcanics and volcaniclastic sediments of the Coldbrook Group which make up much of the Caledonia Highlands in New Brunswick (Figure 2.2). The Coldbrook Group was subdivided into three belts with the eastern belt composed of mainly mafic and felsic volcanics and volcaniclastic sediments which laterally grade into mainly terrestrial felsic volcanics with minor mafics in the central and western belts. These units have an aggregate thickness of over 9,000 m (Ruitenberg et al., 1979) and are thought to have been deposited on the northwest margin of a large basin as a result of volcanism due to rifting (Giles and Ruitenberg, 1977). This interpretation was supported by King et al. (1977) and Rast (1979). The latter considers the dyke swarm which intruded along the Belleisle Fault zone (Figure 2.3) to have been the result of at least three episodes of tension interrupted by compressional events. An alternative suggested by Rast (1976) is that the volcanics were the result of an ensilaic volcanic arc formed along the northwest margin of a closing basin. Poole (1976) shows both sides of the micro-continent with a southward dipping subduction zone to the north (Figure 2.4), which supports evidence gathered by Hughes and Bruckner (1971) from the Precambrian of Newfoundland.

During the Cambrian the entire area of southern New Brunswick was acting as a passive margin with platformal sediments accumulating over fluvial sandstones as the continent foundered and was transgressed by the Iapetus Ocean (Ruitenberg et al., 1977). At the same time to the

Figure 2.3 Distribution of major strike-slip faults in New Brunswick, Nova Scotia and Prince Edward Island (from Webb, 1969).



PALINSPASTIC MAP OF
MARITIME PROVINCES

RESTORED TO END OF DEVONIAN

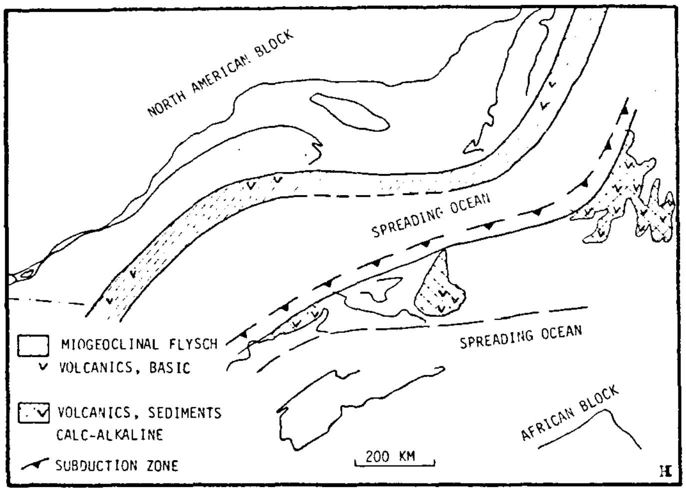
south there appears to have been a major sea which allowed the accumulation, through the Cambrian and Ordovician, of the deep-sea sediments of the Meguma Group of Nova Scotia (Schenk, 1971; Ruitenberg et al., 1977; Haworth and Keen, 1979). This time period is depicted schematically by Figure 2.5 (from Poole, 1976).

By the Ordovician the northern ocean was closing with a subduction zone dipping southward beneath the Avalon Platform (Haworth and Keen, 1979; Haworth et al., 1978) and a northward dipping trench zone to the west (Figure 2.6, 2.7, 2.8). The latter occurred in the Early Ordovician while the southern margin was still coupled to the Avalon Platform (Ruitenberg et al., 1977; Poole, 1976). Closure of the Iapetus Ocean in the north resulted in the Taconic Orogeny and caused the sediments and volcanics to be polydeformed throughout the northern part of the province. Although Poole (1976) showed subduction dipping to the northwest, more recent geophysical and geochemical data summarized by Haworth and Keen (1979) confirmed the hypothesis of Stevens et al. (1974) who suggested a southward dipping zone creating the emplacement of the Ordovician granitic batholiths in southern New Brunswick (Ruitenberg et al., 1977).

Throughout the Silurian and Devonian a series of clastic sediments and volcanics were laid down across the province in response to the closure of the southern ocean. Poole (1976) believed that the subduction zone dipped to the north (Figure 2.9) although, as Haworth and Keen (1979) pointed out, this does not account for the presence of the granites in the Meguma Group of Nova Scotia. If in fact the Meguma

Figure 2.4 Late Precambrian paleogeographic reconstruction of the Maritimes (from Poole, 1976).

Figure 2.5 Cambrian paleogeographic reconstruction of the Maritimes (from Poole, 1976).


NORTH AMERICAN BLOCK
SPREADING OCEAN
SPREADING OCEAN
AFRICAN BLOCK
MIOGEOCLINAL FLYSCH
VOLCANICS, BASIC
VOLCANICS, SEDIMENTS
CALC-ALKALINE
SUBDUCTION ZONE
200 KM
H

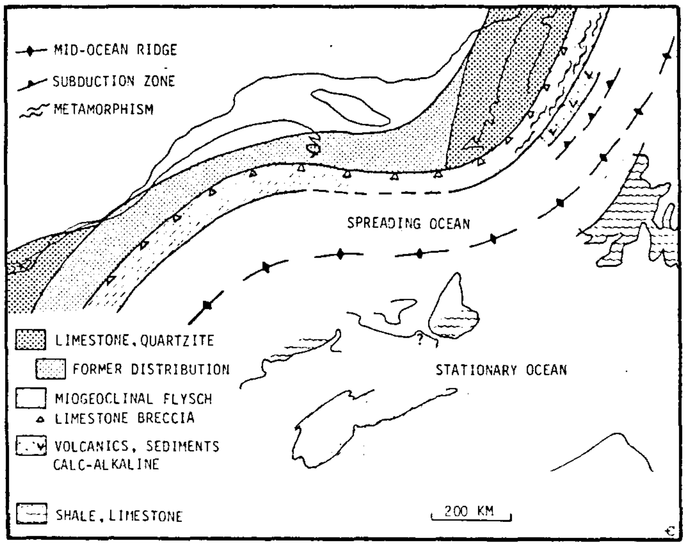
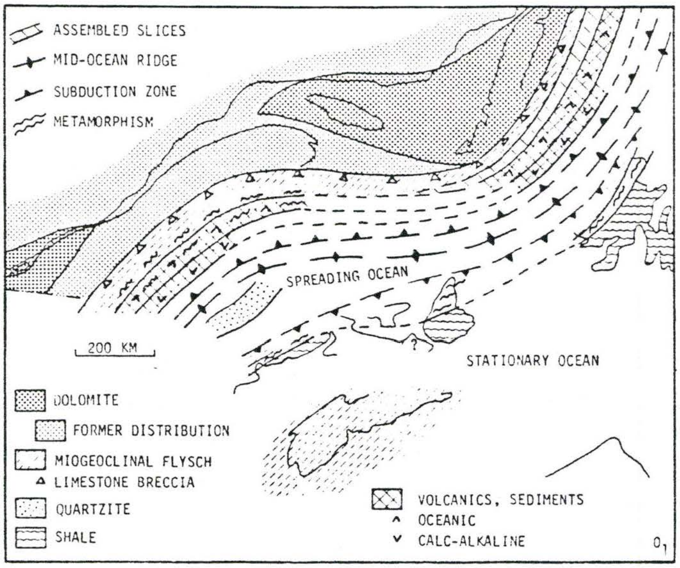

MID-OCEAN RIDGE
SUBDUCTION ZONE
METAMORPHISM
SPREADING OCEAN
STATIONARY OCEAN
LIMESTONE, QUARTZITE
FORMER DISTRIBUTION
MIOGEOCLINAL FLYSCH
LIMESTONE BRECCIA
VOLCANICS, SEDIMENTS
CALC-ALKALINE
SHALE, LIMESTONE
200 KM
€

Figure 2.6 Early Ordovician paleogeographic reconstruction of the Maritimes (from Poole, 1976).

Figure 2.7 Middle Ordovician paleogeographic reconstruction of the Maritimes (from Poole, 1976).


ASSEMBLED SLICES
MID-OCEAN RIDGE
SUBDUCTION ZONE
METAMORPHISM
SPREADING OCEAN
200 KM
STATIONARY OCEAN
DOLOMITE
FORMER DISTRIBUTION
MIOGEOCLINAL FLYSCH
LIMESTONE BRECCIA
QUARTZITE
SHALE
VOLCANICS, SEDIMENTS
OCEANIC
CALC-ALKALINE
O_1

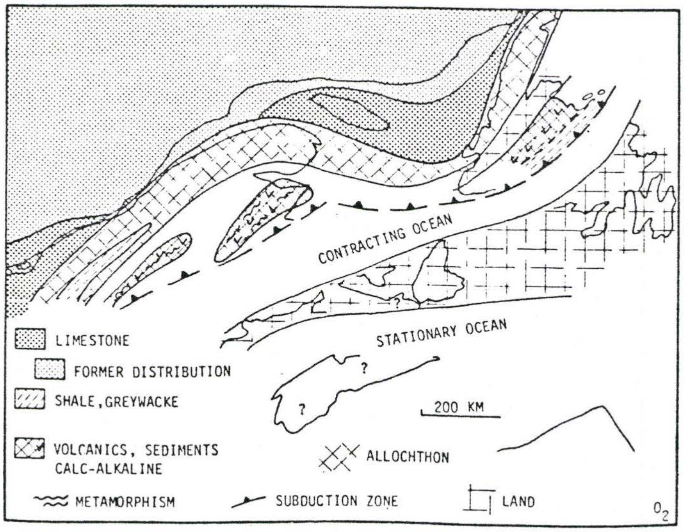
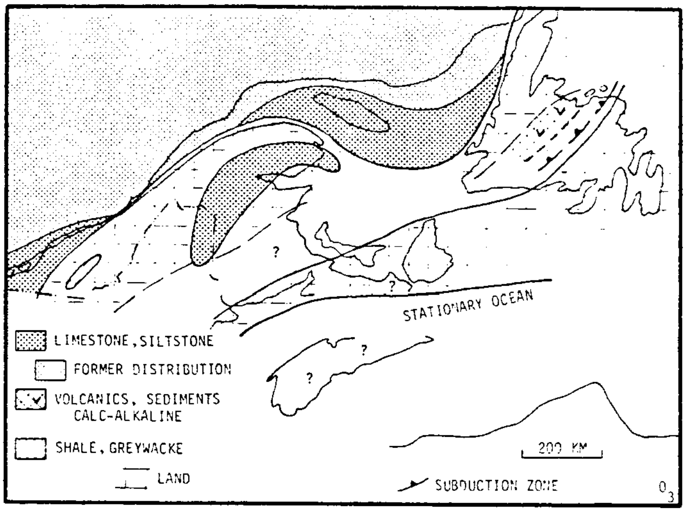
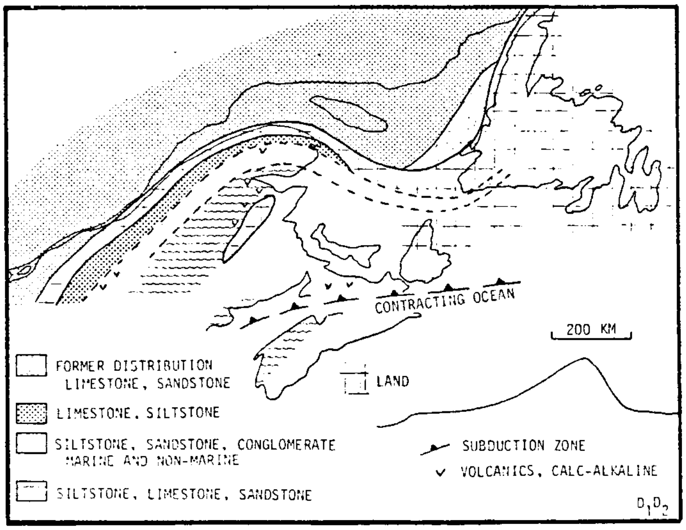

CONTRACTING OCEAN
STATIONARY OCEAN
LIMESTONE
FORMER DISTRIBUTION
SHALE, GREYWACKE
200 KM
VOLCANICS, SEDIMENTS
CALC-ALKALINE
ALLOCHTHON
METAMORPHISM
SUBDUCTION ZONE
LAND
O_2

Figure 2.8 Late Ordovician paleogeographic reconstruction of the Maritimes (from Poole, 1976).

Figure 2.9 Early and Middle Devonian paleogeographic reconstruction of the Maritimes (from Poole, 1976).


STATIONARY OCEAN
LIMESTONE, SILTSTONE
FORMER DISTRIBUTION
VOLCANICS, SEDIMENTS CALC-ALKALINE
SHALE, GREYWACKE
LAND
200 KM
SUBDUCTION ZONE
O_3

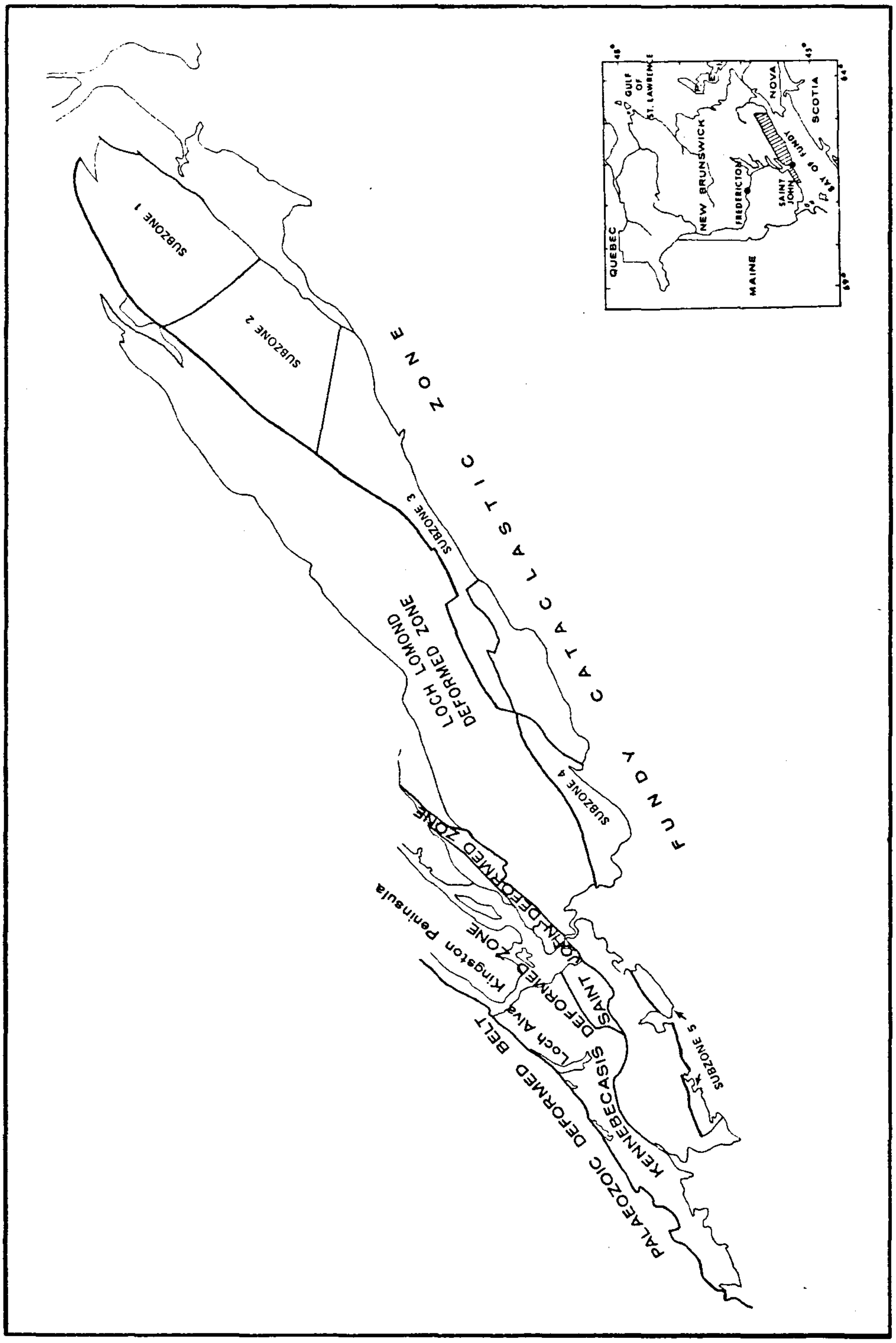

CONTRACTING OCEAN
200 KM
FORMER DISTRIBUTION LIMESTONE, SANDSTONE
LAND
LIMESTONE, SILTSTONE
SILTSTONE, SANDSTONE, CONGLOMERATE MARINE AND NON-MARINE
SUBDUCTION ZONE
VOLCANICS, CALC-ALKALINE
SILTSTONE, LIMESTONE, SANDSTONE
D_1D_2

sediments did accumulate as a deep sea fan as proposed by Schenk (1971) their preservation indicates they probably accumulated on a slope and rise with a subducting plate dipping beneath them to the south (as in the model proposed by Kulm and Fowler, 1974). Paleomagnetic data for this time period obtained by Irving (1977) show the South American plate impacting with the Maritimes prior to the colision with Africa in the Triassic. This,however,is incompatible with the large-scale structures which are common to eastern North America, Europe and Africa and which indicate collision with the African plate in the Devonian (LeFort and Haworth, 1978). The end result was deformation (the Acadian Orogeny) in the Devonian which continued into the Carboniferous as the Maritime Disturbance in Eastern Canada (Ruitenberg et al., 1977). This produced a penetrative cataclastic deformation throughout the southern Caledonia Highlands, in a region termed the Fundy Cataclastic Zone (Figure 2.10). The deformation ended in the northeast by Early Mississippian time while in the southwest it post-dates the Early Carboniferous (Ruitenberg et al., 1979).

2.3 Carboniferous to Triassic

The closure of the southern ocean at the end of the Devonian led to the development of a series of large strike-slip faults throughout the Maritimes (Figure 2.3). Wilson (1962) first suggested these faults, and similar ones in Scotland forming the Great Glen system, could be joined and interpreted as a major sinistral transcurrent fault system (not right-lateral as stated in Ballard and Uchupi, 1975). Wilson called these

Figure 2.10 Structural zonation of the Caledonia Highlands (from Ruitenberg et al., 1979).


SUBZONE 1
SUBZONE 2
SUBZONE 3
SUBZONE 4
SUBZONE 5
FUNDY CATACLASTIC ZONE
LOCH LOMOND DEFORMED ZONE
SAINT JOHN DEFORMED ZONE
KENNEBECASIS DEFORMED ZONE
Kingston Peninsula
Loch Alva
PALAEOZOIC DEFORMED BELT
QUEBEC
MAINE
NEW BRUNSWICK
NOVA SCOTIA
GULF OF ST. LAWRENCE
FREDERICTON
SAINT JOHN
BAY OF FUNDY

the Cabot Fault system. Subsequent work has shown the Great Glen system is in fact left-lateral (Webb, 1969; Pritcher, 1969; Harland, 1975) while the Maritime faults are dominently right-lateral (with some later sinistral movement during the Carboniferous) as determined by Webb (1969). This led Webb (1968) to postulated the existence of a short-lived spreading centre between Newfoundland and Ireland during the Carboniferous to account for the difference in sense of motion. This has been subsequently supported by faunal evidence from offshore Newfoundland which indicates the presence of a deep seaway in the area during the same time as the major marine transgression in the Maritimes, the Windsor Sea, in the Visean (Haworth et al., 1976; Jansa et al., 1978).

Haworth (1975) suggested the origin of these faults was related to the shape of the continental masses which were involved in the closing of the southern ocean. He argued that an oblique collision between a relatively straight edged plate (the African plate) and a stepped plate (Eastern North America), as shown in Figure 2.11, would explain the sense of motion and the spatial distribution of the strike-slip faults in the region. He reasoned that the promentory would be the area of maximum stress forming a single shear which would splay in the lee of the 'step'. In addition the oblique motion could be expected to fracture the approaching straight-edged plate in a more easterly trend to the rest of the faults. The result of an attempt to model such a collision (Figure 2.12) showed very similar structures to what has been observed and predicted the formation of a deeper than normal sedimentary basin in the northwest corner of the reentrant. It was subsequently

Figure 2.11 Schematic origin of the Major strike-slip faults in the Maritimes. (a) an "African" continent approaches a "North American" continent with a transverse component of velocity, and compresses the intervening oceanic sediments. (b) When the suture is complete along the promentory, the transverse motion produces transcurrent faulting parallel to the colliding margin, and movement about the edge of the promentory causes the "Africa" plate to break (from Haworth, 1975).

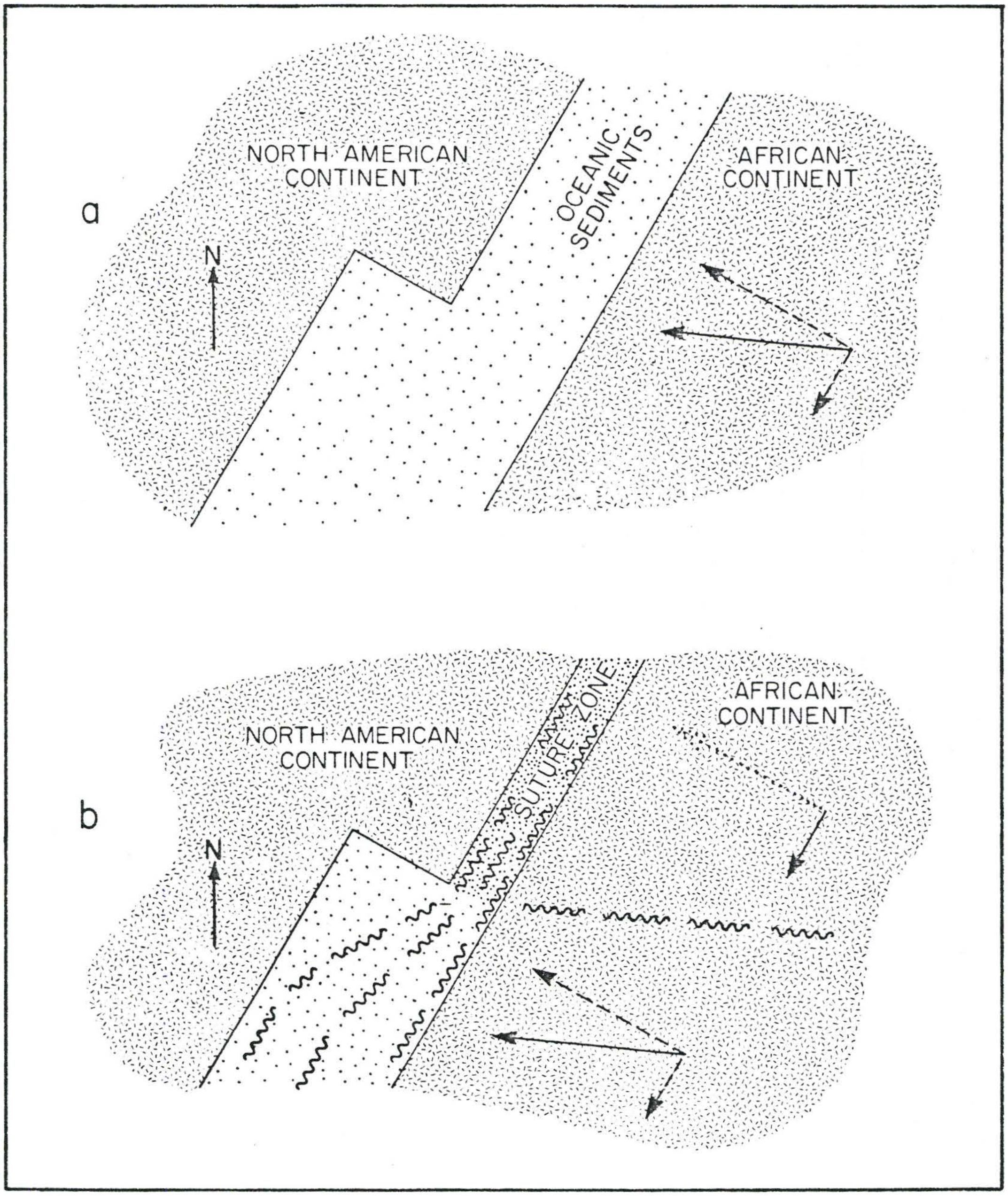
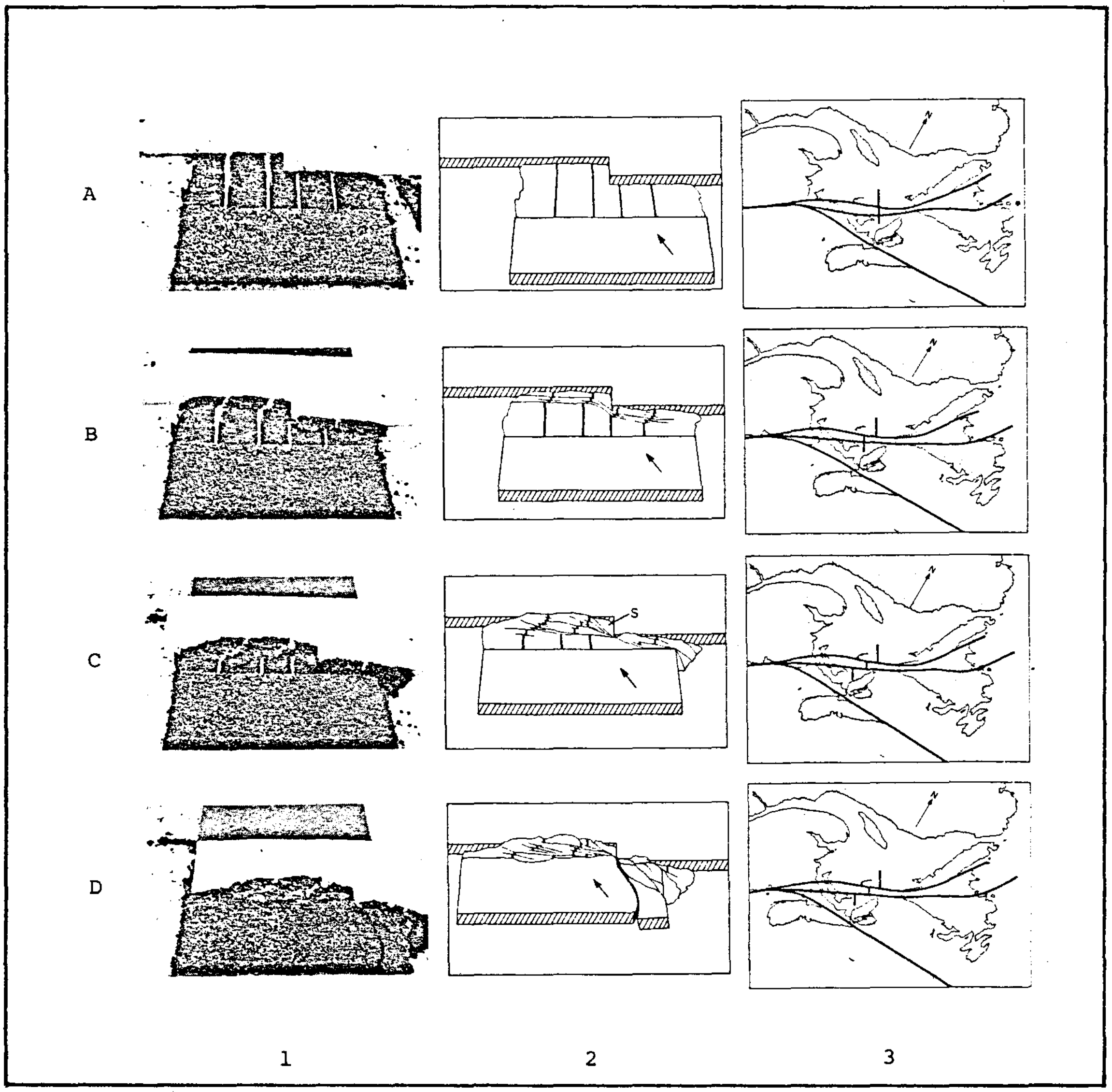

NORTH AMERICAN CONTINENT
OCEANIC SEDIMENTS
AFRICAN CONTINENT
a
N
NORTH AMERICAN CONTINENT
SUTURE ZONE
AFRICAN CONTINENT
b
N

Figure 2.12 Comparison of sand models (col. 1) and their line drawn interpretations (col. 2) with the development of fault systems (col.3) activated during the final stages of collision. The undisturbed model (row A) develops transcurrent faulting (row B) because of an oblique relative direction of approach between the two continents. Upon completion of the suture along the leading edge of the promentory ont he northeastern continental block (row C) the southwestern continental block breaks (row D) along aline roughly corresponding to the direction of approach of the plates. The letter S in Figure C2 defines the undisturbed area in which sediment could be deposited to give the interpreted edimentary basin southwest of the Banc Beauge (from Haworth, 1975).


A
B
C
D
S
N
1
2
3

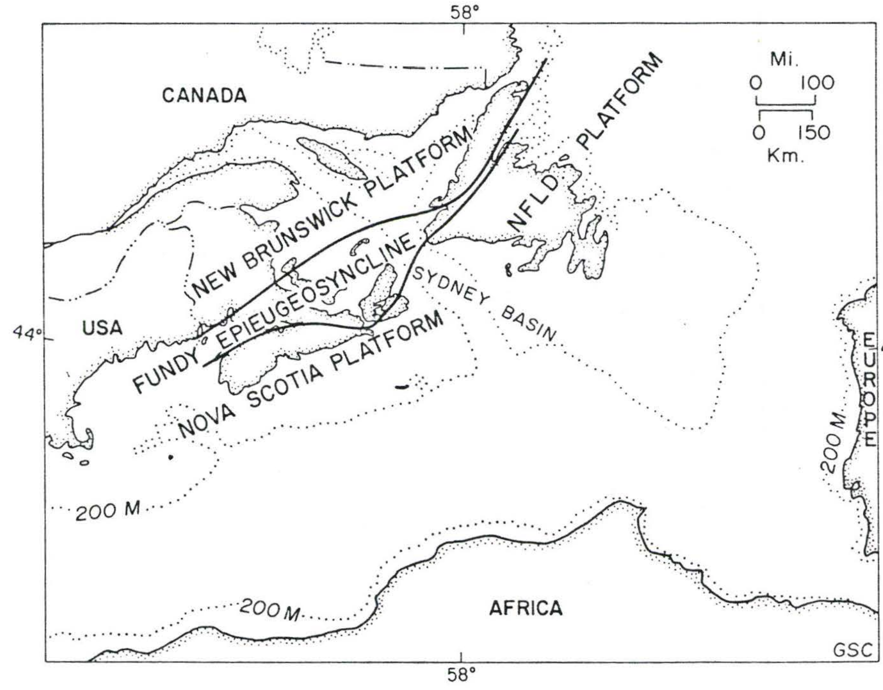
verified by seismic surveys that such a basin is present between Anticosti Island and Newfoundland (Haworth, 1975).

Throughout the Late Devonian and Carboniferous, tectonic movement was dominantly vertical (Howie and Barss, 1975) and formed the Fundy Epieugeosyncline stretching from the Gulf of Maine to Newfoundland (Figure 2.13). The series of basins which formed subsided at different rates but all accumulated thick sequences of mainly continental clastics (Howie and Barss, 1975). The only transgression occurred during the Visean when the Windsor Sea deposited carbonates and evaporites over the whole region. Around the highlands such as the Caledonias of New Brunswick there were fanglomerates which graded laterally into coarse and then fine fluvial sandstones and, in the centre of the basins, lakes (Belt, 1968). The climate changed several times from humid to semi-arid in the Carboniferous, indicated by the presence or absence of coal seams and redbeds (Howie and Barss, 1975). The final climate alteration was toward a semi-arid condition through the Stephanian and Early Permian. This trend probably continued through much of the Permian, given the extensive deposits of arid continental sediments in Europe and the United States (Anderton et al., 1979; McKee, 1979). Because of regional uplift of the entire region no sediments of this age are preserved in the Maritimes.

2.4 Triassic to Jurassic

Triassic sediments occur on the European, African and North

Figure 2.13 The orientation of the Fundy Epieugeosyncline in the Maritimes during the Carboniferous (from Howie and Barss, 1975).


58°
CANADA
Mi.
0 100
0 150
Km.
NEW BRUNSWICK PLATFORM
NFLD PLATFORM
FUNDY EPIEUGEOSYNCLINE
SYDNEY BASIN
44°
USA
NOVA SCOTIA PLATFORM
EUROPE
44°
200 M
200 M
200 M
AFRICA
GSC
58°

American plates. On the east coast of North America they are restricted to a narrow zone of discontinuous basins stretching from South Carolina to offshore Newfoundland. Models for the development of these basins have been proposed since at least 1880, when Russell suggested that they were formed in a continuous rift valley which was subsequently broken up. This apparently was accepted by most of the rest of the workers in the area up to and including Sanders (1963) who was the first to propose four distinct episodes to their formation. According to his studies there was an initial period of graben formation in which structural relief(as well as sediment and volcanic accumulation) reached in excess of 9,000 m (30,000 feet). This was followed by uplift of the centre of the valley by at least 9,000 m which allowed erosion of all previously deposited sediments and caused a reversal in drainage patterns. A second period of graben formation occurred in which the basins were again dropped 9,000 m but this episode was accompanied by the formation of transverse folding. Finally, these folds were offset by transverse faults and the basins refolded with the axes down the strike of the grabens.

The need to appeal to such large vertical displacements disappeared when the works of DeBoer (1968) and Klein (1969) were published. The former showed the correlation of different basins on the basis of the number and thickness of the extrusives present was incorrect. The type example of such a correlation was between the Newark and Connecticut basins,each of which have three volcanic flows in their stratigraphic column. Remnant paleomagnetism in the flows, however, showed the three events in the Newark Basin were all equivalent to the middle event in the Connecticut Basin. Klein (1969) showed that paleocurrents in the Connecticut Basin indicated flow coming into the graben from all sides. He argued that this indicated interior drainage only, and that the basins were separate. The data are hardly conclusive, in that Klein grouped together measurements taken throughout the stratigraphic sequence. At any one time the basins may have been intermittently interconnected.

Beginning in the late 1960's and continuing through to the present an enormous amount of geological and geophysical data have been obtained from offshore, as a consequence of oil exploration, and in response to the need to understand the structural development of passive or Atlantic ocean margins. Jansa and Wade (1975) suggested the main structural control on the formation of the Triassic grabens off the eastern coast was the Cobequid-Chedabucto fault zone, which they renamed the Glooscap Fault, rather than the more north-south control of the Cabot Fault system of Wilson (1962). At the same time dating of the extrusives, which are interbedded with the sediments in virtually all grabens, by DeBoer (1968), Reesman et al. (1973), Krueger (1973), Mattis (1976) and Manspeizer et al. (1976) showed that the ages clustered around 180-200 m.y. which placed them in the Lower Jurassic rather than in the Late Triassic as previously assumed. Similar results were obtained from the corresponding deposits in Morocco (van Houten, 1977).

The revised age determinations were confirmed by a comprehensive pollen analysis. Cornet (1977) showed that much of what had previously been considered Triassic was in fact Lower Jurassic. In addition he was able to show that the initiation of rifting began earlier in the eastern United States starting at the southern end in Carnian time and in the northern basins in the Norian. By the end of the Triassic the southern basins, which recorded a predominantly humid climate, had ceased receiving sediment while deposition in the northern basins continued well into the Jurassic. Figure 2.14 represents a compilation of data from Cornet (1977), Klein (1962), Jansa et al. (1977), Barss et al. (1979), and Jansa et al. (1980) which shows a correlation of all the basins from South Carolina to the offshore Maritimes. The variation in initial rifting as well as sediment supply and differential subsidence is apparent.

Van Houten (1977) attempted a correlation of structures and facies types between eastern North America and western North Africa to try to determine the overall history of Triassic sedimentation. Using the plate reconstruction of Bullard et al. (1965) he suggested the major constraints on graben formation were east-west trending fault systems, the Glooscap-Gibralter and Cornwall-Atlas zones (Figure 2.15). Van Houten also noted that the basal sediments in the grabens on both sides of the Atlantic consisted of conglomerates; from this he inferred that the initial subsidence was rapid. All basins contained alluvial fan sediments, mainly arid, which tended to grade laterally into playas or lakes in the centre. The major difference between the sediments in

Figure 2.14 Correlation chart of the Triassic basins in Eastern North America, from South Carolina to offshore Newfoundland. Datum is the Jurassic/Triassic boundary. Note the break between the northern basins in the United States and the southeastern basins in Canada represented by the Lawin Fracture zone of Figure 2.18. All ages based on pollen analysis except for the Nova Scotian Triassic where the North Mountain Basalt is dated as Lower Jurassic. Data from the U.S. basins from Cornet (1977). Offshore data from Jansa et al. (1977, 1980) and Barss et al. (1979). Nova Scotian Triassic complied from Klein (1962). New Brunswick section represents only the St. Martins basin (from this study).

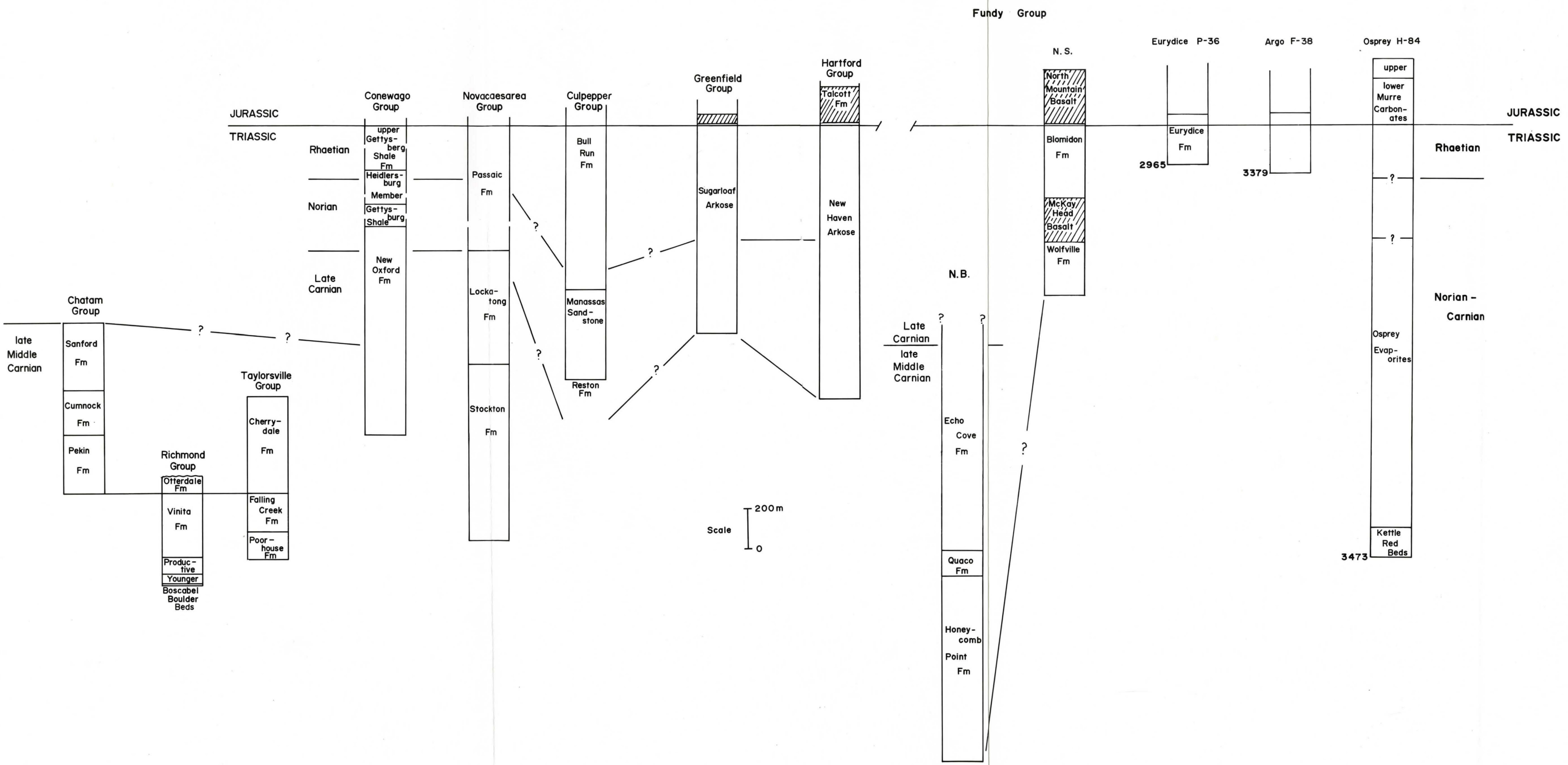
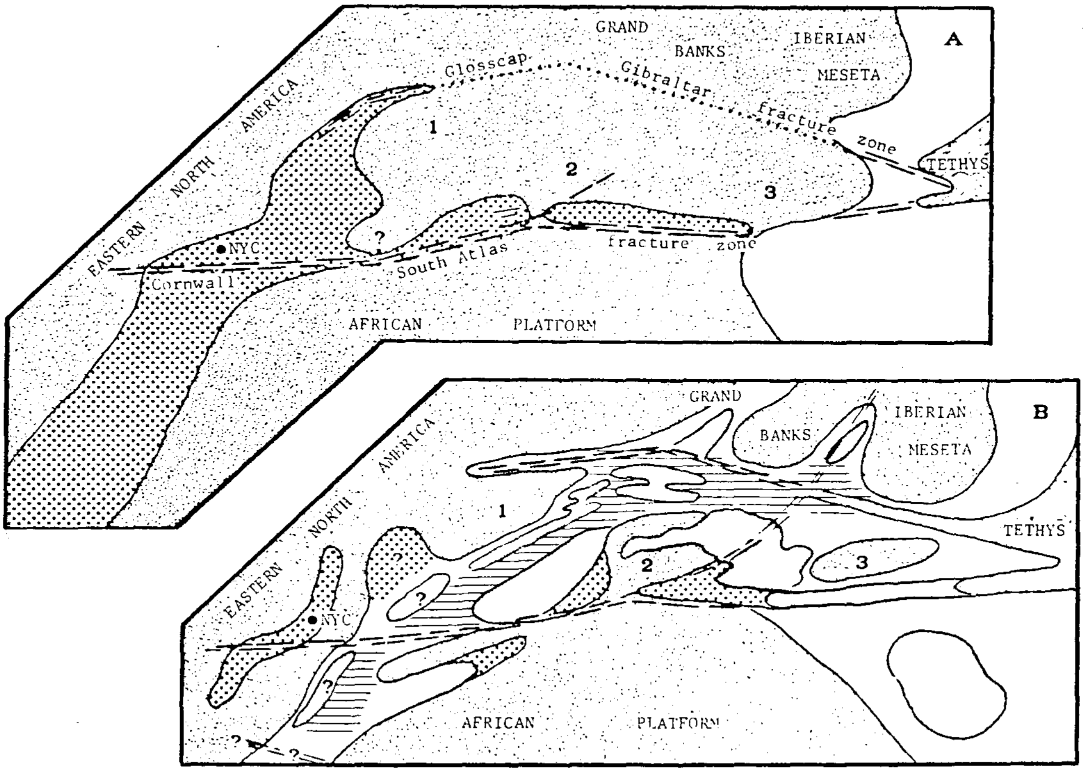

Fundy Group
N. S.
Eurydice P-36
Argo F-38
Osprey H-84
JURASSIC
TRIASSIC
Rhaetian
Norian
Late Carnian
late Middle Carnian
Norian – Carnian
Chatam Group
Sanford Fm
Cumnock Fm
Pekin Fm
Richmond Group
Otterdale Fm
Vinita Fm
Productive
Younger
Boscabel Boulder Beds
Taylorsville Group
Cherrydale Fm
Falling Creek Fm
Poorhouse Fm
Conewago Group
upper Gettysberg Shale Fm
Heidlersburg Member
Gettysburg Shale
New Oxford Fm
Novacaesarea Group
Passaic Fm
Lockatong Fm
Stockton Fm
Culpepper Group
Bull Run Fm
Manassas Sandstone
Reston Fm
Greenfield Group
Sugarloaf Arkose
Hartford Group
Talcott Fm
New Haven Arkose
North Mountain Basalt
Blomidon Fm
McKay Head Basalt
Wolfville Fm
N.B.
Echo Cove Fm
Quaco Fm
Honeycomb Point Fm
Eurydice Fm
2965
3379
upper
lower Murre Carbonates
Osprey Evaporites
Kettle Red Beds
3473
Scale
200 m
0
?

Figure 2.15 Two stages of early Mesozoic fragmentation and basin development, easter North America and northwestern Africa. A, Carnian (about 215 to 210 m.y. ago) predrift framework. B, Early Liassic (about 190 to 185 m.y. ago) predrift framework.

(1) Meguma Meseta; (2) Moroccan Meseta; (3) Oranian Meseta. Light stipple, land; dotted, detrital province; gray, known salt province; lined, estimated extension of salt province or area of additional predrift closure; white, marginal mudstone-evaporite facies, broken lines, fracture zone (from van Houten, 1977).

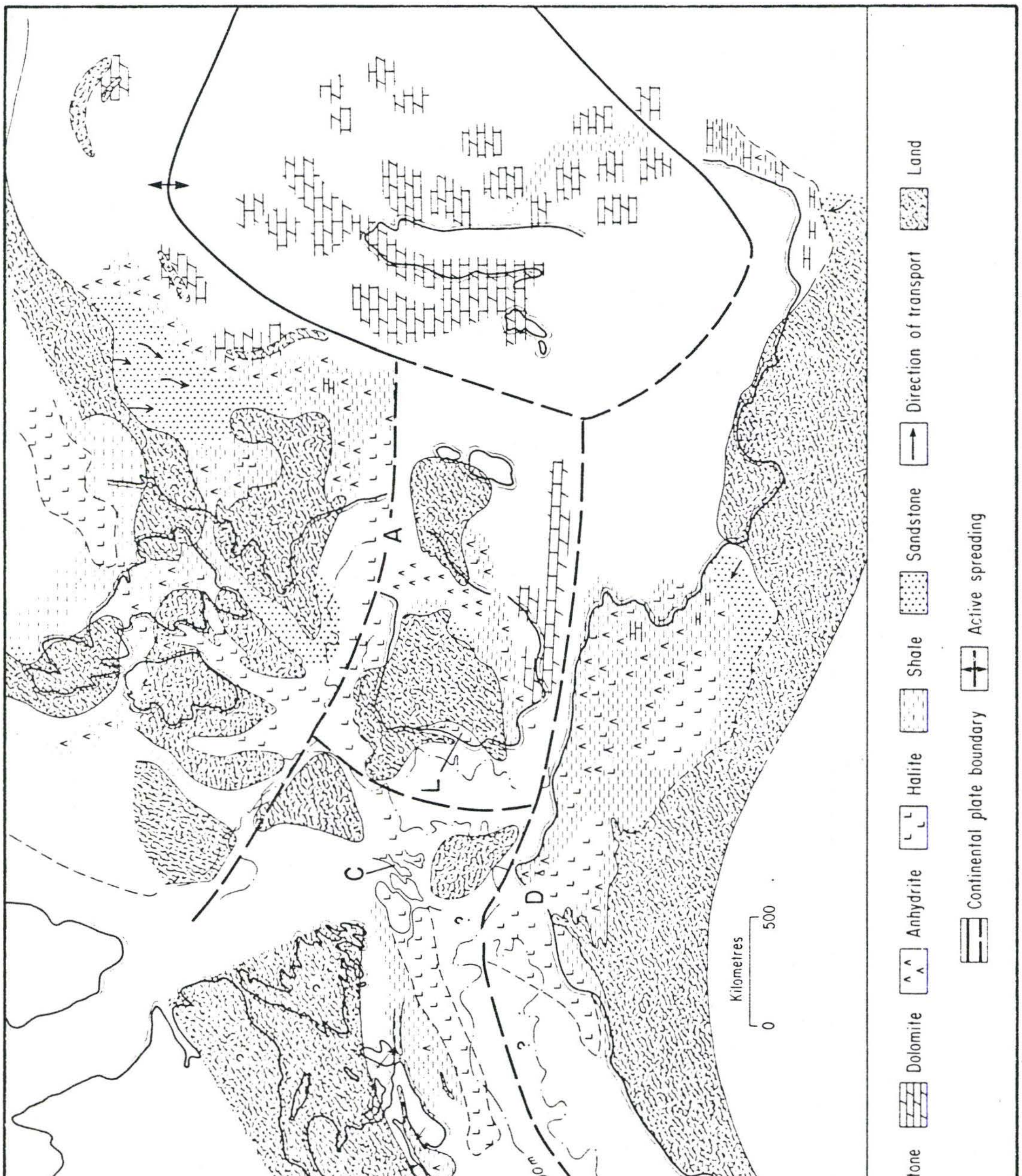

A
GRAND
BANKS
IBERIAN
MESETA
Glosscap
Gibraltar
fracture
zone
TETHYS
EASTERN NORTH AMERICA
NYC
Cornwall
South Atlas
fracture zone
AFRICAN PLATFORM
1
2
3
?
B
GRAND
BANKS
IBERIAN
MESETA
TETHYS
EASTERN NORTH AMERICA
NYC
AFRICAN PLATFORM
1
2
3
?

Morocco and those in eastern North America is the presence of substantial quantities of evaporites in the former and their absence in the latter. The evaporite deposits formed when differential subsidence allowed periodic transgression of the Tethys into some of the grabens. The lack of similar evaporites in North America was attributed to the presence of a broad cratonic arch between the two graben systems which prevented the Tethys from extending further to the west. This arch also implied a westerly or southwesterly drainage pattern in the North America basins, although the author admitted there is no proof for the existence of such a pattern.

The recent drilling off the Newfoundland coast, however, has led to a substantial revision of this model. Jansa et al. (1977, 1980) reported 2,054 m of evaporites, mainly halite, had been found in the Carson Subbasin. Along with the revised continental fit of Le Pichon et al. (1977) they suggested elimination of the cratonic arch and extension of the Tethys several hundred kilometres further westward than in van Houten's initial model. Although this does pose problems for the fit of the smaller continental blocks between North America and Europe and Africa, the model of Jansa et al. (1980), shown in Figure 2.16, does fit most of the observed sediment distributions in all continents.

In the Bay of Fundy itself Johnson (1925) first suggested that the northern margin of the bay was the result of a steeply dipping fault plane which he termed the Fundian Fault. Although Shepard (1930) tried to argue that this was the result of glacial erosion, sparker profiles

Figure 2.16 Paleogeographic reconstruction of the North Atlantic during the Late Triassic. the continental plate reconstruction of Le Pichon et al. (1977) has been modified in the North Atlantic region after Jansa and Wade (1975). A = Aquitaine Basin; C = Carson Subbasin; D - Doukkala Basin; L = Lusitantian Basin (from Jansa et al., 1980).



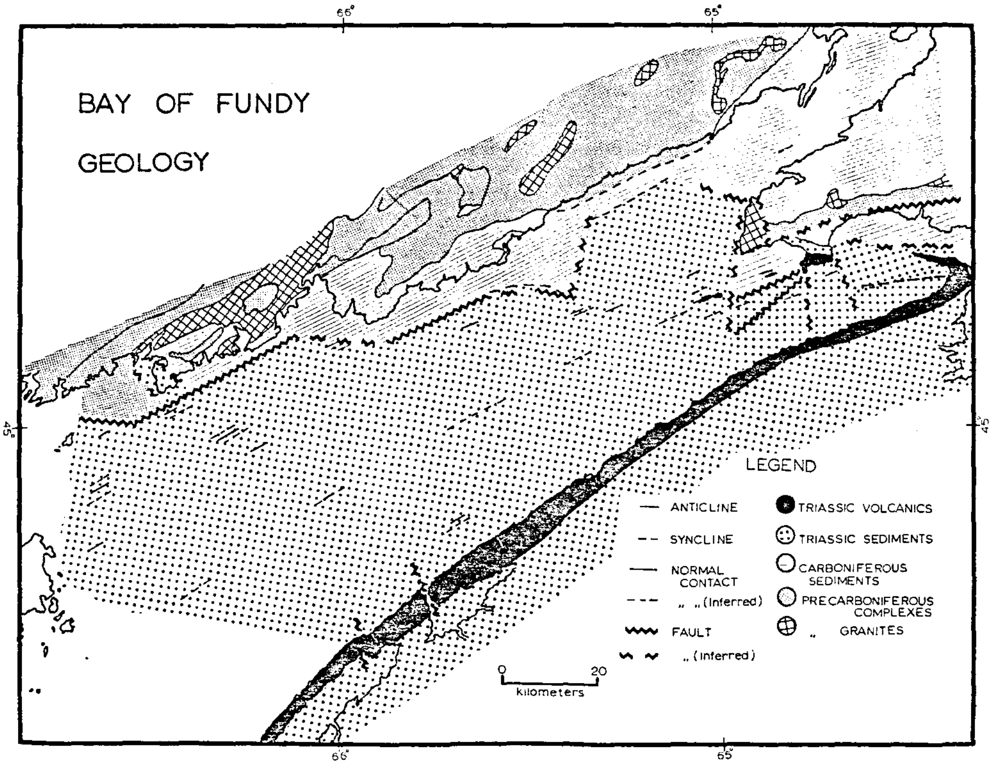
A
C
L
D
3500m
3500m
Kilometres
0
500
Limestone
Dolomite
Anhydrite
Halite
Shale
Sandstone
Land
Direction of transport
Continental plate boundary
Active spreading

taken by Swift and Lyall (1968a, b) proved Johnson to be correct. Swift and Lyall found a discontinuous series of normal faults along the New Brunswick coast (Figure 2.17). Where the fault(s) appear to be missing this may be due to erosion cutting through the Triassic sediments.

The faults are, in general, parallel to the major structure in the region, a broad open syncline with the fold axis closer to Nova Scotia than to New Brunswick. The axis is in turn offset by northwest-southeast trending faults which have small folds (amplitudes less than a kilometre) associated with them. A similar but larger scale survey of the southern portion of the Bay of Fundy and most of the Gulf of Maine by Ballard and Uchupi (1975) revealed similar structures and relationships. These secondary folds have also been recognized in the onshore sediments around St. Martins by Powers (1916) and in the present study. The structures consist of a shallow east-west trending syncline immediately to the north of the town of St. Martins, exposed in both the Irish River and Washburn Brook, and an anticline at Robinson Cove reported by Powers (1916), but not visited in this study.

Swift and Lyall (1968a) concluded the Triassic in the Bay of Fundy region was deposited in a half graben with the flexure on the Nova Scotian side. This is indirectly confirmed in this study by sediment thickness. Whereas Klein (1962) reported a stratigraphic thickness of approximately 1062 m for the Triassic of Nova Scotia (including the North Mountain Basalt which may be Jurassic) the total stratigraphic thickness of the sediments at St. Martins is at least 2,000 m (see Chapter 4) which is what would be expected if the New

Figure 2.17 Structure of the Fundy Basin (from Swift and Lyall, 1968b).


BAY OF FUNDY
GEOLOGY
66°
65°
45°
LEGEND
ANTICLINE
SYNCLINE
NORMAL CONTACT
" " (Inferred)
FAULT
" (Inferred)
TRIASSIC VOLCANICS
TRIASSIC SEDIMENTS
CARBONIFEROUS SEDIMENTS
PRECARBONIFEROUS COMPLEXES
" GRANITES
0
20
kilometers

Brunswick side was down faulted and consequently had greater relief.

The exposures of Triassic along the north shore of the Bay of Fundy in and around St. Martins consist of several fault blocks which are all relatively undeformed and dip to the northeast at between 20° and 40° although the dip seldom exceeds 30°. There appears to have been some rotation during faulting, especially at Quaco Head (see Chapter 7), providing an oblique section northeastward along the coast. At Lepreau the sediments also dip to the north (northwest in this case), however, they vary from 20° to 80° indicating more deformation during movement. In the small northeast trending strip of Triassic along the Lepreau River several anticline-syncline pairs have been reported (Sarjeant and Stringer, 1977), however, the locality was not visited in this study.

All outcrops are faulted internally on a scale measured in centimetres to tens of metres. In the exposures at Robinson Cove, Browns Beach and Fishing Point the faults are large enough to prevent accurate estimate of size and throw and may, in fact, contribute to thickening of the section (see Chapter 4).

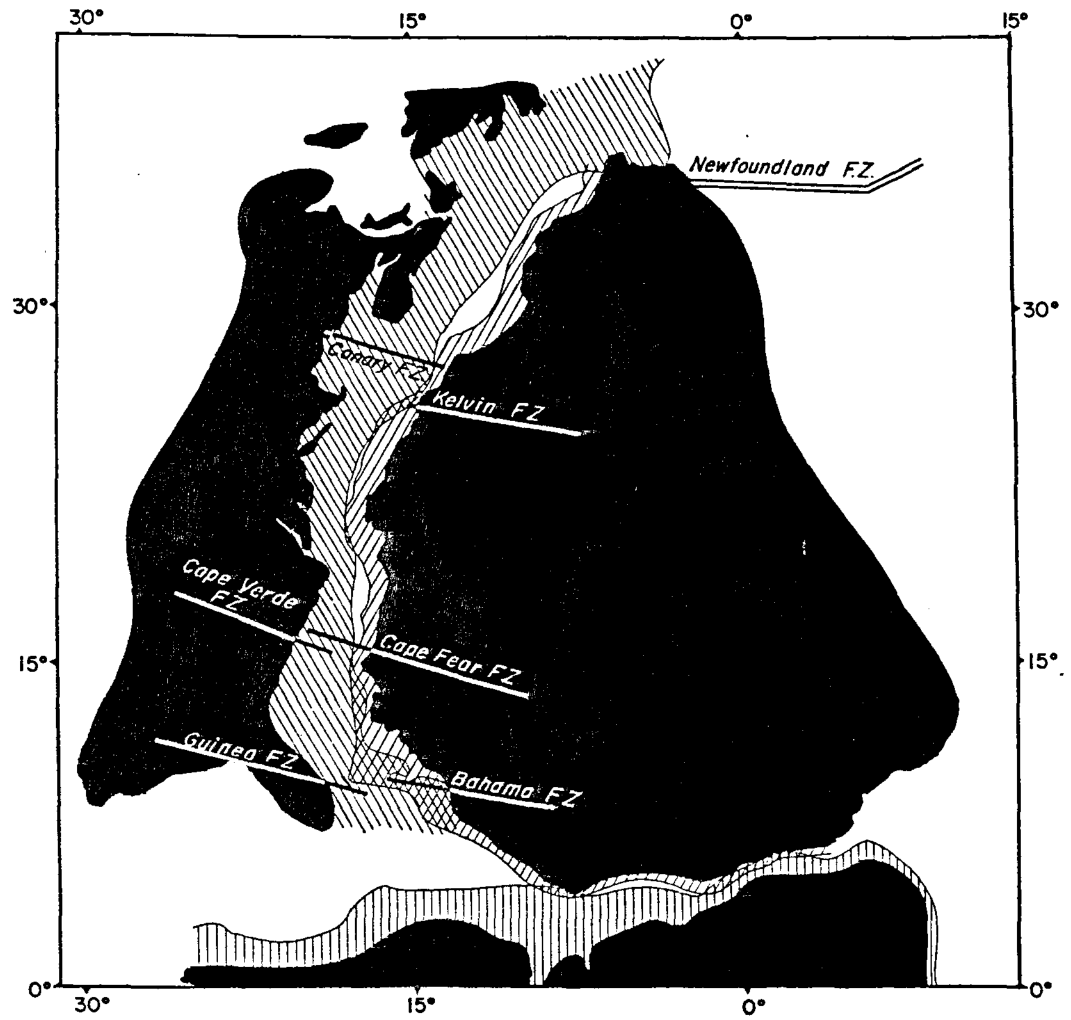
In their study of the Gulf of Maine, Ballard and Uchupi (1975) noted the orientation of the fractures which they detected on seismic surveys was consistent with a hypothesis of regional left-lateral shearing. This was also the conclusions of May (1971) who measured the orientation of dyke swarms in eastern North America, northern South America and western Africa. In addition Ballard and Uchupi reported the existence of a central horst in the middle of the Gulf which they believe was part of the Avalon Platform (their Figure 18). This is bounded to the southwest, northeast, and east by grabens, the northern one forming the Fundy Basin.

More general regional studies of the rifting of the super-continent in Late Triassic time has also led to some interesting conclusions and implications for sediment dispersal. It appears rifting is initiated by a series of hot spots in the mantle which thin the crust and cause an upward doming of the entire region. Normal faults form grabens as isostacy allows crustal blocks to settle (Falvey, 1974; Bott, 1981; Zorin, 1981). Mantle plumes can cause uplift to elevations of 2-3 km above sea level over an area up to 1,000 km in diameter (Kinsman, 1975, p. 109-110) within which form rift valleys, "typically 40 km wide and bounded by large marginal faults are developed in one or more sub-parallel chains and volcanic activity, of considerable intensity, may ensue" (Kinsman, ibid.). If this is correct, and studies of the East African and Western Australian rifts seem to concur (see for example Verrvers and Cotterill, 1976), one would expect sediment to be shed from the sides of the rift and carried along the valleys in different directions on each side of the dome. On the eastern coast of North America just such a mantle hot spot has been suggested to account for the formation of the Kelvin Seamount chain off Cape Cod (Sbar and Sykes, 1973). This would explain, at least in part, the presence of a major northward flowing axial river system in New Brunswick (see Chapter 7). This is supported by paleocurrent data obtained by Hubert et al. (1975, 1976) which indicates the valley floor of the Connecticut Basin sloped toward the southwest (based on the orientation of slump sheets). Currents in these Early Jurassic lakes appear to have been flowing southeast except where deflected by wind patterns.

Earlier work by Le Pichon and Fox (1971) suggested trans-Atlantic correlation of at least four transform fault zones present off the East Coast, from north to south: (i) the Newfoundland Fracture Zone, which corresponds to the Glooscap Fault of Jansa and Wade (1975) and van Houten (1977); (ii) the Kelvin-Canary Fracture Zone, which includes the seamount chain and corresponds to the Cornwall-Atlas Fault system of van Houten (1977); (iii) the Cape Fear-Cape Verde Fracture Zone; and (iv) the Bahama-Guinea Fracture Zone (Figure 2.18). The middle two zones also correspond to patterns of seismicity stretching inland for several hundred kilometres which Sbar and Sykes (1973) attributed to intra-plate motion along these transforms. What no one has yet commented on (although Ballard and Uchupi, 1975, in their Figure 17 show it) is that the basins in Eastern North America are bounded in the north by the Newfoundland Fracture Zone and in the south by the Cape Fear-Cape Verde Fracture Zone (in the case of the basins on the continental United States) or the Bahama-Guinea Fracture Zone (for the series of basin occurring at the shelf break, Grow et al., 1979, their Figure 3).

The basins exposed on the continent form the most westerly north-south rift, which, from pollen analyses, began in Carnian time. The data from basins in the U.S. and offshore Newfoundland initially

Figure 2.18 Distribution of major transform faults in the North Atlantic. The reconstruction of the North Atlantic by Bullard et al. (1965) has been modified to better align the first order structural trends. Mercator projection; Africa in its present position (from Le Pichon and Fox, 1971).


30°
15°
0°
15°
30°
15°
0°
Newfoundland F.Z.
Canary FZ
Kelvin FZ
Cape Verde FZ
Cape Fear FZ
Guinea FZ
Bahama FZ

indicated rifting began in the south and moved northward forming one long series of discontinuous grabens and half grabens. The pollen analysis from the sediments in St. Martins indicate otherwise. This graben was receiving sediments at approximately the boundary between the Middle and Late Carnian, the same time as the most southerly basins in the United States (Chapter 8).

This suggests there were in fact two separate rift systems which opened along the same zone of weakness in the supercontinent. This explains the lateral offset between the most northerly U.S. basin and the Bay of Fundy-Gulf of Maine basin. It now appears that the southern rift system was confined by the Cape Fear-Cape Verde and the Kelvin-Canary Fracture Zones while the northern basins were limited by the Newfoundland and Kelvin-Canary Fracture Zones. In both cases the graben formation began in the south.

The lack of evaporites in the grabens on the continental U.S., which led van Houten (1977) to propose a cratonic arch preventing the transgression of the Tethys, is now easier to explain. There was no possible connection between the basins in the northeast U.S. and the Maritimes. In addition to the doming of the crust in the vicinity of the Kelvin Fracture Zone the age of the basins precludes any connection. The Connecticut Valley Basin is Norian at the earliest (Cornet, 1977) while the Fundy Basin had accumulated over 1,500 m of sediments by Late Carnian.

Further to the east there is a sub-parallel rift system running down the length of the Eastern Seaboard (Ballard and Uchupi, 1975;

Grow et al., 1979). These basins appear to contain more Jurassic strata, especially evaporites, than the basins to the west. By this time it appears the Kelvin Fracture Zone was no longer a factor in basin formation since there is a more or less continuous system from the Newfoundland Fracture Zone south to the Bahama-Guinea Fracture Zone (Ballard and Uchupi, 1975, Figure 17; Grow et al., 1979, Figure 3). Further east again there is the current spreading centre.

In the same context the four episodes of graben formation as described by Sanders (1963) can be related either to the rifting or to the passive phases of ocean spreading. The initial graben formation, which took place over several tens of millions of years, resulted from upward doming of the crust due to a hot convective cell of some type immediately below. The emplacement of the intrusives and extrusives corresponds to the end of this period (Falvey, 1974; Kinsman, 1975). The second phase of graben formation may have been triggered by the eastward shift of the spreading centre allowing compression of the initial grabens. These would now be acting as part of the passive margin. This formed the longitudinal and smaller scale transverse folds. Finally as the spreading centre shifted further to the east the fold axes were offset by faulting which, in the Bay of Fundy, was accompanied by minor folding.

2.5 Summary

Initial rifting of the supercontinent began in Middle to Late Carnian time in at least two areas, South Carolina and southern New

Brunswick-Gulf of Maine. The northern series of grabens is bounded on the south by the Kelvin-Canary Fracture Zone and on the north by the Newfoundland Fracture Zone. The southern system is limited by the Cape Fear-Cape Verde Fracture Zone in the south and possibly the Kelvin-Canary Fracture Zone in the north. In both cases there was a progressive northward movement of basin openings.

All the basins in the United States and most of the basins in Canada were filled with alluvial fan, fluvial or lacustrine sediments. The most easterly basins in Canada and many of the basins in Morocco suffered periodic transgression of the Tethys as differential subsidence of the grabens allowed discontinuous linking of several basins. The lack of evaporites in the grabens of the continental United States is due to the lack of any connection across the Kelvin Fracture Zone. The general northward paleoflow direction of the fluvial sediments north of the Kelvin Fracture Zone and the southward paleoslope inferred for the Connecticut Valley are consistent with the placement of a major plume, and its associated doming, at or near the Kelvin Fracture Zone.

Movement of the spreading centre in the Latest Triassic or Early Jurassic caused renewed subsidence of the older grabens as well as deformation of the sediment and volcanic pile as the area became a passive margin. A new series of basins formed along what is now the shelf break stretching from the Newfoundland Fracture Zone to the Bahama-Guinea Fracture Zone. It appears that both the Kelvin-Canary and the Cape Fear-Cape Verde Fractures Zones ceased to act as controls on graben formation at or before this time. The shelf break basins were filled mainly with Jurassic evaporites and marine sediments. A final shift of the spreading centre to its present position caused further deformation in the older grabens.

The Fundy Basin was formed in Middle to Late Carnian time as a half graben with the faulted side roughly corresponding to the present day shoreline of southern New Brunswick and the flexure in Nova Scotia. The border faults had displacements of at least 2,100 m at St. Martins and 2,700 m at Lepreau based on preserved sediment thicknesses. The material which filled the basin was derived from a complex, polydeformed series of metasediments, metavolcanics, intrusives and sediments ranging in age from Precambrian to Carboniferous. The position of the basin was at least partially controlled by the large strike-slip faults in the region which formed during the closure of the proto-Atlantic in the Devonian to Carboniferous.

Chapter 3

Previous Work

3.1 St. Martins

The first geologic mapping in the St. Martins area was carried out by Gesner (1840). His conclusions were that all the relatively underformed sediments in the region should be assigned to the New Red Sandstone. This assertion was challenged by Robb (1850; vide Bailey and Matthews, 1865, p. 36) who thought there were no rocks younger than Carboniferous in the province. After additional mapping Bailey and Matthews (1865, 1872) maintained that Triassic rocks were present at Split Rock (Robinson Cove) and around the settlement of Quaco, but thought the bulk of the undeformed sediments were Carboniferous. They noted there were bright red beds conformably overlain by an "incoherent conglomerate" derived from the metasediments of the surrounding Caledonia Highlands. They implied, but did not directly state that the Triassic outcropped along the coast up to what is now known as Melvin Beach and dipped inland at angles varying from 25 to 45°. They cite Dawson (apparently personal communication) as identifying fragments of silicified wood from the Vaughan Creek beds as either Peuce or Pinites, both of which are Triassic. Dawson (1878) referred to the fossils as Dadoxylon edvardianum and noted the preservation of the specimens was poor. This species was identified at Split Rock, Quaco and as well at Martin

Head further up the coast. Matthews (1898) was the first to state that the upper member of the New Red Sandstone at Quaco definitely outcropped along the coast north of the village and extended inland to the contact with the pre-Carboniferous volcanics. He also referred to an intrusion of trap into the redbeds at Quaco Head which had altered the sediments. The earliest reference to the environment of formation of any of the sediments is on the Quaco conglomerates by Whittle (1891) in which he stated the unit was a "typical beach conglomerate" derived from Carboniferous limestone and which showed the effects of the pebbles being pushed into each other.

In a study of the Triassic plant fossils, Holden (1913) reviewed the work of Dawson and found that the fossils he had identified were virtually identical with those in the Lower Keuper of Germany (Voltzia coburensis Schaur). She also found a new species, Equisetum rogersii Schimper, which had been described from the Triassic of Virginia by Fontaine (1883; Fide Holden, 1913). She therefore assigned an age of Lower Keuper (Upper Triassic) to the strata at Martin Head and by inference to the rocks at Quaco and Robinson Cove. The most comprehensive work was done by Powers (1916) on the Triassic of the Maritimes in general. In New Brunswick he listed occurrences of Triassic at Split Rocks, Quaco, Martin Head and Waterside. The first measured stratigraphic section was by Powers at north Quaco (Macs Beach); he divided the rocks into three units, the lower and upper redbeds separated by the Quaco conglomerate. The Triassic rocks overlay a pronounced unconformity at both Quaco Head and Split Rock and had a total thickness ranging from 1,550 to more than 2,000 feet. He also noted there was minor folding which pre-dated the faulting since they terminate abruptly against the pre-Carboniferous beds.

Following this work there was a hiatus until the 1930's when two works on the geology of the Saint John region in general were published almost simultaneously. Both Hayes and Howell (1937) and Alcock (1938) used the measured section of Powers (1916). Hayes and Howell noted that the lower sandstone would have a thickness of 3,000 feet instead of 300 (as estimated by Powers) if the section from Quaco Head to Macs Beach was continuous and not repeated by faulting. Alcock also mentioned the presence of two small outliers near the city of Saint John which he thought, but could not prove, were also Triassic on the basis of the lack of deformation, the size of clasts and the calcite cement. A study by Magnusson (1955) was restricted to the beds in the immediate vicinity of St. Martins. He agreed with Matthews (1898) that the sediments extended along the coast to Melvin Beach and inland to the pre-Carboniferous highlands. He also suggested that the three units be termed the Quaco Formation with three members: the lower, Honeycomb Point Member, the Quaco Conglomerate, and the upper, Fownes Head Sandstone. Although Magnusson made a detailed study of the petrology of the area, he did not record paleocurrent data, and his attempts to determine the age of the strata more precisely were not successful, due to the poor preservation of the fossils. Magnusson's overall interpretation was that the Triassic was deposited in an arid basin receiving sediments from a wetter savanah-like upland. Rivers delivered sediment across a piedmont plain to a large lake. The Quaco conglomerate was thought to represent the beach of this lake.

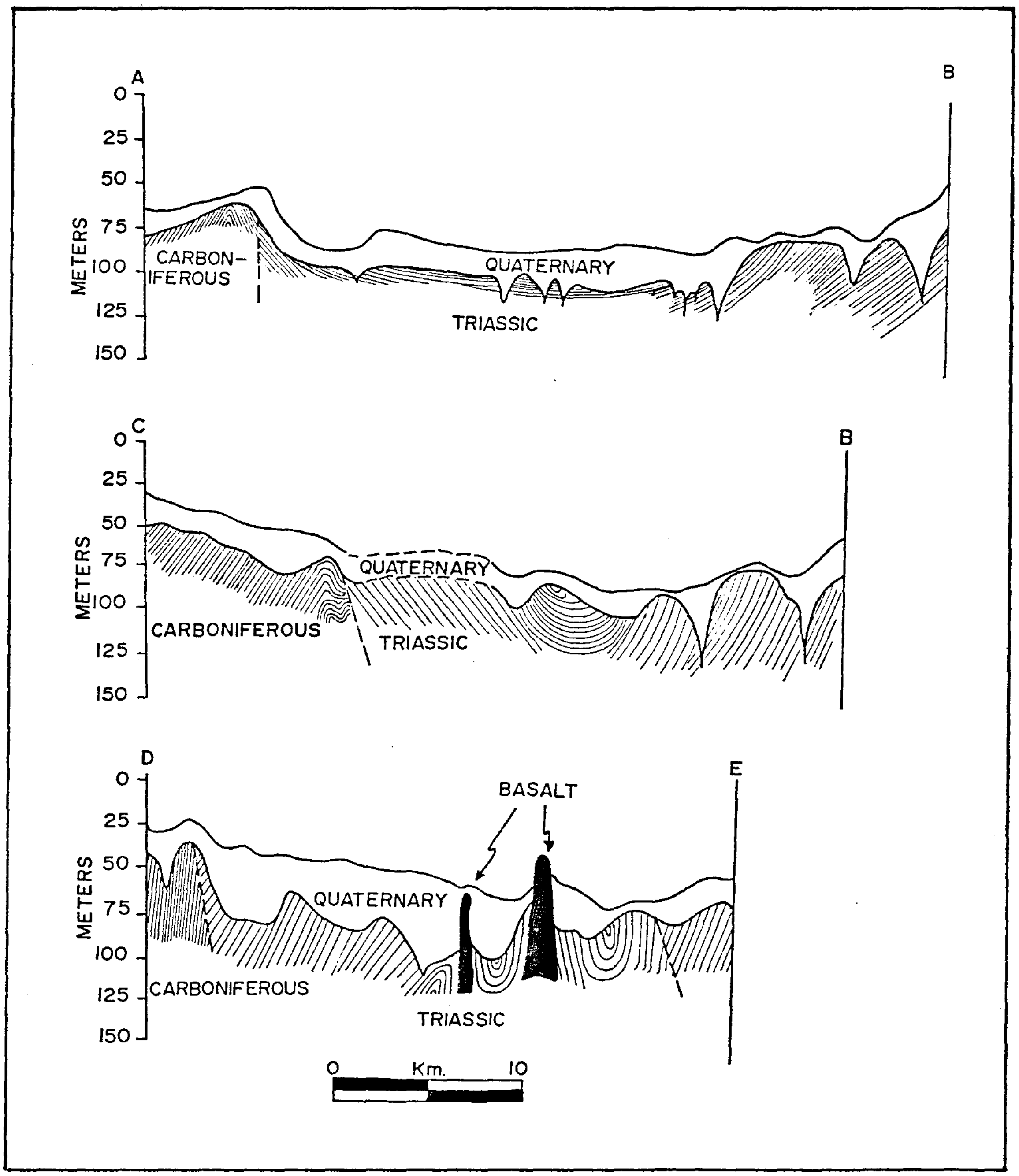
Klein (1962) in his analysis of the Triassic in the Maritimes proposed a change in nomenclature. He suggested the lower unit of redbeds be raised to formational status and named the Wolfville Formation since he thought it was correlative with the formation of the same name in Nova Scotia. The conglomerate and upper redbeds were named the Quaco and Echo Cove Formations respectively. No additional section was measured and the areal extent of the formations was left open to question, but there was an attempt to analyse the paleocurrent data from the area between Brown's Beach and Echo Cove. Klein (1963a) concluded that the drainage pattern was from the west and southwest for all three formations with no change during the Triassic. Using the scheme of Krynine (1948) he classed all three formations as low-rank greywacke. Klein (1962, 1963a) generally agreed with the environmental interpretation of Magnusson (1955) except that he thought that all three formations were the result of deposition on alluvial fans. The Quaco Formation was interpreted as a river, rather than as a beach deposit.

During the late 1960's and early 70's the Mineral Resources Branch of the Department of Natural Resources in New Brunswick mapped the entire Caledonia region of the Province (Ruitenberg et al., 1975, 1979). Rocks of Carboniferous age or younger were not examined in detail, but rather their extent was compiled from the existing literature. The series of maps produced show the narrow strip of Triassic around St. Martins and Split Rock as defined by Alcock (1938) but allows for the possible presence of additional sediments in the small basin east of Gardners Creek (Ruitenberg et al., 1975, Loch Lomond; East Half) (Figure 1.2).

Offshore in the Bay of Fundy, two seismic studies, Swift and Lyall (1968) and Ballard and Uchupi (1975) recorded the extent of the Triassic forming the floor of the bay and the structural relationship it bears with the underlying rocks. The earlier study found the Triassic relatively undisturbed with a faulted northern margin (Figure 3.1) and a major synclinal axis running down the length of the Bay with very shallow dips on the beds. The axis of this structure is repeatedly offset by north trending strike-slip faults which also appear to control the appearance of secondary folds. The authors thought that the lateral continuity of the subsuface strata indicated they were part of the lake deposits of the Blomidon and Scots Bay Formations of Klein (1962). In several areas near the New Brunswick shore there does not appear to be any evidence of a border fault, but the authors concede the possibility of erosion stripping back the softer Triassic sediments from the fault zone. They conclude that the modern Bay of Fundy occupies virtually the same position as the depocentre during Triassic times when the basin was originally formed as a half-graben.

The second study concentrated primarily on the Gulf of Maine and Georges Bank, however some seismic investigations were also made in the Bay of Fundy. The conclusions were that the Fundy Fault system continues into the Gulf of Maine where, in the Late Triassic, stresses from a left-lateral shear couple created a series of normal faults forming three grabens surrounding a horst of Paleozoic and Precambrian

Figure 3.1 Structure under the Bay of Fundy. Line A-B runs from Saint John southeast to Nova Scotia. Line C-B runs from 10 km northeast of St. Martins south-southeast to Nova Scotia (from Swift and Lyall, 1968b).



A
B
METERS
0
25
50
75
100
125
150
CARBON-
IFEROUS
QUATERNARY
TRIASSIC
C
B
METERS
0
25
50
75
100
125
150
QUATERNARY
CARBONIFEROUS
TRIASSIC
D
E
BASALT
METERS
0
25
50
75
100
125
150
QUATERNARY
CARBONIFEROUS
TRIASSIC
0
Km.
10

rocks (see Chapter 2).

There have been some additional paleontological studies, primarily palynology, in the area, but little has been published. Cornet (1977, p. 4) cites Traverse (personal communication) as suggesting an Early to Middle Triassic age for the Quaco and Echo Cove Formations. The data, however, are apparently either incomplete or inconclusive.

3.2 Lepreau

As was the case in St. Martins the first geologic mapping of this locale was completed by Gesner (1839). Based on his observations on Grand Manan Island he identified several groups of rocks as Triassic. Later mapping by Bailey and Matthews (1872) concluded they were Carboniferous. This was confirmed by Matthews (1896) who assigned the rocks to the Lower Carboniferous. Belyea (1939), in a new study of the area, called the rocks the Point Lepreau Formation on the basis that they were "fresh and unaltered and overlied the older (Lancaster) series with obvious unconformity" (p. 84). They were described as coarse arkosic conglomerates, sandstones and occasional shales with a stratigraphic thickness of as much as 10,000 feet. She also stated there were no fossils found and thus an accurate age could not be assigned other than the post-Lancaster (Late Westphalian) age. The name of the formation was changed by Wright and Clements (1943) to the Lepreau Formation. In this form it was used by Alcock (1945) for both the outcrops on the penninsula and those on the Lepreau River (Figure 1.3) which have a similar lithology.

Klein (1962, 1963a) investigated both the lithology and the paleocurrents of the formation and concluded that it was a mixture of low and high-rank greywacke, as well as arkose, derived from the south and southeast, with lithologies similar to the Triassic formations in the St. Martins area. In a comprehensive study of the palynology of the Newark Supergroup Cornet (1977) noted that there were few localities where pollen could be obtained. In one instance the age of part of the Lepreau Formation was thought to be Late-Devonian to early Mississippian (p. 4). It has since been show that this early date came from a small inlier along the Lepreau River (Traverse, personal communication). The most diagnostic fossil found in the area thus far has been a reptile track, found on the bank of the Lepreau River and dated as Middle to Upper Triassic by Sarjeant and Stringer (1977).

Chapter 4

Stratigraphy

4.1 Introduction

Both of the areas studied consist of fault blocks which rest on a complex series of sediments, volcanics and intrusives ranging in age from Precambrian to Carboniferous (see Chapter 2). At St. Martins this is further complicated by the presence of several distinct, completely detached blocks separated by faults of unknown magnitude. Within this region block-to-block correlation is attempted on the basis of lithology and environment of deposition since there are no usable fossils present.

4.2 St. Martins

4.2.1 Introduction

Although the redbeds in this region have been mapped several times the first stratigraphic divisions were propsed by Powers (1916) based on a measured section at McCumber Point. He also examined the exposures at Robinson Cove and Browns Beach, but it appears he did not attempt to integrate these rocks into any of the units at St. Martins proper. The division proposed by Powers lasted forty years until Magnusson, in a detailed mapping program, divided the region into three members of a single formation, estimated thickness on the basis of exposures plotted on a 1:15,840 scale map and proposed, in his unpublished thesis, the first formal names for each of the units (Table 4.1). In a more comprehensive work on the Maritime Triassic as a whole Klein (1962a) raised the three members to formational status and proposed a new set of names: the Wolfville Formation, Quaco Formation, and Echo Cove Formation. The current study also found there were three formations, however a series of name changes and further subdivisions are proposed.

4.2.2 Honeycomb Point Formation

It is here proposed to alter the name of the lower formation from the Wolfville Formation of Klein (1962) to the Honeycomb Point Formation after the name proposed by Magnusson (1955). Klein gave this unit the same name as the lower formation in Nova Scotia, based on the exposure of the basal unconformity in St. Martins at Quaco Head. There is no evidence for either faunal or lithologic continuity across the Bay of Fundy, a distance of 80-100 km, and so a separate formational name should be proposed. The term Honeycomb Point is not perhaps the best choice since the redbeds exposed at this location (on Browns Beach) are a separate fault block from the lower redbeds described by Powers (1916), but it is retained here partly because it has already been proposed and partly because the most distinctive facies of this unit are well exposed in the Browns Beach fault block.

The type section occurs along the coast from approximately 800 m west of Honeycomb Point to 500 m west of Quaco Head (refer to NTS 21 H/5, 50,000 series). Both the upper and lower contacts are faulted off. The

Table 4.1: Name and Thickness Changes in the St.Martins Area Through Time

Author	Formation	Member	Thickness (m)
Powers (1916)		Lower Red Sandstone	91.4
		Quaco Conglomerate	137.3 - 213.4
		Upper Red Sandstone	243.8 - 304.8
Hayes and Howell (1937)	Quaco	Lower Red Sandstone	up to 914.4
		Quaco Conglomerate	137.2 - 213.4
		Upper Red Sandstone	243.8 - 304.8
Alcock (1938)	Quaco		548.6 (+)
Magnusson (1955)	Quaco	Honeycomb Point Sandstone	1074.4
		Quaco Conglomerate	160 - 218.5
		Fownes Head Sandstone	254 (+)
Klein (1962)	Wolfville		?
	Quaco		213.4
	Echo Cove		304.8 (+?)

formation consists of coarse fanglomerates composed mainly of Carboniferous sandstones, interbedded with well sorted medium grained red sandstones (facies B and C_4 of Chapter 5). In the immediate vicinity of the town of St. Martins the formation rests unconformably on Carboniferous sediments at the northwest end of Quaco Head and is unconformably overlain by the Quaco Formation at St. Martins Harbour and McCumber Point.

On the basis of outcrop exposure plotted on 1:10,000 air photos, and assuming average dip values, the thickness of the formation at St. Martins is approximately 925 m. This assumes no repetition by faulting and includes a small (80 m) covered interval near the base of the section. Other exposures of the same formation occur at Browns Beach (460 m) and Robinson Cove (~380 m) although both sections contain faults which may affect the measured thicknesses. Previous authors regarded the latter two exposures as Triassic on the basis of similar colour and poorly preserved plant remains. In this study, however, correlation is on the basis of environment of deposition (see Chapter 5).

There is also the possibility of additional exposures between Bains Corner and Gardners Creek in the western part of the basin. There are exposures in the bed of Ten Mile Creek below conglomerates of the Quaco Formation. Positive identification of the Honeycomb Point Formation in this part of the basin could not be made, however, because of the presence of redbeds in the Carboniferous of the same area, the lack of any faunal evidence or distinctive facies and limited exposure.

Because of the difference in lithologies between the outcrops at Robinson Cove, Browns Beach and Highway 111 and those in and around the town of St. Martins the formation has been subdivided into the Browns Beach and McCumber Point Members. The type section of the former is the same as for the Honeycomb Point Formation, along the coast at Browns Beach. This member, therefore, consists of breccias interbedded with well sorted, medium grained red sandstones. The McCumber Point Member consists of a series of medium grained sandstones which coarsen upward into a pebbly sandstone (facies C_1 of Chapter 5) which is well exposed on the east bank of the Mosher River, in Jacob Brook and at McCumber Point to the east of the town. The type section consists of a fining upward cycle from the pebbly sandstone to a medium grained trough cross-bedded sand exposed on both sides of McCumber Point. The initial coarsening upward cycle is not visible in the type section, however, the exposures are scattered and the pattern is only visible when plotted on air photos. On the whole the member represents the entire 925 m of section exposed at St. Martins from the basal unconformity to the upper erosional contact with the Quaco Formation.

Because it contains the lower unconformity the McCumber Point Member is at least partially a lateral equivalent of the Browns Beach Member. Separation by faulting makes direct correlation impossible although the presence of possible exposures of facies C_4 along the Mosher River may resolve this problem to a certain degree (see Chapter 5).

4.2.3 Quaco Formation

The Quaco Formation consists of a clast supported conglomerate containing a distinctive banded quartzite clast type. This gradually fines upward and becomes more matrix supported while at the same time the clast lithology becomes more varied (facies A_1 and A_2 of Chapter 5). The lower portion rests on the Honeycomb Point Formation with a small angular unconformity which dips to the southeast. The upper contact with the Echo Cove Formation is gradational over 10 to 15 m and best exposed along the coast at the east end of Echo Cove, although it is present on the Irish River and Washburn Brook as well.

This is easily the most distinctive formation in the region and was recognized as a separate unit by all previous authors. It was raised to formational status by Klein (1962). It is well exposed at Echo Cove, Macs Beach (formerly Quaco North Head, hence the name), Washburn Brook and the Irish River. In addition there are poor or dubious exposures along Highway 111, 1.5 km north of the town, in Jacobs Brook (also reported by Magnusson, 1955) and in the bank of a small unnamed brook draining the east bank of the Mosher River. This was previously considered the maximum extent of the formation which ranged in thickness from 330 m at Irish River to 190 m at Echo Cove. During the course of field mapping, however, an additional exposure was discovered along the west side of McGraw Road, 500 m north of Highway 111 and 1.5 km west of Bains Corner. The very distinctive lithology and the similarity of the matrix makes it certain, even in the absence of faunal evidence, that this is in fact a continuation of the exposures at St. Martins. There is also rubble of the same type of rock along Highway 111, 4.25 km west of Bains Corner, and in Ten Mile Creek from the highway to a point approximately 800 m upstream.

Because of the poor exposures, the presence of thick deposits of glacial drift, and heavy vegetation the thickness of the formation in the western part of the basin cannot be estimated. Its presence in what had previously been mapped as Carboniferous by all other workers greatly increases the amount of Triassic preserved in the region.

Although discussed by Klein (1962) the author did not designate a type section. It is proposed here to place the type section of this formation at Echo Cove from McCumber Point where it overlies the Honeycomb Point Formation to the west end of Berry Beach where it grades into the Berry Beach Member of the Echo Cove Formation.

4.2.4 Echo Cove Formation

The Echo Cove Formation gradationally overlies the Quaco Formation and consists of sandstones and pebbly sandstones of different proportions and colours throughout the unit. The upper contact is faulted against the Precambrian volcanics of the Coldbrook Group at the east end of Melvin Beach and on Berry Brook northeast of Fairview (NTS 50,000 series maps 21 H/6 and 21 H/5).

While all previous authors agreed there was an additional unit of Triassic age above the Quaco Formation, the estimates of the thickness and areal extent of the unit has varied considerably through time (Table 4.1). Close examination of the coastal exposures from Berry Beach to Melvin Beach has confirmed the conclusions of Matthew (1898) and Magnusson (1955) who both thought this unit extended northeast to Melvin Beach. Other authors thought that the colour change from red to green beds indicated a faulted contact with the Carboniferous at the east end of Berry Beach (Hayes and Howell, 1937; Alcock, 1938). The contact is in fact conformable throughout, cut only by high angle normal faults with displacements for the most part less than 10 m. This has also been confirmed by pollen analysis (see Chapter 8). The colour change, which is accompanied by a change in faunal content and lithology, occurs over an interval of 20 m in the lower half of the formation and similarly returns to a red colour gradationally over 10-20 m in the upper portion.

It is, therefore, proposed to divide this formation into three members which are exposed along the coast; the lower Berry Beach Member, the Fownes Head Member and the upper Melvin Beach Member. In addition, because of the presence of the Quaco Formation in the western part of the basin the redbeds which overlie the unit in exposures along Gardners Creek, Stony Brook and Ten Mile Creek are named the Stony Brook Member.

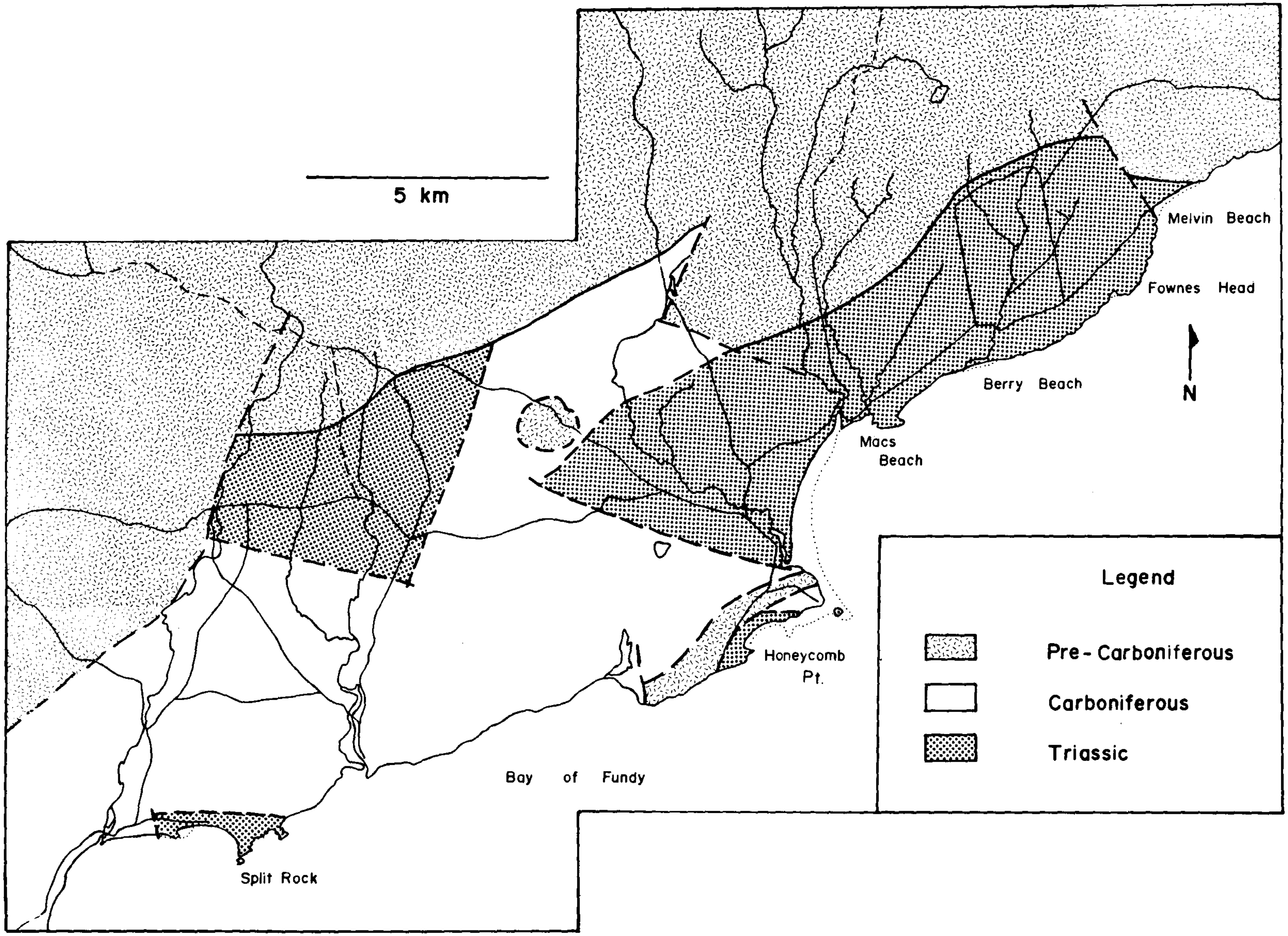
The Berry Beach Member, which corresponds to the upper redbeds of Powers (1916) and the entire Echo Cove Formation of Klein (1962), gradationally overlies the Quaco Formation at the west end of Berry Beach and fades into the Fownes Head Member 950 m east of the beach. The member is made up of interbedded sandstones and shales in the lower half which give way to trough cross-bedded pebbly sandstones in the upper half. The red colouration is due predominantly to the presence of numerous sand sized red shale clasts in the matrix. The total thickness of the unit, assuming no thickening due to faulting, along Berry Brook is 170 m (measured from air photos). The type section for this member is from the lower contact to the west end of Berry Beach along the coast.

The Fownes Head Member gradationally overlies the Berry Beach Member. It is best exposed along the coast up to a point approximately 150 m southwest of Melvin Beach where it forms a gradational upper contact with the upper member of the formation. This unit is distinctive not only for its green colouration but also because of the large amount of plant fragments throughout the member. These fragments range in size from 0.01-1.5 m long and up to 40 cm wide. Although heavily faulted in the upper 200 m of section the thickness of the unit is estimated to be approximately 570 m. The type section is considered to be from the lower contact to the west end of the unnamed beach between Berry Beach and Melvin Beach. The member also outcrops along roadcuts and in streams from Berry Brook northeast.

The upper Melvin Beach Member of this formation has a gradational lower contact with the Fownes Head Member and is faulted against the Precambrian basement in the upper portion. It is at least 170 m thick based on measurements from air photos. The lithology is dominantly breccia (facies B, Chapter 5) with interbedded red shales and medium sands. This colour change along with the disappearance of the plant fragments indicates a change in environment between the two upper members. The type section consists of the outcrop beginning 200 m from the west end of the beach and extending northeast to the fault contact.

In the western end of the basin (Figure 4.1), immediately overlying the Quaco Formation is a thick series of breccias (facies B_1,

Figure 4.1 Revised geologic map of the St. Martins based on the 21 H/5 E and 21 H/6 W maps of Ruitenberg et al. (1975). Contacts between the different aged units are assumed to be normal faults. The extent of the Triassic in the northwest portion of the basin is unknown.


5 km
Melvin Beach
Fownes Head
N
Berry Beach
Macs
Beach
Honeycomb
Pt.
Bay of Fundy
Split Rock
Legend
Pre-Carboniferous
Carboniferous
Triassic

Chapter 5) which gradually fine upward and become interbedded with medium grained sandstones. Although the lower contact is not exposed with the constant north dip of both the Quaco Formation and this unit indicates this is a lateral equivalent of at least the Berry Beach Member of the Echo Cove Formation. It is well exposed in Gardners Creek, Stony Brook, Ten Mile Brook and along the road north of Bains Corner toward Shanklin. From stream exposures it appears the upper contact consists of a high angle fault against the Coldbrook Group to the north.

Although many of the stream exposures are covered in moss the type section for this Stony Creek Member of the Echo Cove Formation outcrops along Gardners Creek 200 m north of Highway 111 and in Stony Creek as a series of discontinuous exposures. From outcrop locations plotted on 1/4 mile map sheets the thickness was found to be 1,350 m. The much greater thickness of this unit than the Berry Beach Member may be a reflection of more rapid subsidence in this part of the basin and/or be a result of redbed deposition during part of the Fownes Head Member time.

4.3 Lepreau

4.3.1 Introduction

The redbeds which make up the Lepreau peninsula were studied by Belyea (1939) and Alcock (1945). It was Wright and Clements (1943) who first applied the term Lepreau Formation to the sediments on both the coast and the Lepreau River. Although Klein (1962) thought that the formation could be correlated with the sediments in the St. Martins region on the basis of lithologies the evidence of the present study makes this unlikely. It was found that the formation could be divided into three members on the basis of lithology. It is here proposed to name the three members, from the base up: the Fishing Point Member, the Duck Cove Member and the Maces Bay Member.

Because of time constraints only those exposures along the coast were examined, and those relatively briefly.

4.3.2 Fishing Point Member

Stratigraphically the lowest member in the formation this unit is exposed along the coast from the faulted eastern contact immediately north of Fishing Point to approximately 1,250 m east of the wharf at the Lepreau Nuclear Generating Station. From Fishing Point to just east of Plumper Hole (refer to New Brunswick 1/4 mile map sheet N-30) the member consists of breccias composed of various types of granites (facies B_4, Chapter 5). Sandstone interbeds are thin, discontinuous and rare. These breccias laterally interfinger with fine sands and pebbly sandstones (facies C_3 and C_1, Chapter 5). These make up most of the exposure west of Plumper Hole although breccias do occur, usually as faulted blocks. The entire unit has a deep red hue as the result of hematite staining of all facies.

All exposures of this member dip uniformly to the north and are cut by numerous faults of unknown magnitude. The lower contact is not exposed. The upper contact is an erosional unconformity with the overlying Duck Cove Member exposed at the eastern end of Duck Cove. Because of the faulting and lack of exposure of the bottom contact, accurate estimates of unit thickness are impossible. From air photos it is thought the thickness is approximately 350 m.

The type section for this member is from approximately 150 m east of Plumper Hole to the top of the member. Although heavily faulted this section of coast shows all major lithofacies of the unit.

4.3.3 Duck Cove Member

This member unconformably overlies the Fishing Point Member. The lower contact is exposed on the coast at the eastern end of Duck Cove. The member is exposed over the bulk of the Lepreau peninsula up to the Welsh Cove Wharf. The exposures from the lower contact to Point Lepreau are designated as type section.

This member consists of cross-bedded conglomerates interbedded with red shales. Except for rip-up clasts and the occasional clast of pink feldspar the bulk of the conglomerates and sandstones are very light red in colour, composed mainly of quartz and orthoclase. The most distinctive feature of the member is the presence of an aphanitic, grey-green volcanic as the main clast component in the conglomerates. Another feature of these beds is the occurrence of the most numerous and diverse ichnofaunal assemblage of any of the Triassic formations studied. The unit appears to have an overall fining-upward trend with the appearance of thicker and more frequent red shale beds up-section. The upper contact was arbitrarily placed at the point where facies B_5 first appears. Therefore, the contact is gradational and exposed immediately south of the Welsh Cove wharf. The thickness of the member is estimated to be 1,200 m.

4.3.4 Maces Bay Member

The lower boundary of this member has been arbitrarily placed at the appearance of the first clast-supported breccia containing clasts composed primarily of cataclasticly deformed dark brown sediments (facies B_5, Chapter 5). Because of this there are numerous beds in the lower part of the Maces Bay Member which are identical, in lithology and trace fauna content, to parts of the Duck Cove Member. The upper contact is the fault contact with the Carboniferous sediments and volcanics approximately 700 m east of the causeway in the Little Lepreau Basin along Highway 790. The number and thickness of the beds of clast-supported breccia increases up-section until approximately 200 m south of the Maces Bay wharf where the unit consists entirely of this breccia. The member is also exposed where the unit consists entirely of this breccia. The member is also exposed along the new highway joining Highway 790 with the generating station. The best exposures are along the coast, however, with the type section from Maces Bay (where Highway 790 turns east) to the causeway in the Little Lepreau Basin. The estimated thickness of this member is 1,175 m.

4.4 Summary

The sediments of the St. Martins area are at least 2,100 m thick and consist of three formations (from base to top): the Honeycomb Point Formation (new name), the Quaco Formation (Klein, 1962) and the Echo Cove Formation (Klein, 1962) (Figure 4.2). The lower formation consists of redbeds made up of coarse breccias interbedded with medium grained sandstones in the west forming the Browns Beach Member (new name). Around the town of St. Martins the formation consists of a coarsening upward followed by a fining upward cycle of sandstones and pebbly sandstones making up the McCumber Point Member (new name).

The Quaco Formation overlies the Honeycomb Point Formation with an erosional unconformity. It consists of a roundstone cobble conglomerate with interbedded coarse sandstones. This is overlain by the Echo Cove Formation.

The Echo Cove Formation gradationally overlies the Quaco Formation in the eastern part of the basin and erosionally in the western part. Along the coast east of St. Martins the formation has been subdivided into three members on the basis of changes in lithology and flora. The lower Berry Beach Member (new name) consists of a coarsening upward cycle of redbeds which consist of medium to coarse sandstones giving way to pebbly sandstones and becoming progressively greyer in the process. This is gradationally overlain by the Fownes Head Member (new name). This unit is made up of grey-green sandstones and pebbly sandstones with abundant plant material. The upper contact with the Melvin Beach Member (new name) is also gradational. The

Figure 4.2 General stratigraphic column of the St. Martins area. Based on exposures from Quaco Head northeast to Melvin Beach. Coarsening and fining upward trends shown schematically. Dashed contacts refer to gradational boundaries. Grain size depicted by facies types

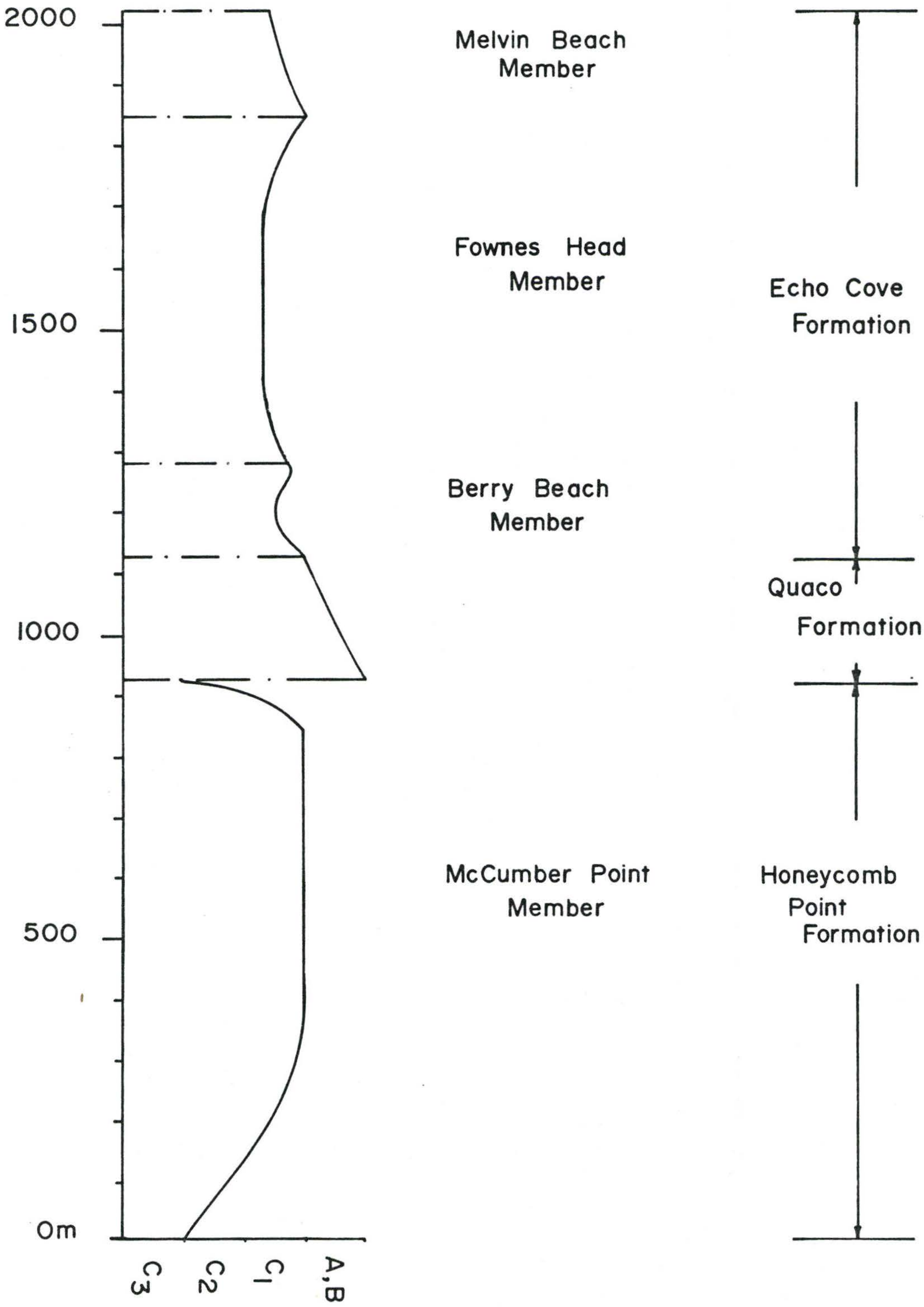
A,B - conglomerate and breccia

C_1 - pebbly sandstone

C_2 - coarse sandstone

C_3 - medium sandstone

Shales are not shown.


2000
1500
1000
500
0m
C3
C2
C1
A,B
Melvin Beach Member
Fownes Head Member
Berry Beach Member
McCumber Point Member
Echo Cove Formation
Quaco Formation
Honeycomb Point Formation

Melvin Beach Member consists of redbeds made up of breccias, sandstones and shales. These gradually fine upward through the section.

In the western part of the basin the red breccias and interbedded sandstones outcropping along Gardners Creek, Stony Brook and Ten Mile Brook overlie the Quaco Formation and therefore are assigned to the Echo Cove Formation as the Stony Brook Member (new name) (Figure 4.3). This is considered the lateral equivalent of at least the Berry Beach Member and perhaps part or all of the Fownes Head and Melvin Beach Members as well.

The Triassic sediments exposed along the Lepreau Peninsula are about 2,725 m thick and form the Lepreau Formation (Wright and Clements, 1943) which has been divided into three members, from base to top: the Fishing Point, Duck Cove and Maces Bay Members. The Fishing Point Member (new name) is composed of breccias, consisting almost exclusively of granite clasts in the east. These laterally interfinger with fine sandstones and pebbly sandstones near the upper contact in the western exposures. The Duck Cove Member (new name) erosionally overlies the Fishing Point Member at the eastern end of Duck Cove. This unit consists of conglomerates and interbedded coarse sandstones which gradually fine upward. Near the top of the unit the red shale beds become progressively thicker and more numerous. This is gradationally overlain by sandstones and clast-supported breccias of the Maces Bay Member (new name). This member forms a coarsening and thickening upward cycle of breccias which is truncated by the boundary fault on the southern coast of the Little Lepreau Basin (Figure 4.4).

Figure 4.3 Generalized section through the St. Martins basin showing the relative thicknesses and spatial associations of the various formations and members. Thicknesses taken from measurements on 1:10,000 air photos.

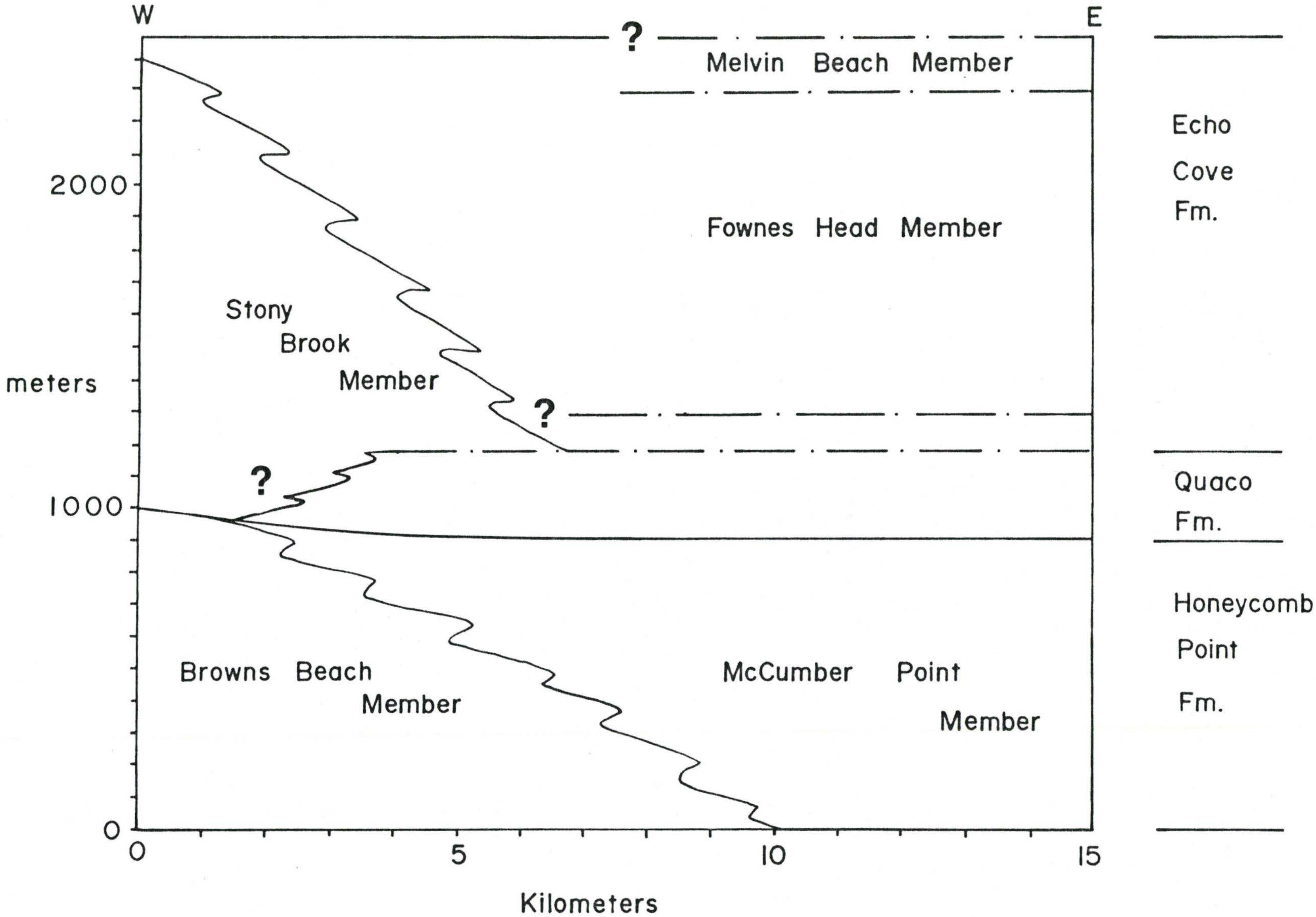
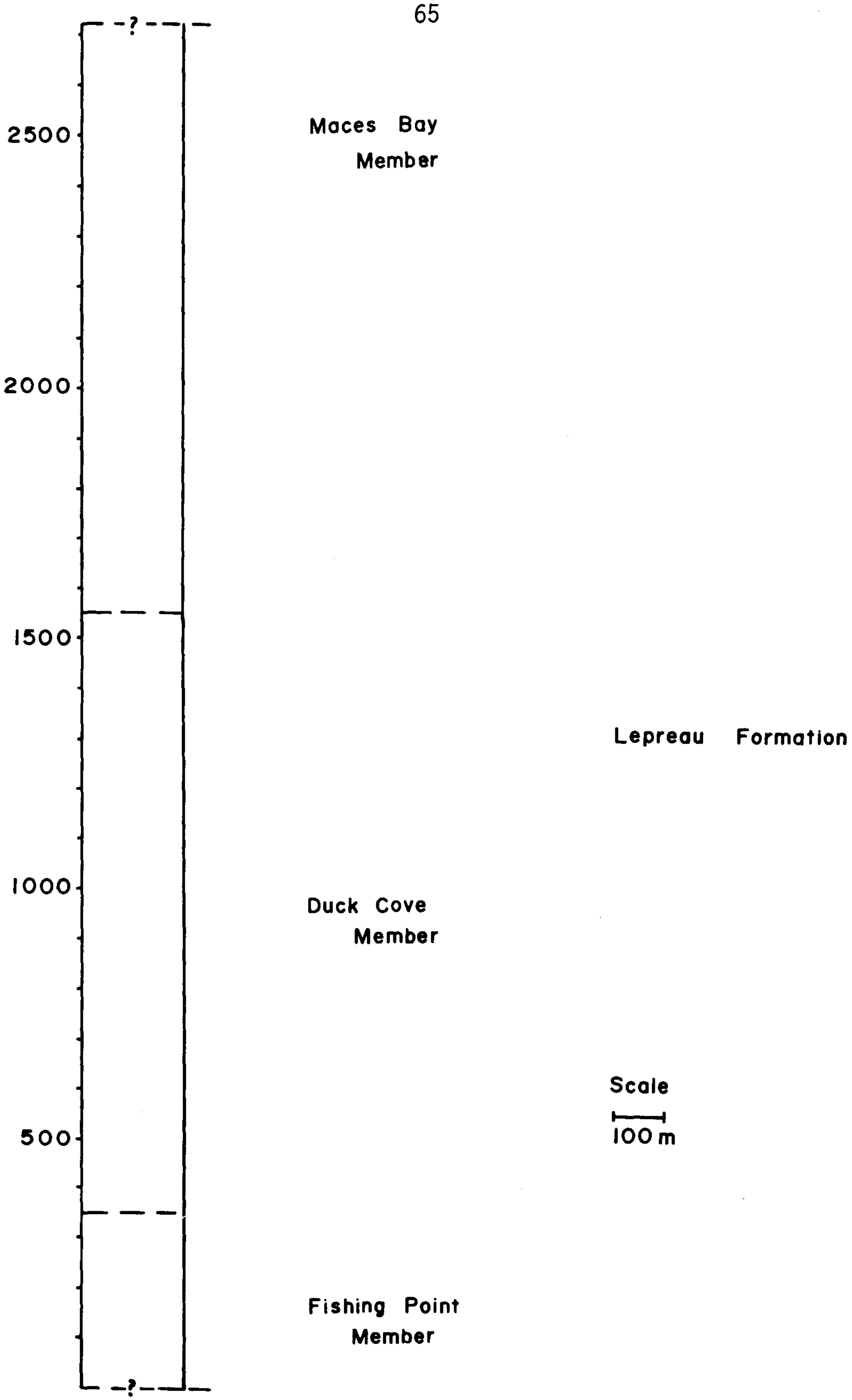

W
E
?
Melvin Beach Member
Fownes Head Member
Echo
Cove
Fm.
Stony
Brook
Member
meters
?
?
Quaco
Fm.
Honeycomb
Point
Fm.
Browns Beach
Member
McCumber Point
Member
2000
1000
0
0
5
10
15
Kilometers

Figure 4.4 Generalized stratigraphic column for the Lepreau Formation. The fining upward of the Duck Cove and possibly Fishing Point Members and the coarsening upward of the Maces Bay Member are not shown due to lack of measured sections.



2500
2000
1500
1000
500
?
?
Maces Bay Member
Duck Cove Member
Fishing Point Member
Lepreau Formation
Scale
100 m

Chapter 5

Facies Description and Interpretation

5.1 Introduction

Facies as defined in the field are distinguished by lithologic, structural and organic features which can effectively separate one group of sediments from another (Walker, 1979). The amount of subdivision in each facies type depends both on the diversity inherent in the sediment and the amount of time available for study. The exposures at St. Martins and Lepreau show considerable variation in some of the facies. Time restraints precluded a detailed study and subdivision of all the facies. Therefore, while some of the facies are well defined and finely divided there are others that remain poorly defined and undifferentiated.

The facies were described and subdivided in the field at the end of the field season after all the rocks had been examined. Not all are represented on measured sections (particularly those in Lepreau) but their distribution was recorded on air photos during the area mapping. Each facies type was given a letter classification with numerical subscripts for variations within types (Table 5.1).

Table 5.1

Main Facies Types

Facies A	Conglomerates
Facies B	Breccias
Facies C	Sandstones
Facies D	Shales, with or without calcareous concretions

5.2 Facies Description

5.2.1 Facies A

5.2.1.1 Introduction. This facies is composed of conglomerates from both areas, with clasts of various sizes and lithologies (Table 5.2). Although the conglomerates have been divided into 6 subtypes there is room for refinement, especially in the St. Martins area. This facies is distinguished from the breccias by the presence of more than 75% rounded to well-rounded clasts.

5.2.1.2 Facies A_1. This is a dominantly clast-supported conglomerate made up of rounded to well-rounded fragments of quartzite, metamorphic and volcanic quartz, granites, various types of acidic and basic volcanics as well as sandstones. These conglomerates comprise up to 80% of the Quaco Formation at St. Martins. The clast size varies from 2 cm to 60 cm. Average clast size changes from 15 cm at the bottom to 4 to 5 cm at the top of the formation. The most distinctive feature is the presence of well-rounded cobbles of banded quartzite, on which, in specimens with long (A) axis greater than 15 to 20 cm, there are numerous crescentic percussion marks scattered over the surface. In addition, there are shallow, circular indentations where the clasts are in contact. A few of the cobbles and boulders have a hematitic stain on the surface. Inter-clast voids are filled with a grey-green, coarse to medium sand made up of quartz and felspar with a calcite cement.

Table 5.2

Facies A

Facies A_1	-	Clast supported, roundstone oligomictic conglomerate (quartzite clasts predominate)
Facies A_2	-	Matrix supported conglomerate, similar to A_1
Facies A_3	-	Matrix supported, polymictic conglomerate. Trough cross-bedded with red shale clasts.
Facies A_4	-	Matrix supported polymictic conglomerate. Bedded or cross-bedded. Lacks red shale clasts, but contains plant fragments.
Facies A_5	-	Matrix supported intraformational conglomerate with abundant red or green shale clasts.
Facies A_6	-	Matrix supported polymictic conglomerate with abundant green volcanic clasts. Poorly defined bedding. Calcite cement.

The amount of cementation varies throughout the exposures from well-indurated to almost non-existent. The latter is common where the clasts are large (e.g., at the base of individual beds) and the amount of sandstone fill is a minimum. The rock is well cemented where the clast size drops below 10 cm or is in matrix-support.

Beds are generally 0.5 to 2 m thick. Lower contacts of beds are erosional with scours up to 3 m wide and 2 m deep occurring (although rare). The upper contacts vary from erosional where overlain by another gravel unit to gradational into facies C_2. Sedimentary structures preserved in this facies include large planar tabular crossbeds, well exposed in the cliffs along Echo Cove (Figure 5.1), imbricated clasts (Figure 5.2) (discussed in detail in Chapter 7), and crude hoizontal bedding. The beds are normally graded and either alternate with facies C_2 or, less frequently, pass abruptly into facies C_3. In this case the sands of facies C_3 are thin, laterally discontinuous, and rippled.

5.2.1.3 Facies A_2. This is a dominantly matrix-supported conglomerate similar in lithology to facies A_1. The content of banded quartzite clasts is much smaller, there is an increase in the abundance of quartz, and the average clast size decreases to 2.5 to 3 cm. The fragments are as well rounded, as the previous case, but without the percussion marks and circular pits present on the larger cobbles. Hematitic staining is more common (or at least more obvious with the presence of the white quartz). The matrix is the same medium-to-coarse sand made up mainly of quartz and feldspar, but in this sub-type the

Figure 5.1 Planar tabular cross-bedding in the Quaco Formation, facies A. Location is approximately halfway up the section at Echo Cove. Scale is 1 meter.

Figure 5.2 Imbricated clasts in the Quaco Formation. Facies A_1. Location is the base of the formation at Echo Cove.

rock is invariably well-cemented. The percentage of clasts in individual beds ranges from 50% to 80% with a mean, based on visual observation in the field, of 75 to 80%.

The beds have an erosional lower contact and gradational upper contact with trough cross-bedded sandstones of facies C_2 and C_3. This facies sub-type is restricted to the upper half of the Quaco Formation and the Berry Beach Member of the Echo Cove Formation outcropping both inland and along the coast. No sedimentary structures were recorded from this type and no grading, either normal or reverse, was noted.

5.2.1.4 Facies A_3. This is a matrix-supported conglomerate consisting of clasts ranging in size from 0.5 to 4cm. The clasts are angular to well-rounded and made up of quartz, granites, epidote, volcanics of various types and numerous fragments of fine grained red siltstone/shale intraclasts. Preferential weathering of the intraclasts gives exposures a honeycomb appearance. The matrix consists of a poorly sorted coarse-to-medium sand (the latter occurring as infrequent lenses) with abundant sand-sized fragments of the red fine sand/shale which, on the whole, gives the rock a reddish hue not readily apparent on closer examination. The size and amount of the intraclasts appears to decrease up-section in the Berry Beach Member and disappears completely prior to the transition to the Fownes Head Member. In contrast to facies A_1 and A_2 the rock is well bedded with layers ranging from one to 2.5 m thick. These are invariably trough cross-bedded with individual sets as much as one m thick and 2 m long. Scours truncating troughs are common but rarely exceed a metre in thickness. The facies is generally well indurated by calcite cement. It is best exposed along the coast on either side of Berry Beach but also occurs in road cuts between Bayview and Berry Brook.

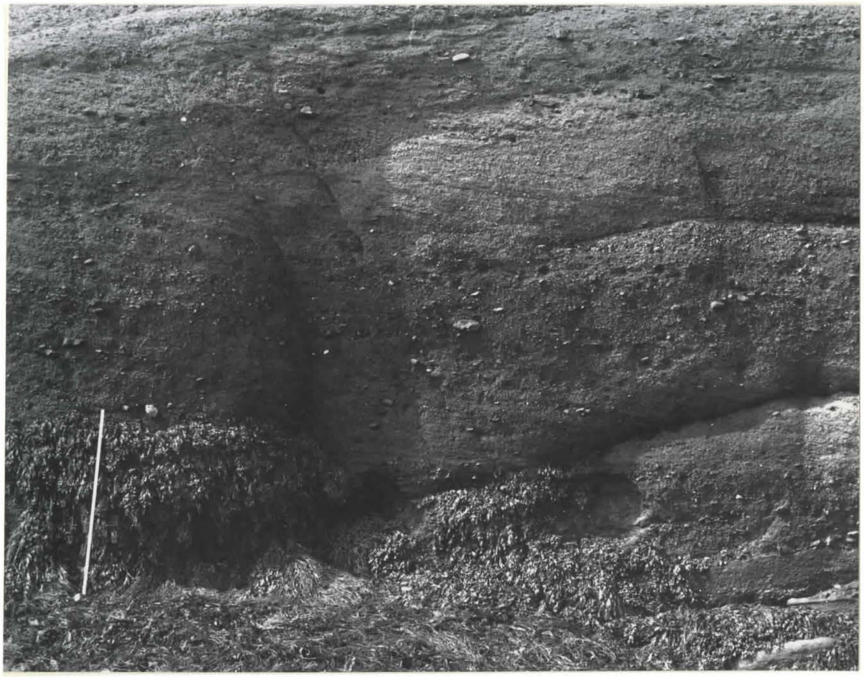
5.2.1.5 Facies A_4. Similar in style to the previous sub-type, this matrix-supported conglomerate is composed of a wide variety of lithologies (including rhyolite and jasper which facies A_3 lacked) in well defined beds which are either massive or planar tabular, or trough cross-bedded. The clast size varies from 2 to 15 cm with an average of 4-5 cm. Clasts are set in a matrix of medium to coarse sand with a higher percentage of medium sand than the previous type. Both clasts and matrix lack the red, fine sand/shale intraclasts characteristic of A_3. Large plant fragments, as much as 30 cm wide and over 1.5 m in length, occur sporadically throughout the facies with smaller fragments scattered in the matrix. The lower contacts are always erosional, frequently into facies C_1 and C_3, while the upper contacts are generally abrupt to gradational into parallel laminated facies C_3. From reconnaissance surveys of coastal exposures of the Fownes Head Member, in which this facies occurs, it appears the number of beds and the average size of the clasts increases toward the top of the member although there are no measured sections through this area with which to prove this one way or the other.

5.2.1.6 Facies A_5. This is a matrix-supported, intraformational conglomerate. It is composed of clasts of fine sandstone and/or shale which make up 70 to 90% of the rock (Figure 5.3). These clasts are generally prominent in negative relief since they weather out of the rock much faster than the matrix. The latter is usually composed of medium sand, with lenses of coarse sand, moderately well sorted, and cemented by calcite. There are, however, some cases in which there are granules and pebbles occurring in isolated patches or singlely within the matrix, but these make up less than 1% of the facies. The colour of the clasts is usually red although in the Fownes Head Member they are green. In the transition from the Fownes Head Member to the Melvin Beach Member the clasts are both red (brownish-red) and green. It appears from field relationships they were initially green and have been altered after burial.

As a general rule these beds, which have well defined lower contacts, are erosional into facies types C and D_2. The upper contacts are erosional, abrupt or gradational, usually into facies C_3. Bed thicknesses range from 5 to 50 cm with an average approximately 25 cm in the Berry Beach Member at Echo Cove and 5 cm in the upper 60 m of the Honeycomb Point Formation at McCumber Point. This facies type is also well exposed in the Duck Cove Member of the Lepreau Formation and the Melvin Beach Member of the Echo Cove Formation.

Figure 5.3 Intraformational conglomerate, facies A, from the Berry Beach Member of the Echo Cove Formation at the west end of Berry Beach. Note mud cracks at the base of the bed. Assistant for scale (162 cm).

Figure 5.4 Planar tabular cross-bedded conglomerates of facies A_6 in the Duck Cove Member of the Lepreau Formation. Location is approximately 250 m east of the tourist information center of the N.B.E.P.C. Nuclear Generating station. Looking west.



5.2.1.7 Facies A_6. This is a matrix-supported conglomerate made up of several types of granites, cataclastic volcanics and sediments, and a distinctive gray-green aphanitic volcanic. The latter is present as rounded to well rounded clasts, 2 to 15 cm in diameter, which makes up 60 to 95% of the rock and may locally be in clast support. The size fraction less than 2 cm in diameter is dominated by fragments of quartz and feldspar or aggregates which have survived transport. The average clast size is 6 cm with a range of one to 33 cm. The sedimentary structures in this facies consist of trough or planar tabular cross-beds up to 1.5 m thick. Apparent imbrication of pebbles is common (Figure 5.4). The presence of poorly defined cross-bedding makes it highly probable many "imbricated" pebbles are lying on the lee slopes of planar tabular structures. Where grain sizes decrease enough to allow good definition of bedding the troughs (which make up less than 25% of the facies) have highly asymptotic toesets. The whole facies is well cemented by calcite and stringers of this material are present throughout the exposures as well. This facies type makes up a large part of the Duck Cove Member of the Lepreau Formation.

5.2.2 Facies B

5.2.2.1 Introduction. Facies B consists of various kinds of sedimentary breccias, i.e., sediments with more or less angular fragments, in both matrix and clast-support with the matrix varying from shale to coarse sand (Table 5.3). Volumetrically they comprise most of

Table 5.3

Facies B

Facies B_1	-	Clast supported, monomictic breccia (porphyritic granite clasts dominant).
Facies B_2	-	Matrix supported breccia composed mainly of sandstone clasts.
Facies B_3	-	Matrix supported breccia with poorly defined crossbedding. Clasts of rhyolite present.
Facies B_4	-	Clast supported breccia composed of granites. Calcite cemented.
Facies B_5	-	Clast supported breccia. Abundant cataclasticly deformed sediment as clasts. Calcite cemented.

the Lepreau Formation and significant amounts of both the Echo Cove and Honeycomb Point Formations. In general they are poorly sorted, with one or two lithologies dominant in a given area, and well cemented.

5.2.2.2 Facies B_1. A clast-supported breccias with clasts consisting almost exclusively of a maroon, porphyritic granite. The clasts vary from subrounded to angular but are generally subangular to angular. The remaining clasts, less than 5%, are made up of mafic and felsic volcanics. Clast size varies from 2 to 43 cm with an average of 10 to 12 cm. Bedding is poorly defined in the lower third of the exposures in Gardner's Creek north of Highway 111 (west of St. Martins) but can be seen where there are interbeds of facies C_3 in the upper two-thirds. Where visible, both upper and lower contacts appear to be erosional in the lower section while in the upper there are abrupt and gradational transitions into sandstones of facies C. The matrix is a dull red and is made up of poorly sorted, coarse to medium sandstone with a calcite cement. The rock appears to be fairly well indurated, however, the amount of cementation is difficult to assess as most of the outcrops are either in the streams or are covered with a thick growth of moss. Faults in this facies are common and easily seen by their effect on stream morphology but the extent to which they have affected the cementation and diagenesis of the facies could not be determined in the field. This facies is well exposed in both Gardner and Ten Mile Creeks north of Highway 111 between the boundary fault

fault at Fairfield and the road north from Bains Corner to Shanklin (quarter mile map sheet Q-28) and makes up the bulk of the Stony Brook Member of the Echo Cove Formation.

5.2.2.3 Facies B_2. This is a predominantly matrix-supported breccia with local clast-supported concentrations. Clasts are composed of gray-green coarse-grained sandstone, pebbly sandstone, polymictic conglomerate and minor amounts of banded rhyolite. The matrix is a red medium-grained sandstone (locally coarse-grained) which is fairly well sorted with only a minor amount of feldspar and what appears to be pyrolusite and/or manganite (Hanson, 1932). Clast sizes range from 3 to 65 cm with an average in the neighbourhood of 16 cm. The rock is well cemented by calcite and has been subjected to extensive faulting on both large and small scale. At Robinson Cove bed thicknesses are frequently erosional (but may be abrupt) with no evidence of major channeling. The largest scours seen were of the order of a few tens of centimetres deep and more than a metre wide. Planar tabular cross-beds 40 cm high occur rarely. Upper contacts are abrupt and show even less scouring than the lower contacts, especially when overlain by facies C_4. The clast lithologies are easily traceable to the Carboniferous clastic rocks exposed in different parts of the same sedimentary basin. The manganese found in the matrix also appears in outcrops in a small fragment of Windsor limestone at Quaco Head. This facies sub-type is found exposed in the small fault bounded remnants at Robinson Cove and at Browns Beach, in the Browns Beach Member of the Honeycomb Point

Formation.

5.2.2.4 Facies B_3. This is primarily a matrix-supported breccia with angular to sub-angular clasts ranging in size from 2 to 50 cm and averaging 10 to 20 cm (the average size varying between individual beds), in a matrix of coarse to medium-grained sandstone. The largest fragments are composed of banded rhyolite of the type exposed along the Irish River approximately 5.5 km upstream from the Orange Hill bridge. The remaining clasts are made up of mafic volcanics, quartzites, and red shale clasts (Figure 5.5). The latter are especially common in the lowest 50 cm of some beds where they may, in local concentrations, make up as much as 80% of the rock. In areas where these breccias have cut down into shales and siltstones of facies D_2 the intraclasts are up to 1.2 m in length.

Bedding is well defined although it appears some of the thicker units may be due to amalgamation of two or more separate beds. Thickness varies considerably from 0.7 to 8 m. Lower contacts, which are invariably erosional, also have preserved in them large groove marks, 40 to 50 cm wide, up to 10 cm deep and at least 2 m long (the maximum extent visible in outcrop) which are slightly undulatory and aligned roughly parallel to flow as defined by other paleocurrent indicators in surrounding facies. These marks occur only where the breccia has cut into facies D_2. Upper contacts vary from abrupt, mostly passing up into parallel laminated sandstones of facies C_3, to

Figure 5.5 Breccias of facies B_3 from the Melvin Beach Member of the Echo Cove Formation at Melvin Beach. Looking north. Scale is 30 cm long.

Figure 5.6 Breccias of facies B_4 from the Fishing Point Member of the Lepreau Formation. Just south of Fishing Point, looking west.

gradational where these breccias merge up into pebbly sandstones of facies C_1. Thicker units of the breccia may show normal to inverse grading, although the latter may be the result of welding of two beds with a poorly exposed scoured surface. Imbrication was sporadically present but may indicate the development of planar tabular cross-bedding as in facies A_6 rather than being an artifact of the current. This facies type is found only at Melvin Beach in the upper member of the Echo Cove Formation.

5.2.2.5 Facies B_4. This is a clast-supported breccia composed entirely of different types of granites with clasts 2 to 30 cm in diameter and averaging 2.5 to 3 cm. The matrix consists of coarse sand to fine breccia made up of angular fragments of quartz and feldspar crystals and granitic rock cemented by calcite (Figure 5.6). There are some isolated but quite common areas in the lower portion of the exposure where there is no matrix as described above. Instead, blocky calcite fills the entire void space. In some outcrops, there are thin, lenticular interbeds of coarse sandstone (similar in lithology to the matrix) which may be the only indication of bedding planes. A characteristic feature of this facies type is the presence of large, 5 cm wide, 1 to 2 cm deep and up to 1.5 m long, branching, arcuate, horizontal carbonate-filled traces. These are more fully described in Chapter 8. Although no serious attempt was made to trace the clast types to outcrops present nearby there are numerous granitic bodies in the Lepreau-Musquash region (Figure 1.3) which are possible sources. This facies laterally interfingers with facies C_1 and C_3 over a distance of 20 to 50 m in the western end of the outcrop. The facies is exposed only in the eastern (and hence lower) portion of the Fishing Point Member of the Lepreau Formation.

5.2.2.6 Facies B_5. A clast supported breccia with angular to sub-angular clasts for the most part but with a few very large well rounded fragments of granite, up to 1.2 m in diameter, are found in the upper portion. The dominant lithology is a dark brown, cataclasticly deformed sediment which can be traced to Pennsylvanian outcrops less than 3 km from the coastal exposures and less than 2 km from the roadcuts. The upper part of the section has substantially more granite, up to 20 to 25% (visually extimated), in clasts which are much better rounded than those of the cataclasticly deformed sediment and have a larger average size, 20 cm vs 2 to 5 cm. The matrix, where present, varies from shale to coarse sand. In some exposures the finer grained sediment appears to 'drape' over the breccia with clasts protruding from below. Where matrix is absent the void spaces are filled with blocky calcite although nowhere does this appear to be as extensive or laterally continuous as in the previous example. The lower half of the Maces Bay Member has well defined beds of this facies which range in thickness from 0.75 to 2 m and has abrupt to erosional bottom contacts and abrupt upper contacts. These beds have poorly exposed planar tabular crossbeds occasionally at right angles to channeling (Figure 5.7). In the upper half the bedding has been obscured by one breccia cutting into another. Trace fossils were not found within the breccias although they were common in associated facies in the lower half of the member. This facies type is best exposed along the coast on either side of the Maces Bay wharf and along Highway 706 just to the south of the Little Lepreau Basin.

5.2.3 Facies C

5.2.3.1 Introduction. This facies consists of sandstones of various grain sizes, structures and composition (Table 5.4). Although important in terms of environmental and paleohydraulic interpretation, the amount of time available for close examination of this type was limited and a more complete subdivision, though merited, could not be justified. Sandstones occur in all formations in both areas, so each sub-type will be described formation by formation.

5.2.3.2 Facies C_1. This is composed of pebbly sandstone in which the clasts make up 25 to 50% of the rock as estimates visually in the field. While some classifications, e.g., Colorado School of Mines (1955) maintain this should be classed as a conglomerate the dominant visual characteristic is the abundance of sand. The clasts range in size from 0.5 to 15 cm and average, generally, between 1 and 2 cm. They vary from angular to well rounded although in individual formations the degree of roundness is relatively constant. For example, in the

Table 5.4

Facies C

Facies C_1	-	Pebbly sandstone. Matrix varies from medium to coarse sand. Clasts comprise 25 to 50% of the bed.
Facies C_2	-	Coarse sandstone either massive or crossbedded.
Facies C_3	-	Medium sandstone.
Facies C_4	-	Light red, medium grained sandstone with large-scale crossbedding. Present only in the Browns Beach Member.

Honeycomb Point Formation the clasts are angular to sub-angular while in Echo Cove Formation they are mostly sub-rounded to rounded.

In the Honeycomb Point Formation (Figure 5.8) the angular to sub-angular clasts are slightly imbricated and in some cases show the development of small-scale planar tabular cross-bedding (sets less than 5 cm thick). The sand is coarse with rare medium-grained lenses and made up of quartz and feldspar. The clast composition varies considerably with sandstones, volcanics, quartz and numerous types of matamorphic types present. The bedding appears to be laterally quite continuous from a distance but closer examination reveals it is highly lenticular with any one bed present over only 1 to 3 m and generally only 1 to 3 cm thick. These beds make up the McCumber Point Members of the Honeycomb Point Formation.

The Fownes Head Member of the Echo Cove Formation contains trough cross-bedded pebbly sandstones with the number of clasts ranging from 10 to 25%. The pebbles range in size from 1 to 4 cm with an average of 1.5 to 2 cm. They are made up of rounded to well rounded mafic and acidic volcanics for the most part, with minor amounts of quartz and rhyolite or jasper. The enclosing sand is a grey-green, coarse-grained, fairly well sorted sandstone with a calcite cement. Bed thickness varies up to 2 m with troughs reaching 50 to 75 cm in height, and 1 to 15 m long.

The Melvin Beach Member of the same formation also has this facies type, however, here the percentage of pebbles is much higher, 20 to 50%, and the clasts are angular to sub-rounded. They are

Figure 5.7 Breccia of facies B_5 in the Maces Bay Member of the Lepreau Formation. Location is roughly 650 m north of the Welsh Cove Wharf. Note the channeling and cross-bedding. Hammer for scale.

Figure 5.8 Pebbly sandstone of facies C_4 from the McCumber Point Member of the Honeycomb Point Formation, looking northwest. Scale is 1 meter.

arranged in beds of planar tabular cross-sets with gradational lower contacts into breccias of facies B_3. Bed thickness ranges from 0.25 to 1.3 m with the upper contacts erosional to abrupt. The sand is coarse-grained and poorly sorted.

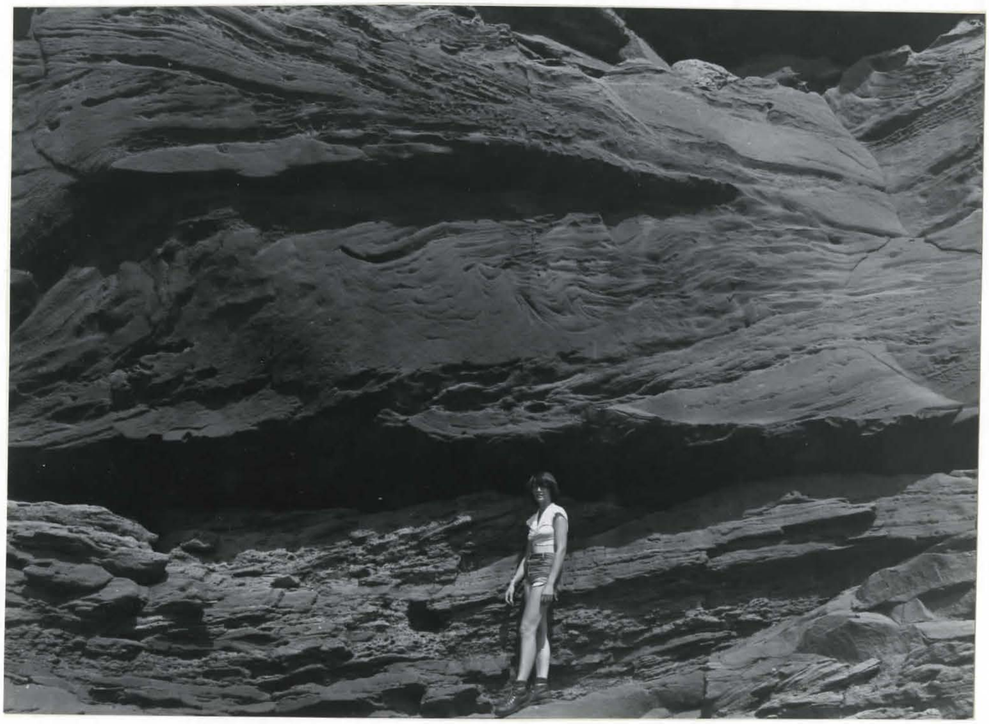
In the Lepreau Formation the pebbly sandstones of the Fishing Point Member laterally interfinger with breccias of facies B_4, and sandstones of facies C_3. The amount of clasts varies from 10 to 50% of of the rock. The size is much smaller, 2 to 7 mm, than in other examples of this facies. Here the granules are sub-rounded to well rounded and bound in a matrix of medium- to fine-grained sand well cemented by calcite.

5.2.3.1 Facies C_2. This is composed of coarse sandstone which may be either massive or trough cross-bedded. In all cases the sands are poorly sorted and have a few lenses of medium sand and pebbles (less than 50% scattered throughout.

In the Quaco Formation these sands occur as lenses up to 2 m thick and at least 50 m in length (perpendicular to the current) (Figure 5.9). At the east end of Macs Beach, where these sand lenses are exposed in the cliffs, the lenticularity is more pronounced parallel to the current direction. The beds grade upward from the underlying conglomerate, facies A_1, with scattered pebbles at the base. The upper contacts with the conglomerates are always erosional. The troughs are best exposed on the upper half of the wavecut platform in Echo Cove.

Figure 5.9 Trough cross-bedded sandstones of facies C_2 in the Quaco Formation. Exposed on wavecut platform at low tide at Echo Cove. View is looking north. Scale is 1 m.

Figure 5.10 Convolute lamination in the Berry Beach Member of the Echo Cove Formation. Location is east end of Berry Beach. Assistant for scale.



Here they appear to be stacked en-echelon, but well formed, 1.5 to 2 m wide and up to 0.5 m thick. Unfortunately the lower half of the platform is totally covered with seaweed which cannot be removed from the rock.

The Echo Cove Formation contains sandstones of this grain size which vary in colour in all three members. Most exposures, particularly in the lower two members, are in inaccessible cliff faces, however, inspection using binoculars did not reveal any planar tabular sedimentary structures in facies associated with conglomerates, breccias or pebbly sandstones (where coarse sand would be expected). Most of the beds which contain coarse sand in the Berry Beach Member are classed in the C_1 facies because of the high percentage of pebbles (10 to 50%). In the Melvin Beach Member there are trough cross-bedded coarse sandstones which have abrupt transitions from the underlying breccias and are in turn cut into by overlying breccias. These are an average of 70 cm thick and can be traced laterally only for 2 to 3 m. They closely resemble those of the Quaco Formation.

The largest volume of coarse sand appears in the Duck Cove Member of the Lepreau Formation. It is found throughout the unit interbedded with facies A_6, C_3, D_1, and D_2. The bottom contacts are erosional into facies C_3 and C_4 and usually gradational from facies A_6. Upper contacts are abrupt to gradational into C_3, D_1 and D_2 or erosional where overlain by A_6. The sand is poorly sorted and similar in composition to the matrix of quartz and felspar of facies A_6. It is well cemented by calcite.

Most of the exposures appear massive but there are infrequent trough cross-bedded units.

The massive units are extensively bioturbated but this is visible only where enhanced by weathering (see Chapter 8, Section 2.2.2). Similar sandstones are found in the Maces Bay Member of the same formation because of the transitional nature of the contact. In these samples bioturbation appears less often but this may be a consequence of the lack of extensive bedding plane exposures which are common in the Duck Cove Member. The coarse sandstone is absent in the upper half of the upper member.

5.2.3.4 Facies C_3. This is made up of medium-grained sandstones and, as in the last example, is exposed in all the formations with a wide variety of associated sedimentary structures.

In the Honeycomb Point Formation there are trough cross-bedded, rippled and parallel laminated sandstones of this grain size. These vary in colour from bright red to dull red-brown and are best exposed at McCumber Point. They are moderately to well sorted and cemented by calcite and, less frequently, quartz. Where they are overlain by facies D_2 (red mudrocks) they can be seen to be penetrated by shrinkage cracks filled either with red shale or sands from the overlying bed. The parallel laminated sandstones range in thickness from 5 to 90 cm with an average of 27 cm. Many broken surfaces show parting lineation. Beds of this type are overlain with abrupt to gradational contacts either by trough cross-bedded or rippled sands or less commonly by facies D_2.

The trough cross-bedded units occur in the upper part of the formation on either side of McCumber Point. The troughs are an average of 20 cm wide, 4 cm high and give way to parallel laminated and pebbly sandstones. Rippled sands are less common but more widespread. They tend to occur on the upper surfaces of plane laminated beds and in turn are covered with a thin mud drape. Ripple heights average 0.5 cm with a 7 cm wavelength (measured from crest to crest). Where exposures are good bedding plane surfaces occasionally show traces which are also covered with the mud veneer.

This sand size is rare in the Quaco Formation and is restricted to a few lenticular beds, less than 3 m long and 10 cm thick, with abrupt lower and erosional upper contacts out of and into facies A_1. Ripple heights average 1 to 2 cm with wavelengths of the order of 10 cm. These beds make up less than one per cent of the formation.

The Echo Cove Formation has the greatest volume of this type of facies with the greatest variety of sedimentary structures. Here too, there are trough cross-bedded, rippled and plane laminated sands but there are also convolute laminated beds as well.

The Berry Beach Member contains all types of structures. The parallel laminated sands, which commonly show parting lineation, have gradational to abrupt lower contacts from facies A_2 or C_1 and occur in beds up to 2.6 m thick. These occasionally pass into rippled sands of similar grain size which have either an abrupt upper contact with facies D_2 or an erosional contact with facies A_2. Shale clasts are frequent in all beds but are less than 2 mm in diameter. The convolute laminated units are visible in exposures on either side of Berry Beach. These range in thickness from 0.4 to 2.5 m (Figure 5.10). They are visible laterally for up to 30 m in the cliff faces with abrupt upper and lower contacts. The latter may, in fact, be erosional but show no signs of scouring at the base. Some of the beds of this type (generally parallel laminated) are definately erosional as indicated by the presence of flutes and grooves cut into the beds of facies D_2 at several places in the lower part of this member.

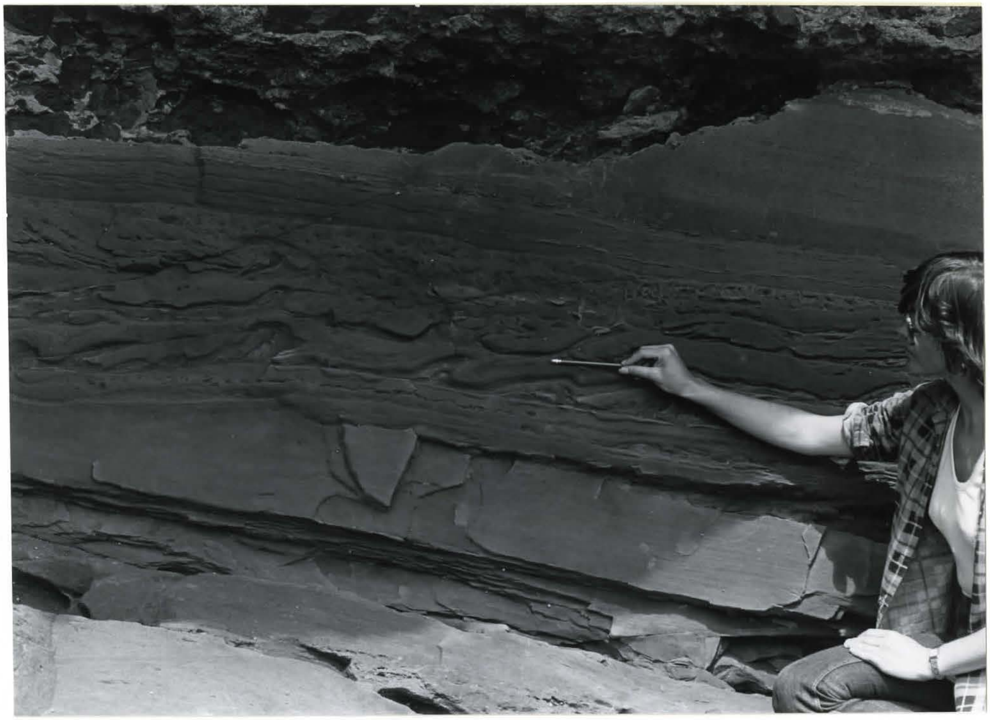
The Fownes Head Member consists of gray-green, medium-grained, micaceous sands with some convoluted intervals (particularly in the lower part of the unit) and occasionally well developed flame structures near the base of some beds (Figure 5.11). There is an increase in the amount of trough cross-bedding exposed. The sets are commonly 1 to 1.5 m thick with individual troughs 1 m deep and 2 to 2.5 m long (parallel to flow). A few measured more than 2 m across the toe of the set (perpendicular to the flow direction). These may have small pebbles (1.5 to 2 cm) scattered along the base which generally disappear over 10-20 cm. The basal contacts are often erosional while the upper contacts are either erosional (overlain by facies C_2) or gradational into parallel laminated medium-grained sandstones. There are no measured sections through this interval, however, from field observations, it appears there is more parallel laminated sandstone in the lower than in the upper half of this unit. Ripples were not noted in any of the exposures in the area. Beds of medium sand which appear to be massive are found in the upper half of the member but these are generally only visible in portions of the cliff face which are out of reach. They are easily distinguished from the other types by the presence of bubble structures, on both a small and large scale, permeating the entire bed. In all cases there are fine, disseminated plant fragments found on bedding planes. Because of the associated pyrite, the rocks are stained a light yellow.

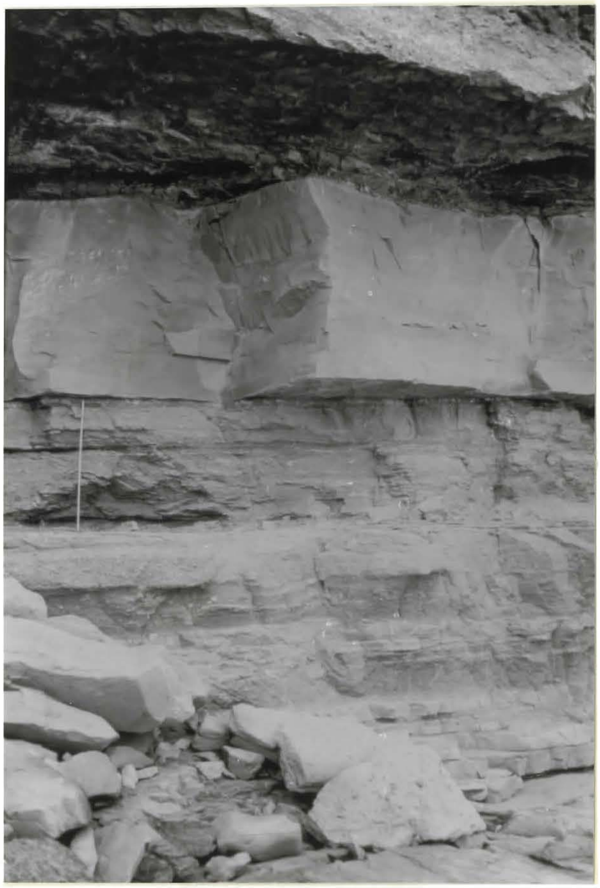
The Melvin Beach Member contains primarily plane laminated sands in beds ranging from 0.4 to 2.9 m thick (Figure 5.12). These all show parting lineation but, in addition, there are some that show organic traces along with the striations. These beds generally overlie the pebbly sandstones with a gradational contact and are cut into from above by the breccias. Ripples are found on some bedding plane surfaces but they are rare.

The Fishing Point Member of the Lepreau Formation contains a red micaceous medium-grained sandstone which laterally interfingers with facies B_4 and is interbedded and eventually overlain by facies C_2 in the western exposures. Fresh surfaces do not reveal the grain size, however, weathered, glaciated bedding planes reveal a well sorted sand with less than 10% mica. Calcite and quartz occur as cements. Bedding is hard to determine as there appears to be little pattern to the thickness or lenticularity and the contacts between beds do not show any appreciable grain size changes or other distinguishing features. Nevertheless bedding is exposed (Figure 5.13) in all outcrops and

Figure 5.11 Flame structures in facies C_3 in the Fownes head Member of the Echo Cove Formation. Location approximately 1.4 km east of Berry Beach. Pencil for scale.

Figure 5.12 Parallel laminated sandstone of facies C_3 in the Melvin Beach Member of the Echo Cove Formation at Melvin Beach. Underlain by red shales (facies D_2) and overlain by breccia with basal intraformational conglomerate. Scale 1 m. Looking north.





averages 25 cm in thickness. Small circular green spots occur throughout the section but make up less than 5% of the rock. On a few bedding planes a thin veneer of mud is preserved, which has associated with it either small traces or warty lumps (Figure 5.14).

The Duck Cove Member has this sand size scattered throughout either as ripple laminated, plane laminated or massive units. These are generally 0.2 to 2 m thick. Ripples have a wavelength of 9 cm and an amplitude of 1 cm. They are covered with a thin film of mud and are commonly bioturbated. The massive beds were not studied in sufficient detail to determine whether the lack of structure was due to bioturbation or not. Parallel laminated beds have gradational or abrupt bottom contacts with facies A_6 or C_2 and upper contacts which are abrupt into facies D_1 or D_2, or erosional, cut into by facies A_6 or C_2. Mud cracked horizons occur throughout the upper half of the Duck Cove and lower half of the Maces Bay Members. The cracks are infilled either by mudrock or coarse sand.

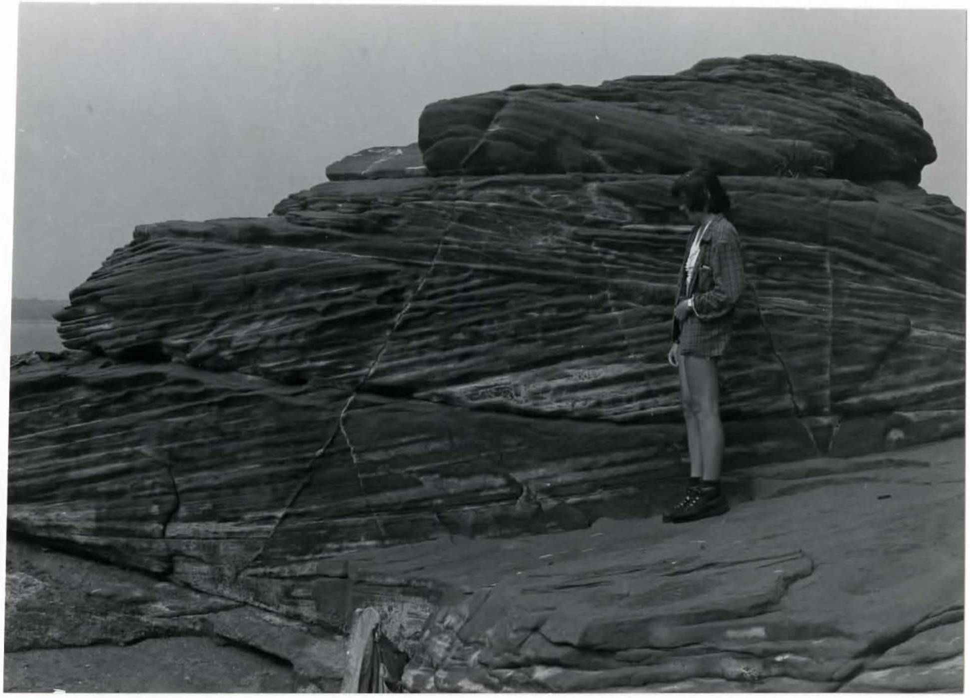
5.2.3.5 Facies C_4. This is also a medium-grained, light red, quartz rich sandstone. However, it is dominated by a single type of sedimentary structure, very large scale cross-bedding which is trough or planar tabular (Figures 5.15 and 5.16). The sets average a little over 1 m thick with individual bedding planes measurable over 3 to 5 m before being truncated by the next set of cross-beds. The large scale sets are exposed in the Browns Beach Member of the Honeycomb Point

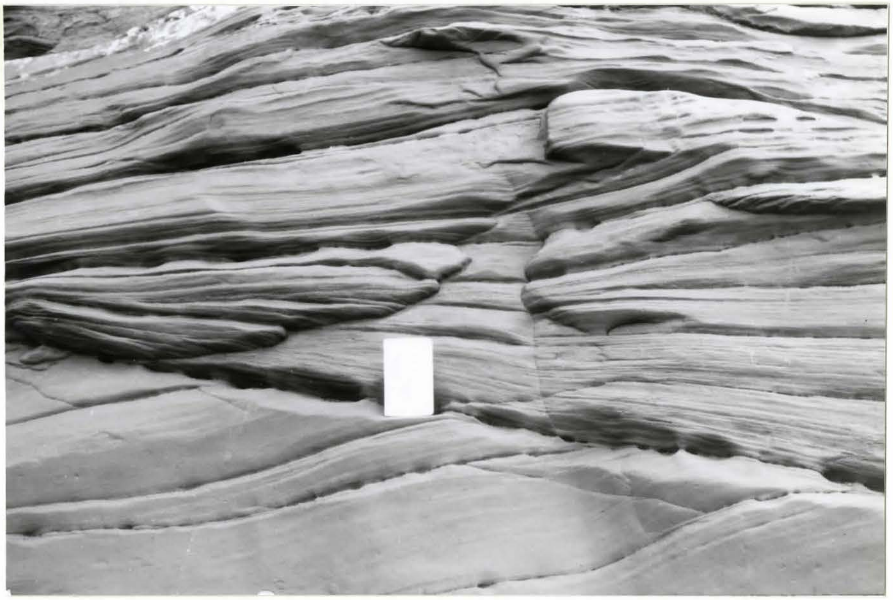
Figure 5.13 Massive fine-grained sandstone of facies C_3 in the Fishing Point Member of the Lepreau Formation. Lo ation is approximately 2 km east of the tourist information center at the Point Lepreau Generator. Scale is one meter. Looking north.

Figure 5.14 Adhesion ripples (?) from a bedding plane in facies C_3, the Fishing Point Member of the Lepreau Formation. Location is 1.3 km east of the tourist information center at the Lepreau Generator. Hammer for scale.

Figure 5.15 Planar tabular crossbedding in breccias of facies B_2 in the Brown Beach Member of the Honeycomb Point Formation at Robinson Cove. Location is in Split Rock, looking west. Assistant for scale

Figure 5.16 Wedge tabular crossbedding in facies C_4 in the Browns Beach Member of the Honeycomb Point Formation at Browns Beach. Location is approximately 50 m east of main beach. Notebook is 19 cm high.





Formation at Robinson Cove, Browns Beach and Quaco Head. In addition, there also may be outcrops of this facies along the Mosher River and on either side of McCumber Point.

The examples at Robinson Cove are either trough or wedge planar, the latter occurring where the sets are thickest. The large sets are interbedded with facies B_2, with abrupt lower contacts and erosional upper contacts. Troughs are common in the area of the measured section. They are best exposed at Quaco Head (Figure 5.17). Very low angle stratification, thought to be the toesets of large troughs, is also common. All exposures show a low scatter of cross-bed dip directions, especially when compared with similar exposures in other areas (see Chapter 7). Minor clay layers with mud cracks occur but these layers are less than 5 cm thick and never more than 4 m in lateral extent. Cementation of the sands is generally poor and usually by calcite. A few small pebbles are found isolated in the middle of the largest units. There is also one occurrence of small, stair-like structures here which is peculiar to this facies (see below).

The exposures at Browns Beach are more interesting. These occur in cosets up to 2.5 m thick which form beds which can be measured for at least 100 m along the cliffs and possibly up to 700 m. As before these abruptly overlie breccias and are in turn truncated by the same type of breccia. The light red colour and calcite cement is also present here. Small scale stair-like structures similar to those at Robinson Cove were also seen although the repetitive, regular nature and low amplitude (1 to 3 mm) and relatively long wavelength (30 to 40 cm) could mean these are a shallow bedform as well (Figure 5.18). Bioturbation was seen in one exposure on the west side of the beach on the lower contact face of a bed. This feature is described in Chapter 8.

The best exposures are found at Quaco Head, but the time available for observation is limited by the short time the tide conditions permit access. Here troughs average 1.3 m in height and the toesets are as much as 70 m wide (again measured perpendicular to the flow direction). Sets are truncated by troughs of the same material and no other facies types were found. Vertical thickness of the units is at least 4 m although exact measurement was precluded by the seaweed growing on the lower part of the section. The sand is the same light red, well sorted material noted previously. The only structure, other than the troughs, is the series of columns between bedding planes in individual troughs. These are perpendicular everywhere to the bedding in each set of laminations, regardless of angle, and may be the result of weathering and cementation. No bioturbation or small-scale structures were found.

The possible exposure at McCumber Point occurs as trough cross-bedded sands on the Macs Beach side and as very long, low-amplitude sets on the Echo Cove side although they are both at the same stratigraphic level (Figure 5.19). In both cases the sands are a deeper red colour than before and bedding is picked out by a light green coloration which has formed along bedding planes. In the first instance the troughs are at least 1 m in thickness while at Echo Cove the bed is approximately 1 m

Figure 5.17 Large-scale corssbedded sandstones of facies C_4 in the Browns Beach Member of the Honeycomb Point Formation at Quaco Head. Looking north. Assistant for scale is 162 cm.

Figure 5.18 Small-scale structures in facies C_4 in the Browns Beach Member of the Honeycomb Point Formation at Browns Beach. Approximately 1.1 km from the west end of the beach. Scale is 19 cm high.

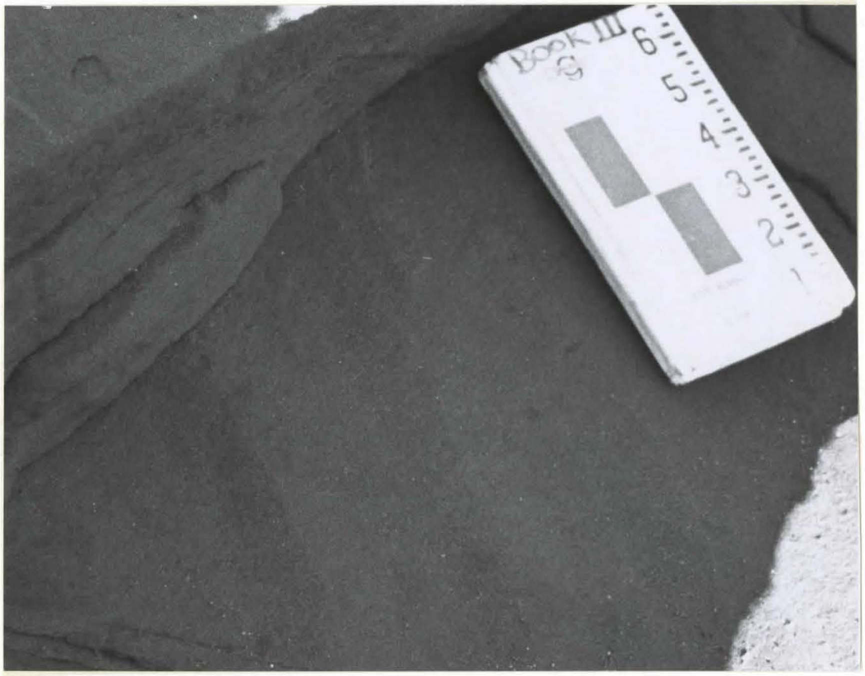
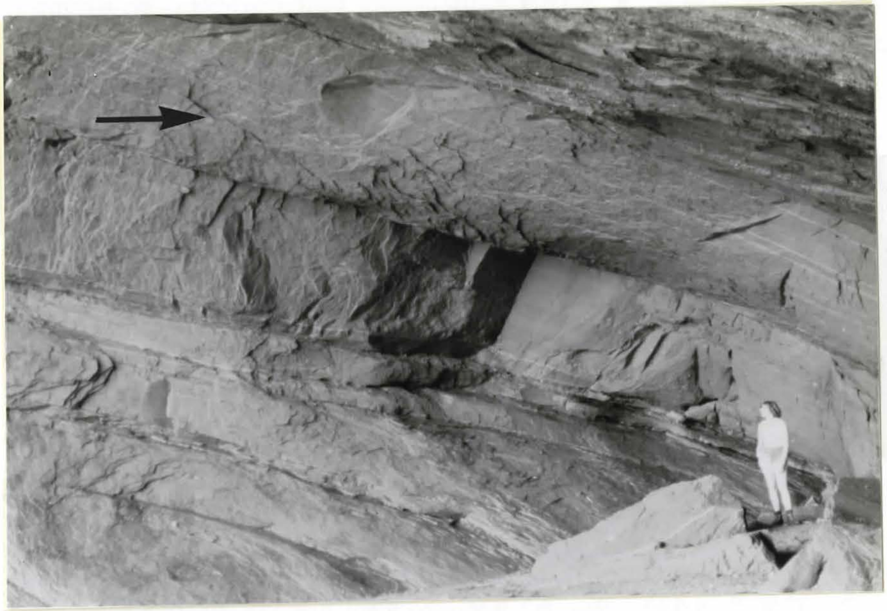
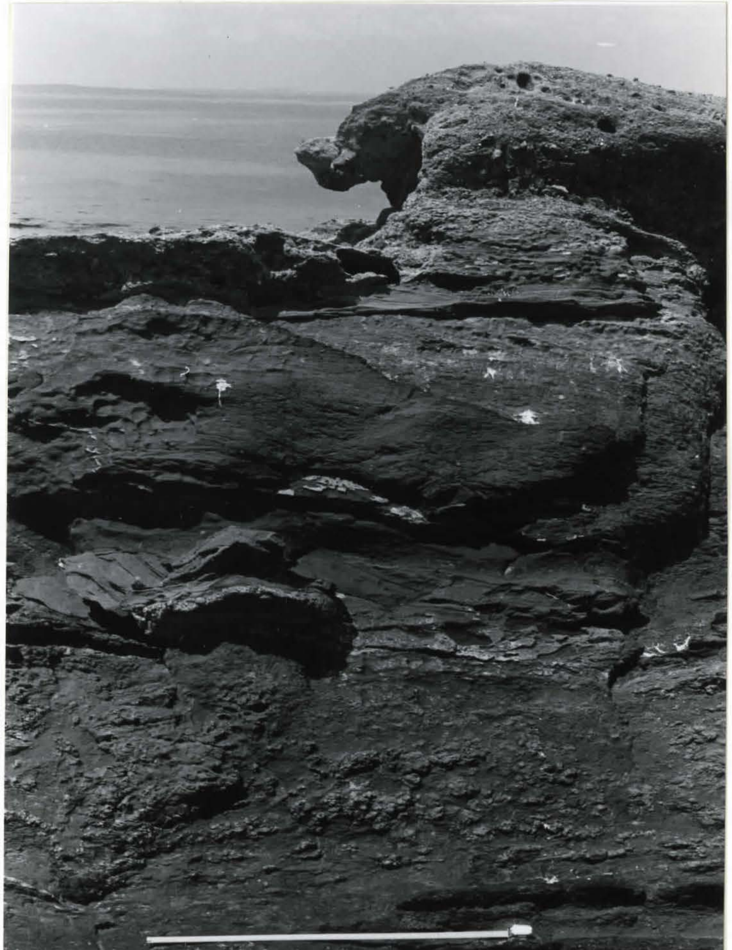

BOOK III

Figure 5.19 Low angle cross stratification in the McCumber Point Member of the Honeycomb Point Formation. Location is near the top of the formation of the Echo Cove side of McCumber Point. Looking west. Assistant for scale.

Figure 5.20 Caliche development in shales of facies D_1 in the Duck Cove Member of the Lepreau Formation. Located approximately 400 m south of the Welsh Cove Wharf. Looking west. Meter for scale.





thick with the bedding planes traceable for 15 m in the outcrop.

5.2.4 Facies D

5.2.4.1 Introduction. This facies type can be described as fine sand to shale, generally red in colour although there is some light green shale in the upper portion of the Fownes Head Member. These deposits are frequently bioturbated to such an extent no sedimentary structures, with the exception of shrinkage cracks, are found. This type has been sub-divided on the basis of presence or absence of more than 15 to 20% calcareous concretions (Table 5.5).

5.2.4.2 Facies D_1. This sub-type is distinguished by the bedded nodular concretions. It is most common in the Duck Cove Member of the Lepreau Formation especially in the upper half just to the south of the Welsh Cove wharf (Figure 5.20). These nodules are composed of calcium carbonate arranged in horizontal (or near horizontal) beds. One exception to this case, however, is shown in Figure 5.21. The nodules appear to disrupt the original bedding although this may have been due to bioturbation (there are burrows found at all the locations where this facies is exposed). The beds average 1.2 m thick with abrupt lower contacts resting on several different facies. This facies is invariably erosionally overlain by facies A_6. The average size of the concretions is 3 to 4 cm.

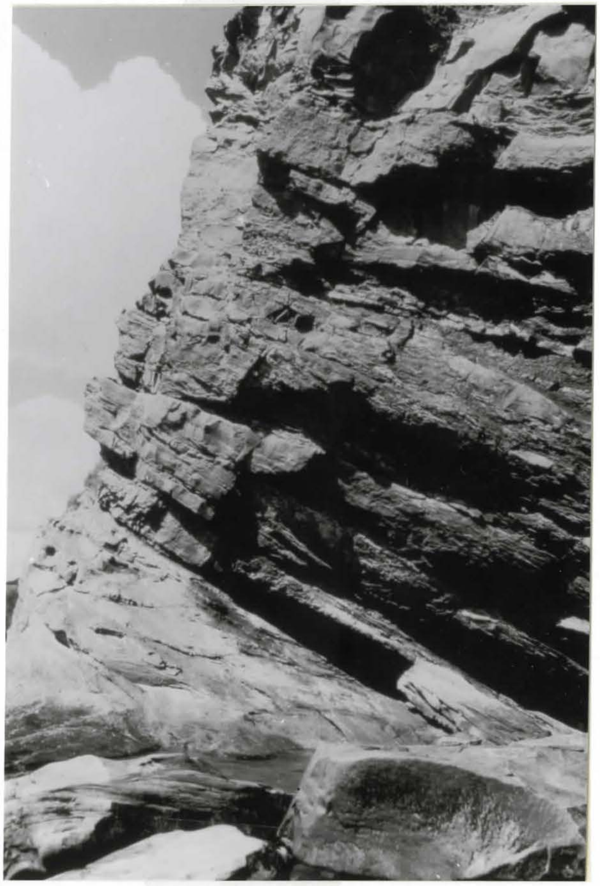
Table 5.5

Facies D

Facies D_1	-	Red shales and fine sandstone with calcite concretions in layers.
Facies D_2	-	Red shales, either laminated or massive, without concretions other than occasional burrows.

Figure 5.21 Disrupted caliche profile in facies D_1 of the Duck Cove Member of the Lepreau Formation. Location the same as Figure 5.20. Scale is one meter.

Figure 5.22 Shales of facies D_2 in the Berry Beach Member of the Echo Cove Formation. Location is west end of Berry Beach. Looking northwest. Cliff is roughly 60 m high.



A smaller outcrop of this facies occurs in the Honeycomb Point Formation in an exposures along Highway 111, 3.8 km west of St. Martins. Here it forms a thin, 10 cm, bed which can only be traced laterally for 3 m before it is scoured out by the overlying breccias of facies B_2. The nodules here average 4 cm wide and make up 75 to 90% of the bed.

5.2.4.3 Facies D_2. A much more common variant of this facies, it is found in virtually all formations. As with previous types it has green reduction spots associated with it and bedding is generally not visible. The thickness of the beds ranges widely, from 5 to 80 cm, partially because of the more extensive exposure. No sedimentary structures were seen and most outcrops show a hackly fracture pattern in the rock which allows it to crumble easily.

In the Honeycomb Point Formation this is most common in the upper part of the unit where it forms thin, mud-cracked units which are frequently scoured out by the overlying lithology. At the outcrop on Highway 111, west of St. Martins, the bed thickness is 1 to 2 m however blasting has reduced the exposure to a broken mass.

In the Echo Cove Formation, particularly in the Berry Beach and Melvin Beach Members there are substantial beds of this facies. In both cases bioturbation structures, calcite filled burrows, are fairly common and the bedding is not visible. All exposures show an abrupt lower contact (with a wide range of facies) and erosional upper contacts with coarse-grained sediment. In the Berry Beach Member mud cracks, while not common, do occur on the upper surfaces of some beds and are preserved by the overlying coarse sand or conglomerate (Figure 5.22). At Melvin Beach none were observed.

In the Lepreau Formation these beds occur as thin. laterally persistant units made up of fine to very fine sands with occasional thin interbeds of medium sand. In contrast to the other beds described these have well defined bedding planes, no evidence of bioturbation, no green reduction spots and no preserved examples of mud-cracks. The beds average less than 1.5 cm thick and have calcite as the cement. They abruptly overlie facies A_6, C_2 and C_3 and are cut into from above by facies A_6. On the eastern shore of the Lepreau peninsula, where they are best exposed, they can be traced laterally at least 0.6 km. Over this distance they appear to separate into two distinct beds separated by a unit of facies A_6. Although the bedding was well preserved and adequately exposed no sedimentary structures were observed.

5.3 Facies Interpretation

5.3.1 Introduction

Because each formation has a different environment of deposition and interpretation of facies it requires a detailed examination of their inter-relationships as groups, each of the formations will be considered separately and then a synthesis of each area will be formed.

5.3.2 Honeycomb Point Formation

The previous work in the St. Martins area resulted in only two attempts to discuss the environment of deposition. Magnusson (1955) described the Honeycomb Point Formation as the product of deposition on a piedmont below a mountainous terrain (p. 77). Klein (1962) in his brief description of this formation agreed with Magnusson. This was based heavily on comparison with the studies done in the Connecticut Basin by Krynine (1950). Describing the sediments as peidmont (bajada) deposits is rather vague; however, in general, this study confirms the previous interpretations. More detail on the processes and environment of the alluvial fan(s) can be obtained by analysis of the facies distribution throughout the formation.

Strictly speaking an "alluvial fan" is a geomorphological term for a "fan-shaped segment of a cone that radiates downslope from an apex where a single-trunk stream leaves the source area" (Bull, 1977, p. 261). Although this ideal shape is rarely found in modern fans (due to the effects of other fans, different tectonic settings, changes in source rock lithology and climate), the key is the single stream flow for each fan. Much of the recent literature which has dealt with the processes on modern fans approach only the surficial deposits and relatively little is known (in detail) of the lateral and vertical facies changes at depth. Many of the studies simply measured the effect of different parameters on the size and shapes of fans, primarily in the U.S. Southwest (e.g. Blissenbach, 19541 Bull, 1961, 1962, 1964a, 1964b; Denny, 1965), although there have been process oriented papers as well (Blackwelder, 1928; Blissenbach, 1952; Hooke, 1967, 1968 and Wasson, 1974) including attempts to model fan growth from random processes (Price, 1974). Unfortunately the best understood aspect of a fan, its surface morphology, is not preserved. Only the tectonic setting, the interrelationship of the various facies, and the paleocurrents can be used to infer deposition on an alluvial fan. Summaries of the data available to make such interpretations were compiled by Bull (1972, 1977).

The coarsest sediment in the formation occurs in the western portion of the basin in the Brown Beach Member. The breccias of facies B_2 correspond to the Gms lithofacies of Miall (1978) and include the Gp (planar cross-bedded gravels) of Rust (1978) (refer to Table 5.6). Interbedded with these breccias are the sandstones of facies C_4 (Figure 5.23). Strictly speaking they would be classed as equivalent to the St facies of Miall (1978) although these are considered to be eolian rather than subaqueous as implied by Miall. The eolian interpretation was reached because of the well-sorted nature of the sands, the absence of pebbles in the cross-sets, the large-scale nature of the cross-bedding, and the fairly uniform nature of the paleocurrent directions, all heading toward the southwest (see Chapter 7).

The size of the clasts in facies B_2 appears to decrease from west to east as the beds thin. In contrast the sandstones of facies C_4 form much thicker beds toward the east. The cross-bedding appears to be trough shaped at Robinson Cove but this may in fact be an artifact of the preferential preservation of the toesets of much larger, more planar,

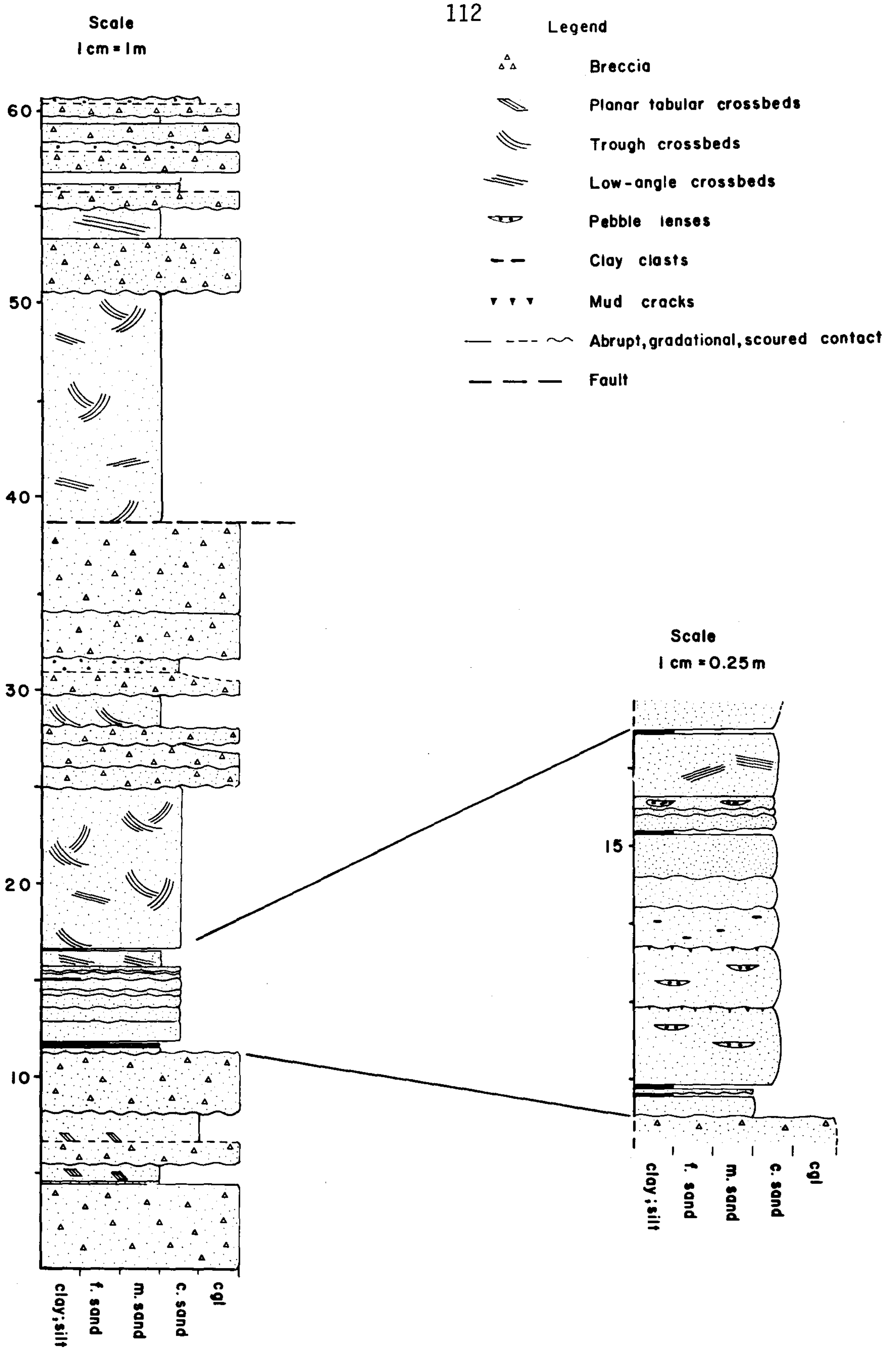
Table 5.6 Comparison of Facies Classifications

Facies Code		Lithofacies		Sedimentary Structures		Interpretation	
Miall(1978) Rust(1978)	Nadon	Miall(1978)	Rust(1978)	Miall(1978)	Rust(1978)	Miall(1978)	Rust (1978)
Gms	B_2,B_3	massive matrix supported gravel		none		debris flow deposits	
Gm	A1	massive or crudely bedded gravel	massive or horizontally bed framework gravel	horizontal bedding imbrication	commonly imbricate	longitudinal bars or lag sieve deposits	
Gt	A_1	gravel, stratified		trough crossbeds		minor channel fills	
Gp	B_3,B_5	gravel, stratified		planar crossbeds		linguoid bars or deltaic growths from older bar remnants	
St	C_1, C_2 C_3	sand, medium to v.coarse may be pebbly		solitary (theta) or group (pi) trough crossbeds	Tabular crossbeds	dunes (lower flow regime)	
Sp		sand, medium to v. coarse may be pebbly		solitary(alpha) or grouped (omikron) planar crossbeds	Planar tabular crossbeds	linguoid, transverse bars sand waves (lower flow regime)	
Sr	C_2,C_3	sand, very fine to coarse		ripple marks of all types	rippled	ripples (lower flow regime	
Sh	C_3	sand, very fine to very coarse may be pebbly		horizontal lamination, parting or streaming lineation	horizontally stratified	planar bed flow(l. and u. flow regime)	
Sl		sand, fine		low angle(<10°) crossbeds		scour fills, crevass	shallow high velocity flow into source
Se	A_5	erosional scours with intraclasts	intraformational conglomerate	crude crossbedding	intraclasts no bedding	scour fills, crevass splays, antidunes	erosion surface

Table 5.6 (Cont.) Comparison of Facies Classifications

Facies Code		Lithofacies		Sedimentary Structures		Interpretation	
Miall(1978) Rust(1978)	Nadon	Miall(1978)	Rust(1978)	Miall(1978)	Rust(1978)	Miall(1978)	Rust (1978)
Ss	A_4	sand, fine to coarse may be pebbly		broad shallow scours including eta cross-stratification		scour fills	erosion
Sse, She Spc	C_4	sand		analogous to Ss, Sh Sp		eolian deposits	
Fl	D_1 .	sand, silt, mud		fine lamination, very small ripples		overbank or waning flood deposits	
Esc	D_1	silt, mud		laminated to massive		backswamp deposits	
F		mud		massive, with freshwater molluscs		backswamp mud deposits	
Fm	D_1	mud, silt		massive, dessication cracks		overbank or drape deposits	
Fr		silt, mud		rootlets		seatearth	
C		coal, carbonaceous mud		plants, mud films		swamp deposits	
P	D_2	carbonate	calcite	pedogenic features		soil	

Figure 5.23 Detailed measured section from Robinson Cove in the Browns Beach Member of the Honeycomb Point Formation. Base of the section is approximately 350 m from the east end of the beach. All the medium grained cross-beds are of facies C_4. The low angle cross-beds are thought to be the toe sets of larger eolian dunes cut off by the breccias. Scale is in meters.

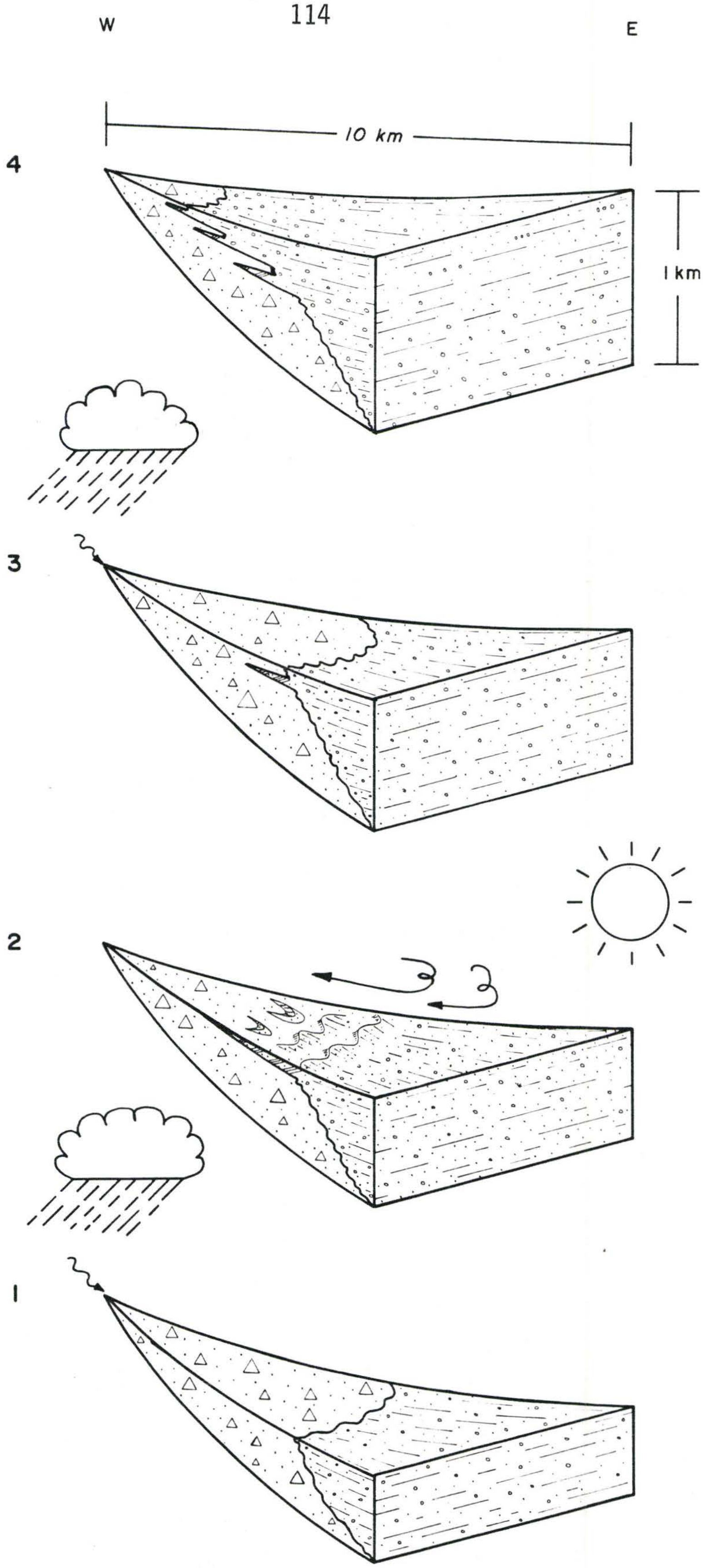

Scale
1 cm = 1 m
Legend
Breccia
Planar tabular crossbeds
Trough crossbeds
Low-angle crossbeds
Pebble lenses
Clay clasts
Mud cracks
Abrupt, gradational, scoured contact
Fault
60
50
40
30
20
10
clay; silt
f. sand
m. sand
c. sand
cgl
Scale
1 cm = 0.25 m
15
clay; silt
f. sand
m. sand
c. sand
cgl

sets which have been truncated by the overlying breccias. The progressive fining of the coarser sediments indicates transport toward the east (Blissenbach, 1952) apparently contradicting the direction obtained from the eolian deposits. The interpretation resulting from this pattern is shown in Figure 5.24. The coarse sediment is brought into the basin during rainy seasons (or particularly large flood events). Once the sediment dries the sands are reworked by the wind (step 2) into small dunes and sand sheets which advance up the valley. During the next wet cycle the uppermost deposits are eroded by the next influx of breccias and part of the sand incorporated into the matrix. The presence of planar tabular cross-bedding although rare, indicates the sediments were brought down by braided streams rather than debris flows. The latter would be expected to produce a more disorganized bed with only pebble imbrication or graded bedding (Rust, 1978; Wasson, 1979). With the thinning of the flood sediments downslope more of the eolian sands were preserved shown by the presence of progressively larger sets of crossbeds toward the east. Repetition of these events, which occurred at random and are not as cyclical as represented in the diagram, formed the interbedded coarse and medium grained deposits which characterize the western member of the formation as shown in Figure 5.16.

The eastern member of the formation rests unconformably on Carboniferous sediments on the east side of Quaco Head and forms nearly a continuous section which begins with parallel laminated sandstone of facies C_3 (equivalent to the Sh designation of Miall, 1978) and may include some examples of facies C_4 in the exposures along Mosher River.

Figure 5.24 Schematic interpretation of the interbedded sandstones and breccias of the Browns Beach Member.

1. Rain in the source are brought coarse and fine sediment into the basin.
2. The finer sediments, once dried were reworked by winds into eolian deposits, probably dunefields.
3. Renewed influx of coarse clastics eroded the dunes completely on the upper fan but simply truncated and covered them on the lower fan.
4. Repetition produced the interbedded breccias and sandstones although events were not as periodic as depicted here.


W
E
10 km
1 km
4
3
2
1

This gradually becomes a fine breccia of facies C_1 which, in the lower sections, does not contain any sand beds but which gradually becomes interbedded with rippled, parallel laminated and finally trough cross-bedded sands of facies C_3 (Sr, Sh and St of Miall, 1978) (Figure 5.25; 5.26; 5.27). These are interbedded, particularly in the upper 60 m of the formation, with mud layers of facies D_2 (Fm of Miall, 1978) which frequently show dessication cracks. While the amount of pebbly sandstone decreases up section individual beds of variable thickness are still present, virtually to the top of the formation. There appears to be a decrease from west to east in the size and number of largest clasts with individual units in sections of similar stratigraphic level (based on the distance below the Quaco Formation) and the largest scour in the unit is found on the west side of St. Martins Harbour approximately 1.5 km west of McCumber Point. Because of the thin bedded nature of facies C_1 it is interpreted as a result of deposition by either or both braided streams and sheet floods. All that can be reasonably deduced is the sediments were deposited on the mid-fan region downstream of the intersection point (Wasson, 1974; Bull, 1979). Similarly the sandstones indicate deposition from streams with small-scale dunes and ripples occassionally preserved. The presence of a thin veneer of mud and trace fossils over some of the rippled beds may indicate ponding of the stream took place intermittantly.

The mud layers may be the result of either overbank deposits of larger than normal flood events or the last deposits of the stream flow

Figure 5.25 Detailed section of the McCumber Point Member of Honeycomb Point Fromation on the Maces Beach side of McCumber Point. Note the gradual fining upward sequence and the abundance of clay layers although there does not appear to be a significant amount of intraformational conglomerate. Scale in meters. Each paleocurrent indicator represents one measurement. Abbreviations for the different indicators are as follows:

f = flutes

g = groove

p = planar tabular cross-beds

r = ripple marks

t = trough cross-beds (both uni- and bi-directional)

c.c = current crescents

c.l. = current lineation

imb = imbrication

Honeycomb Point Fm
McCumber Point Member
Macs Beach

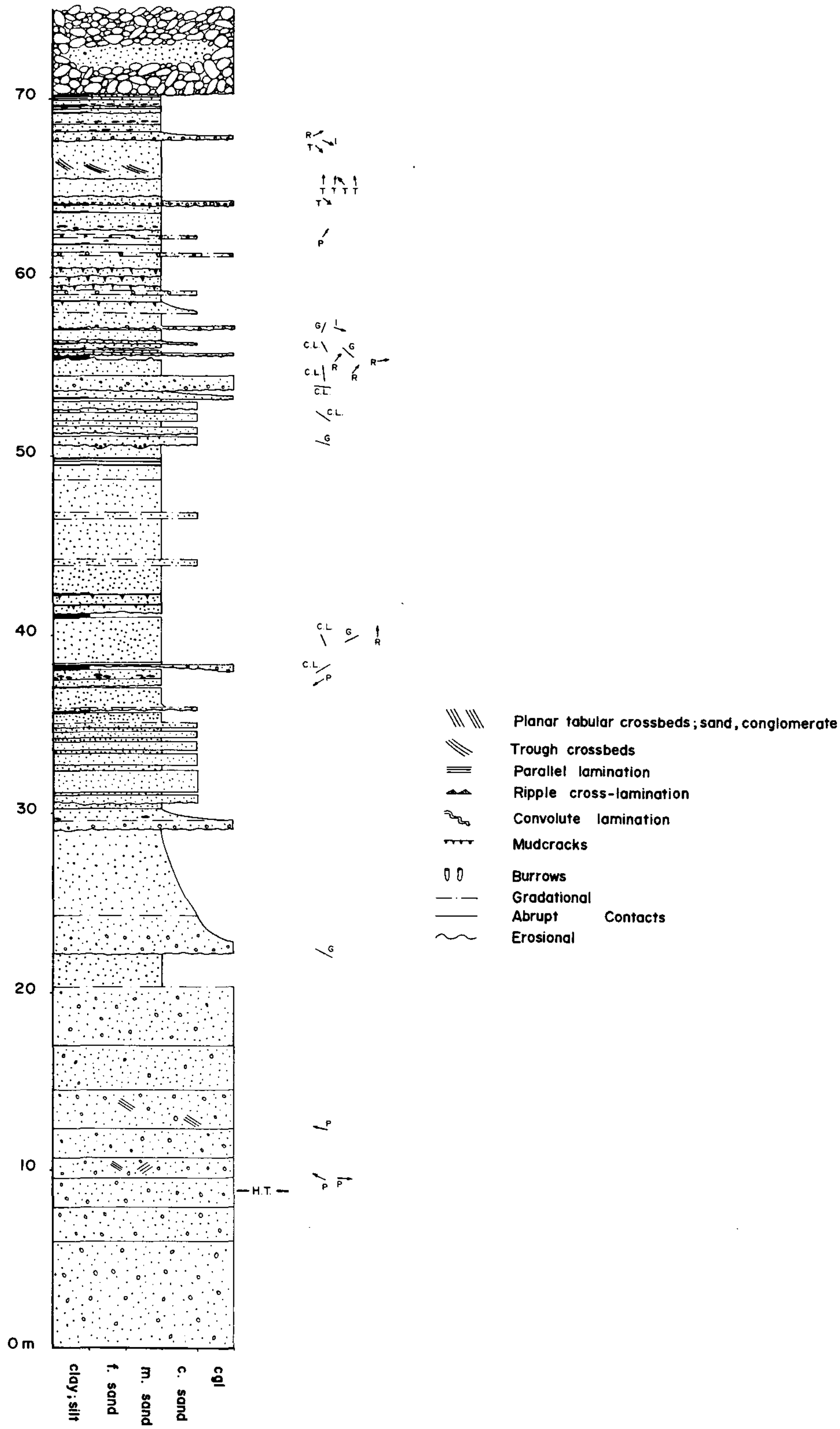


Figure 5.26 Detailed section of the McCumber Point Member of the Honeycomb Point Formation at Hidden Cove (an informal field term for the small embayment between Maces Beach and Echo Cove). The basal bed of this section is the same as the pebbly sandstone at the 22.2 m level of Figure 5.25. Note the overall fining upward sequence. Scale is in meters. The main difference in lithology is the preservation of many more thin clay layers (facies D_2). Abbreviations for paleocurrent indicators are the same as Figure 5.25. Scale in meters.

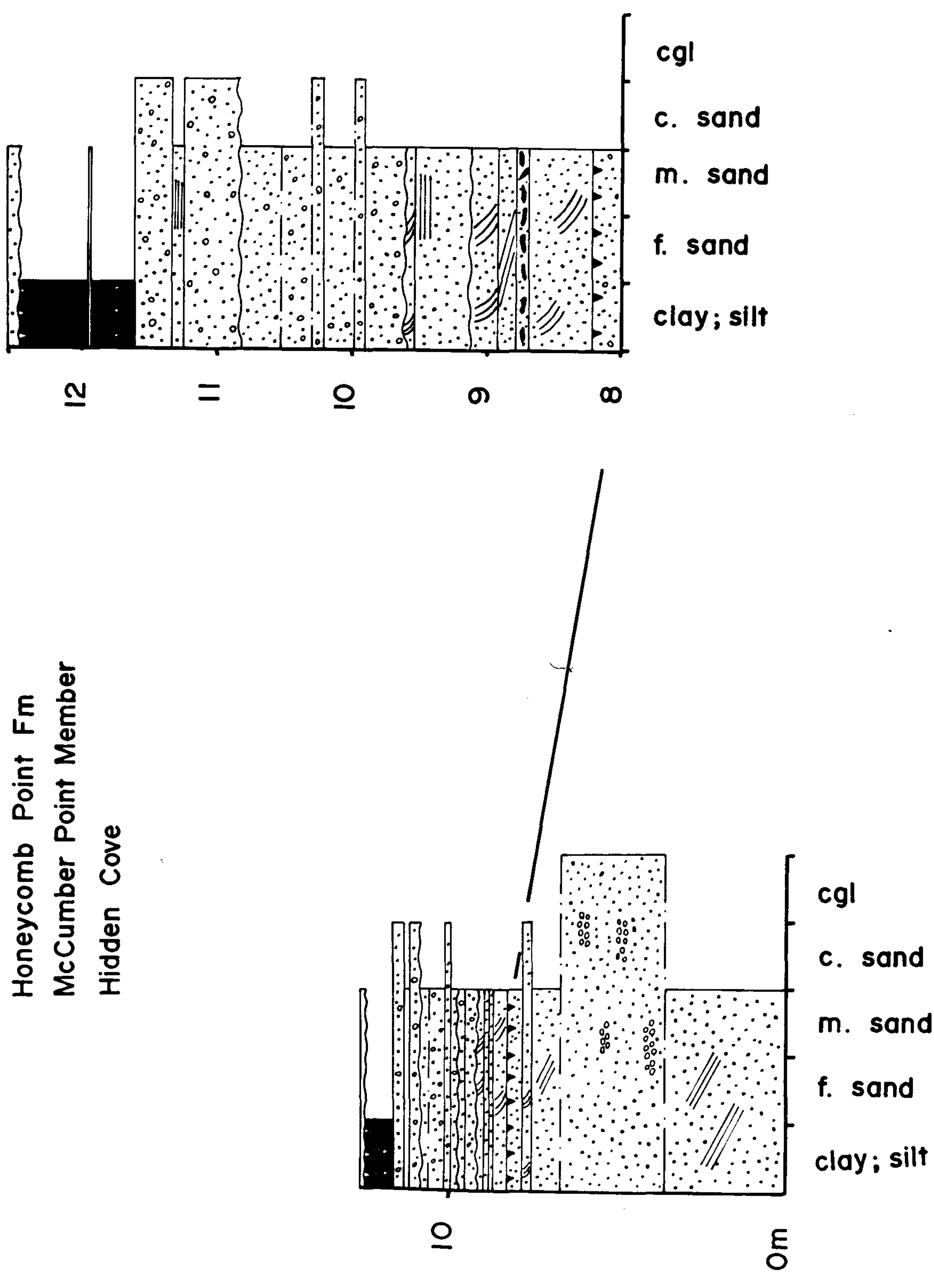
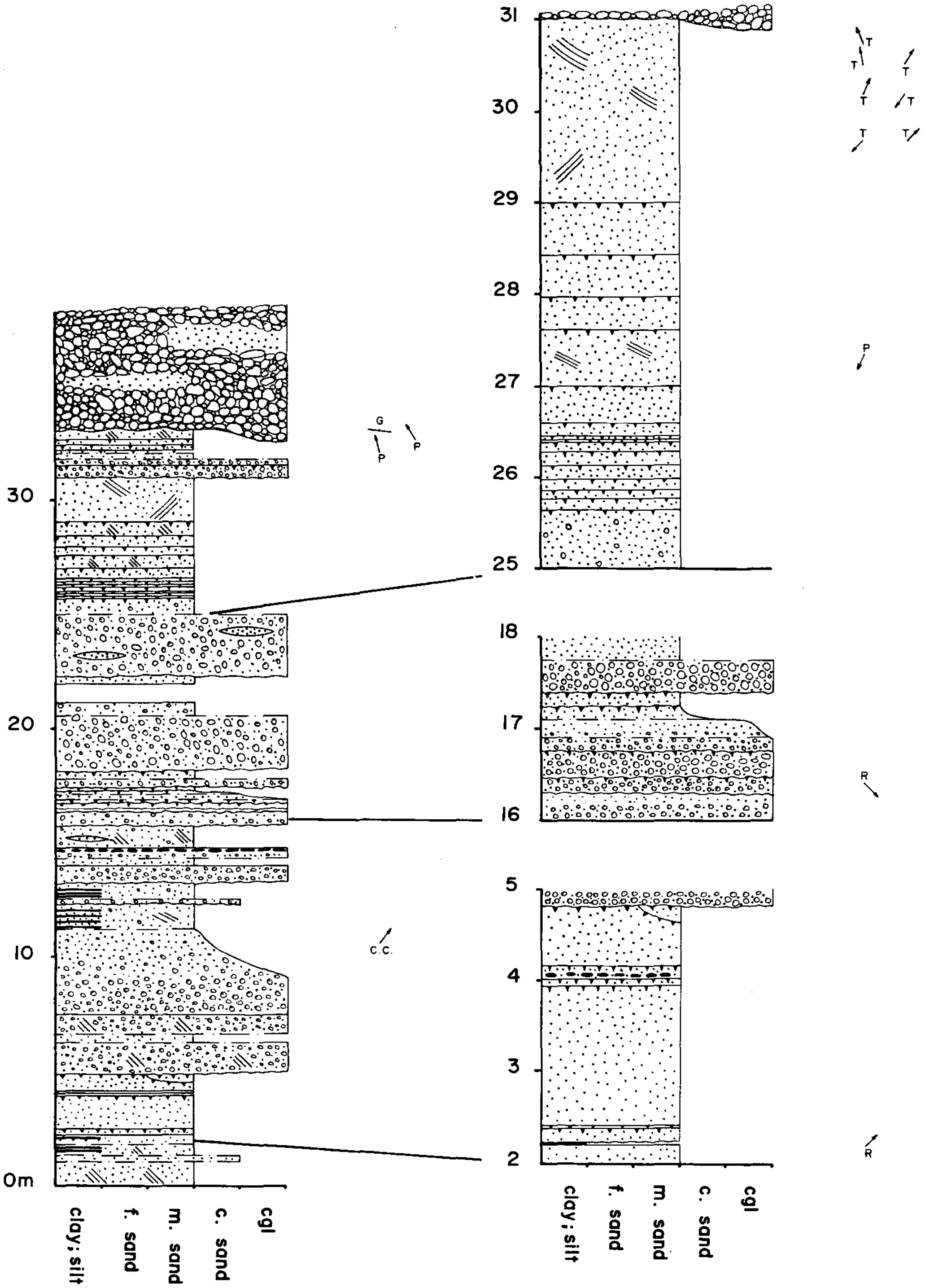

Honeycomb Point Fm
McCumber Point Member
Hidden Cove
cgl
c. sand
m. sand
f. sand
clay; silt
12
11
10
9
8
cgl
c. sand
m. sand
f. sand
clay; silt
10
0m

Figure 5.27 Detailed measured section of the McCumber Point Member of the Honeycomb Point Formation on the Echo Cove side of McCumber Point. Here sands are dominent with intraformational clasts are more common. The low angle crossbeds at the 3.9 m level may be the same bed as the low angle beds at 42.45 m level in the Macs Beach section. The former is 29 m from the upper contact while the latter is 27.3 m indicating only minor erosion if the beds are in fact correlative. These may be the last expression of facies C_4 but are not well enough preserved to determine this accurately. Abbreviations for paleocurrent indicators the same as Figure 5.25. Scale in meters.

Honeycomb Point Fm
McCumber Point Member
Echo Cove



(Bull, 1977). Dessication of these units points to repeated exposure to the atmosphere (but not necessarily an arid climate).

The lack of well developed caliche horizons (or soil horizons of any type) in these finer sediments is partly the result of more frequent inundation of the lower parts of the fan by stream flow. In addition this absence also points to a general decrease in aridity, at least in the source area, which kept the water table fairly high. The lack of desert varnish which characterizes modern fan deposits in most arid regions (Bull, 1964a, 1964b, 1977; Denny, 1965) also indicates a less harsh climate, though varnish may have been lost during diagenesis.

The initial coarsening upward of the fan sediments indicates progradation, either by uplift of the source area and fan head entrenchment (Bull, 1977, Figure 20; Heward, 1978, Figure 6) or by an increase in precipitation in the source area which increased the competence of the streams and enabled the sediments to reach further out into the basin. The last fining upward sequence similarly may be viewed as either (or both of) scarp retreat which increases the distance the streams must transport material and decreases slope or decrease in source area precipitation leading to reduced stream flow. In the first case an increase in precipitation seems to be indicated by the absence of any eolian features and the thick sequence of facies C_1 present. A gradual decrease in the amount of rain in the highlands allowed the fining upward sequence to form with the individual gravel beds formed by larger than normal flood events. This interpretation is aided by the presence of the engimatic cross-bedded unit, which may in fact be eolian, 29 m from the top of the formation at McCumber Point (Echo Cove side). At the same time scarp retreat probably occurred which decreased the slope of the fan and allowed the Quaco Formation to cover it, with what is generally a slight unconformity. The absence of any fine grained material as far east as the St. Martins Harbour, where Quaco conglomerate rests directly on facies C_1, could indicate either non-deposition, being too high on the fan, or erosion of a thinner deposit of fines, again due to the proximal nature of the area relative to the sediment source.

If the fan size were of the order of 5-10 km (radial distance), which is possible since the sandier, wetter fans have a much lower slope and cover a wider area than do dry fans draining a clay rich source area (Hooke, 1967; Bull, 1977) the slope at the toe of the fan would be approximately 0.2-1.0° (by comparison with modern fans, Bull, 1964a). This too agrees with the observed shallow dipping angular unconformity which is formed between the Honeycomb Point and Quaco Formation.

5.3.3 Quaco Formation:

This formation consists solely of well-rounded conglomerate of facies A_1 (and to a lesser extent A_2) interbedded with rough crossbedded coarse sands of facies C_2 (facies Gp, Gm and St of Miall, 1978; Rust, 1978) in the lower half of the formation (see Table 5.6). These are virtually identical with outcrops of conglomerate from the Unita Basin in Utah (Garvin, 1969) and are interpreted similarly: a large, coarse, braided river complex.

The sedimentary structures present, the planar tabular crossbedded and horizontally bedded gravels, and trough crossbedded coarse sands, are very similar to features reported from glacial outwash (e.g. Eynon and Walker, 1974) and from sandur deposits (Williams and Rust, 1969; Bluck, 1974).

The most distinctive feature is the presence of large-scale planar tabular crossbeds which increase in frequency up-section as the grain size decreases (a characteristic also noted by Bluck, 1974). It most be borne in mind however the exposures are generally sheer cliffs, up to 30-40 m in height, and the observation of the crossbedding may have been a function of the amount of interstitial sediment that was available to highlight the structure, as well as the orientation of the beds with respect to the cliff-face. Structures similar to these were described by Eynon and Walker (1974) as bar front facies and were considered the result of avalanching of the clasts over the front of a bar form.

The crudely horizontally stratified gravel sheets which range up to 2 m thick and can be traced in the cliff faces for at least 50 m were also found in the outwash gravels. Eynon and Walker (1974) describe them as being formed in the centres of bars composed of imbricated clasts. Proof of imbrication is lacking in this study due to lack of accessibility; however, similar deposits from the Kicking Horse River were formed by the transport of gravel as a 'diffuse sheet' (Hein, 1974) which, when transport ceases, freezes into an imbricate gravel layer. These sheets commonly contain the largest gravel clasts, as can be seen from photos published by Williams and Rust (1969) and Bluck (1974).

The trough cross-bedded sands which are interbedded with gravels, particularly at the base of the formation, generally have gradational lower boundaries and abrupt to erosional upper boundaries leading back into conglomerate. These beds, which are 0.5-1.5 m thick and can be traced for 250 m on the wave cut platform in Echo Cove (although there is considerable thickening and thinning of the sands laterally), are of the same size and contain structures of the same scale as the side channel facies of Eynon and Walker (1974). A few beds of rippled coarse sands are preserved between conglomerate beds indicating a lower flow regime and possible movement of the sand fraction while the gravel remained as a lag. Considering the coarseness of the clasts, especially at the base of the formation where they frequently exceed 20 cm (A-axis), any current capable of moving such clasts as bedload was strong enough to transport all the sand fraction as suspended load. Therefore any sand in the lower part of the formation exists as infilling between the clasts. In the upper part of the formation the clast size falls to 2-3 cms, and matrix-support is more common. Both clasts and sand may have moved as bed load.

The imbrication of the clasts (discussed more fully in Chapter 7) reveals deposition on the lee slopes of bars with several orientations, most of which indicate flow transverse to the crossbed data. This is consistent with observations on modern braid bars made by Hein (1974) and Bluck (1974).

Comparison of the Quaco Formation and sandurs is valid even though the former flowed through a relatively arid environment while the latter are glacially fed. A necessary prerequisite for the formation of any braided river is variable discharge and little vegetation (Rust, 1978) which is the general rule in both climates. The discharge in this instance may have been heavily influenced by episodic flows from the alluvial fans on the western margin of the valley. Clast counts at different stations in the Quaco Formation (Chapter 6) reveal input of volcanics and sediments from the highlands to the west at periodic, possibly random, intervals.

It was, at first, surprising that such a large thickness of fluvial conglomerates was present in the St. Martins area. The discovery of additional outcrop in the western part of the basin indicates the lateral extent of the system was at least 10 km. In order for more than 200 m of gravels to accumulate, however, the river had to be relatively stable in position and confined to the north side by the graben for a long period of time. The structural evolution of the graben provided the necessary control. In a half graben the regional paleoslope rises gently toward the flexure (to the east) and then more steeply on the faulted side of the basin (the west) where alluvial fan deposition was taking place. Subsidence through time along the same fault zone maintained the system in a state of quasi-equilibrium with only minor fluctuations. The eastward thinning of the conglomerates from 380 m at St. Martins harbour to 190 m at Echo Cove (a distance of 1.3 km) may be a reflection of control imposed on the region by the westward dipping paleoslope.

The northward component of the paleocurrents indicates that the river was flowing axially along the rift system, a common occurrence in this tectonic setting (Miall, 1981). The northward paleoslope direction may have been due to a combination of upwarping of the crust in New England and the presence of a major horst in the southern end of the Gulf of Maine (see Chapters 2 and 7).

Among the depositional models of various braided river deposits presented by Miall (1978) only the Scott (dominated by the Gm facies type) appears comparable. This facies is equivalent to the G_{II} facies assemblage of Rust (1978) who used the Donjek as a modern example and the Devonian Malbaie Formation as an analogue in the stratigraphic record. The size of the clasts shown in Figures 5 and 6 of Rust (1978) are roughly equal to the Quaco clast sizes but the clasts appear to be better rounded in the latter. Although both the Scott and Donjek are described as proximal braided rivers, according to Williams and Rust (1969) there is only a rather short reach which displays these characteristics. Given the limited extent of the exposure at St. Martins it is possible the Quaco Formation could likewise change facies rapidly toward the northeast. The fact most of the largest clasts at the base of the formation are of a lithology which cannot be found in the immediate area, however, argues strongly for a coarse river system which moved such clasts into and through the basin for distances greater than 50 km (generally larger than most of the modern proximal examples).

The shift in flow direction from essentially north to more northeasterly in the upper half of the formation (Chapter 7) and the increase in the amount of volcanics (Chapter 6) indicate the flow was deflected by rejuvenated alluvial fans from the west. Progradation of distal fans over the alluvial valley was also responsible for a gradational upper boundary between the Quaco Formation and the Echo Cove Formation.

5.3.4 Echo Cove Formation:

This formation has been divided into 4 members (Chapter 4) all of which represent deposition on alluvial fans.

In the western end of the basin, overlying the Quaco conglomerate there is the Stony Brook Member. At the base it consists exclusively of facies B_1, however, it later becomes interbedded with parallel laminated medium sands (facies C_3). The clast supported breccia remains difficult to interpret due to the poor exposures. It may be classed as either the Gm or Gms facies type of Miall (1978). The clast sizes are large, up to 35 cm, but not as large as the clasts generally found in most debris flows (facies Gms). This along with the apparent deficiency in matrix suggests the Gm facies type is more appropriate. The most likely environment is a proximal braided river (either Scott or Donjek) probably flowing from the west (or northwest). Although there are no paleocurrent measurements from this unit the lithology indicates the source was a granitic pod less than 3 km to the northwest (Chapter 6). As the fan grew and the slope decreased more sand was deposited in the system, mainly in parallel laminated sets. Once again poor exposure prevents accurate assessment of the deposit; however, it most likely corresponds to the G_{II} facies assemblage of Rust (1978).

In the eastern end of the basin the formation is composed of three units, the Berry Beach, Fownes Head and Melvin Beach Members. The lower member consists of redbeds, which gradually lose their colouration and become gray up section, with virtually all types of sand facies described by Miall (1978) and Rust (1978). The distinct, well defined red shale horizons, facies D_2, (both Fm and Fl of Rust, 1978) have mudcracked upper surfaces and are generally overlain by facies A_4 (intraformational conglomerates). The shales show some traces, but preservation is poor. In addition to the mudcracks there is at least one instance of well developed flutes indicating the shales were not dessicated prior to the next influx of sediment (i.e., ponded water was present). The most common sedimentary structures are trough crossbeds, mainly in pebbly sandstones of facies C_1 which also contain numerous intraclasts. The parallel laminated sands generally overlie conglomeratic beds (Figure 5.28) forming as the flow waned. Although sand becomes more prominent in this member than in any of the underlying formations, the presence of a significant portion of gravel (up to 50% of individual beds but 15-25% overall) suggests this member can be classed as the G_{III} facies assemblage of Rust (1978). This corresponds to the Donjek model of Miall (1978). In both cases fining upward cycles are present and inspection of Figures 5.28 and 5.29 indicates this may well be the case here as well. The only significant difference in this area is the lack of the Gm facies although this may simply be a function of distance from source.

In terms of environment, the gradational decrease in the size

Figure 5.28 Detailed measured section of the lower portion of the Berry Beach Member of the Echo Cove Formation at the west end of Berry Beach. The lower 33.2 m are actually the uppermost beds of the Quaco Formation. Note the presence of convolute lamination at 56 and 58.5 m levels. There is also a much higher proportion of intraformational conglomerate present. Paleocurrent abbreviations the same as Figure 5.25. Scale in meters.

Echo Cove Fm
Berry Beach Member
Echo Cove

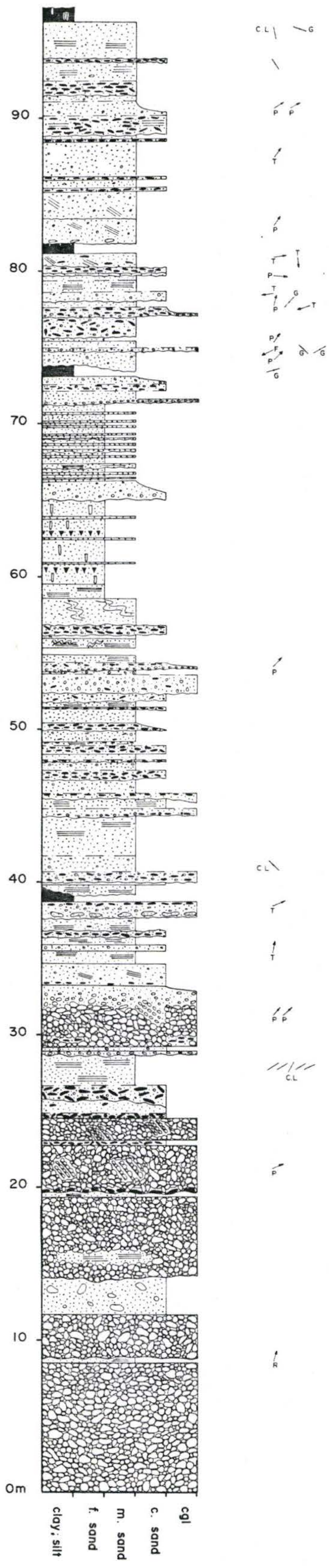


Figure 5.29 Interbedded sands and shales in the Berry Beach Member of the Echo Cove Formation at the west end of Berry Beach. Looking northwest. Note possible cyclicity. (Scale is 1 m).

and number of redbeds in the unit, the progressively grayer sandstones and the gradual increase in grain size up-section, all indicate an increase in precipitation in the source area. This would bring much more sediment into the basin, decreasing the slope of the fan(s) (Bull, 1977) and allow the formation of a large sandy braided river system. The presence of convolute beds in the Berry Beach Member also points to the possibility of tectonic uplift of the source area (with accompanying seismic events). This would increase the slope of the fans and bring the coarser sediment further out into the basin. The size of the cross-bedding, however, indicates flow at least several meters deep over much of the time the river was in flood supporting the first argument. The abundance of thick redbeds in the lower part of the secion is considered the result of overbank spill from the river system. The gradual decrease is due in part, to more frequent channel switching as the flow became more steady.

This member is undoubtedly the lateral equivalent of at least part of the Stony Brook Member although whether it corresponds to the lower, gravel beds or the upper gravel and sandstone cannot be determined. The inferred size of the fan is the right order of magnitude when compared to modern fans (e.g. Bull, 1964a; Denny, 1965).

Gradationally overlying the Berry Beach Member is the Fownes Head Member. This consists of gray-green beds with no red shales at all. Here the main component is sand although gravels and pebbly sandstones do occur sporadically in the member. The sands, which vary from medium to coarse and may include up to 10% pebbles, are mainly trough and planar tabular crossbedded (St and Sp of Rust, 1978; Miall, 1978) with parallel laminated sands present as well.

The presence of interbedded planar and trough crossbedded sands is similar to what Cant and Walker (1976) found in the Battery Point sandstone of Quebec, especially the tendency for the planar tabular beds to have current direction in opposite senses (i.e. both east and west). The lack of shale deposits of any colour poses a problem in fitting this deposit in any of the available models. According to Rust (1978) his S_I facies assemblage has both vertical and lateral variability but in this case although there are rapid vertical changes, and frequent occurences of scoured surfaces (facies Se of Rust, 1978) the beds show surprisingly little lateral change for the width of the exposures. The S_{II} facies assemblage on the other hand has fining upward sequences which were not seen in the field.

The lack of conglomerate throughout the section eliminates the Donjek type of Miall (1978) and although the structures are similar to those found by Cant (1978) in the South Saskatchewan River, the absence of shale horizons is not typical. It would appear, therefore, that this member was formed by a rather large, braided river system which either carried too little silt to allow the formation of the overbank deposits or managed to completely erode the deposits which did form. The latter is most likely the case as green shale clasts do form intraformational conglomerates (facies A_5) in some places although they are not common (see Figure 5.11, for example).

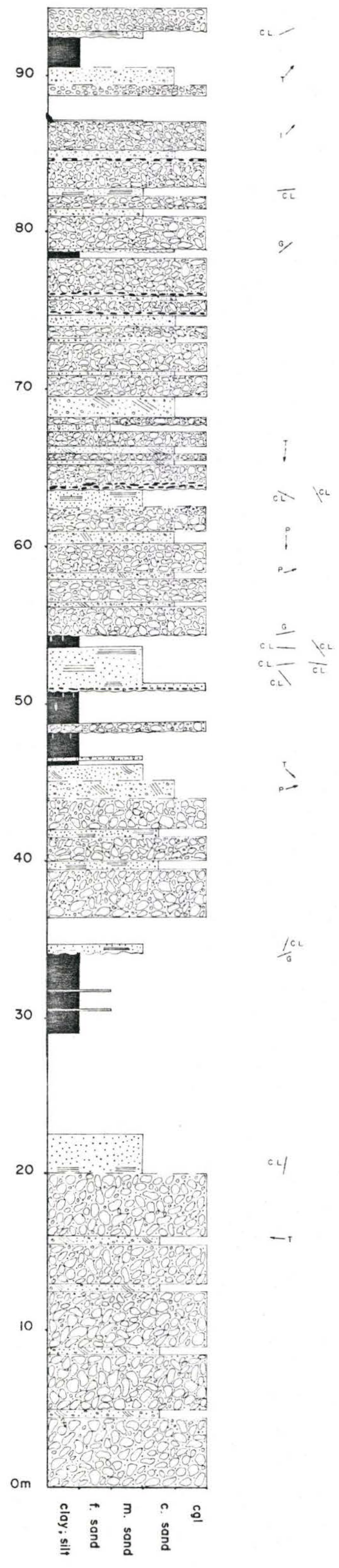
The evidence available from the paleocurrent data (Chapter 7) suggests the river initially flowed to the southeast and progressively moved further east up section. The size of the member and the abundant plant material present throughout reveals it was formed under a relatively humid climate with a constant flow in the river system. This would have resulted in a much larger fan with very low slope angles similar to the Kosi fan of India (Gole and Chitale, 1966) although not of the same magnitude.

The upper 30-50 m of the member contains interbedded breccias of facies B with abundant feldspar clasts and intraclasts. The clays (facies D_2) are both green and red-brown initially but become red by the top of the unit. The breccias are either planar tabular; trough crossbedded or massive (although the latter may be the result of poor exposure rather than lack of structure) and form the base of the upper Melvin Beach Member of this formation.

Once again the flow direction is from the west but in this case there is the return of the redbeds of all grain sizes. The breccias form thick beds with abundant intra-clasts at the bases (facies A_4) and frequent interbeds of coarse-grained trough-crossbedded sandstone (facies C_2). Overall these make up 60-70% of the unit (Figure 5.30). There are also parallel laminated medium sands (facies C_3) which have gradational bases, many from underlying breccias, and erosional upper surfaces covered by more breccia. The red shales of facies D_2 are both laminated and massive (facies Fm and Fl of Rust, 1978) however they lack any indication of soil formation (facies D_2). This general lack of soil development, which is common throughout the St. Martins area is puzzling

Echo Cove Fm

Melvin Beach Member
Melvin Beach



in view of the fact such horizons are commonly found in alluvial fan deposits of all ages (Bull, 1977; Wasson, 1977, 1979). Nevertheless the only calcite present infills burrows in the shales (Chapter 8).

The lack of disorganized layers of breccia due to debris flow deposition and the frequent occurrence of planar tabular crossbedded sets puts this member in the G_{II} facies assemblage of Rust (1978), a proximal braided stream. It is much closer to source than the underlying member as indicated by the rapid coarsening upward sequence. The return of redbed deposition leads to the conclusion the climate became increasingly more arid (also supported by the lack of any plant material in the upper member), therefore it is necessary to invoke tectonic uplift of the source area to account for the size of the clasts. Such uplift is common in areas of alluvial fan deposition (Bull, 1977) and result in the stream cutting through previous deposits and bypassing the former fan to create a new, coarser fan further out in the basin (see Figure 20 of Bull, 1977 or Figure 6a of Heward, 1978). The slight fining upward sequence seen in Figure 5.30 may be the result of the decrease in competence of the river due to the aridity. Definite evidence of such an entrenchment is lost due to erosion of the proximal deposits of the upper portion of the Fownes Head Member.

In summary, the Echo Cove Formation consists exclusively of alluvial fan deposits with the coarsest, most proximal, material found in the western end of the basin. Deposition of the Berry Beach Member first deflected and then finally buried the Quaco conglomerates with a dominantly pebbly sandstone, braided river deposit. Initially the climate was at least semi-arid but this gradually changed to a humid climate the time the Fownes Head Member was being deposited. In terms of the megasequences of Heward (1978) this represents an overall fining upward sequence which was probably accompanied by scarp retreat and an overall lowering of the fan relief and slope. Deposition on the fan surface gradually prograded eastward, however, rather than by switching the depositonal lobes as suggested by Heward (1978).

Tectonic uplift of the source area and a gradual return to more arid conditions resulted in entrenchment of the fan surface and deposition of coarser proximal braided river deposits further out into the basin, forming the upper Melvin Beach Member.

5.3.5 Summary of the St. Martins Area:

After the intial formation of the graben alluvial fans began to build out from the western margin. At first the climate was at least semi-arid allowing periodic formation of eolian deposits which were preserved on the lower slopes of the fan(s) covered with conglomerates and breccias. The coarse sediment of the Browns Beach Member of the Honeycomb Point Formation laterally gives way to a coarsening upward sequence in the lower portion of the McCumber Point Member, indicating progradation of the fan, probably due to increased precipitation int he source area as the eolian sediments disappear at the same time. This is followed by a fining upward sequence reflecting decreased stream competence as the result of a return to more arid conditions. The progradation of the fan probably also decreased the slope so that the Quaco Formation overlies these deposits with only a smaller angular difference in bedding.

The Quaco conglomerates were deposited by a major coarse-grained braided river system which initially flowed almost due north along the axis of the graben and then was deflected in the upper half by rejuvenation of the fans along the fault scarp. The width and thickness of the deposit indicate that the river did not shift its position substantially through time but was confined by the fans to the west and by the regional westward-dipping paleoslope of the half graben, to the east.

Reactivation of the fans was probably due to an increase in precipitation in the source area which created an overall fining upward sequence in the lower two members of the Echo Cove Formation along the coast. It is not known if the Stony Brook Member in the western part of the basin is the lateral equivalent of just the Berry Beach of both the Berry Beach and the Fownes Head Members. The flow direction of the lower member was dominantly eastward. It shifted to the southeast in the lower part of the Fownes Head Member. The increase in humidity of the climate allowed the formation of a large, dominantly sandy, braided river system to form similar to, but slightly coarser than, the South Saskatchewan River. This system moved across the fan with time until the top of the member flow was again eastward.

Uplift of the source area, at the same time that the basin was returned to a semi-arid climate, allowed entrenchment of the fan and deposition of the coarse clastics further out in the basin over finer fan sediments. Here too, flow was from the west. Although flow was more intermittent than during the deposition of the lower deposits, the upper deposits also formed in a braided river system.

5.3.6 Lepreau Formation:

Because of the limited time available for work in this area and the lack of any detailed measured sections, there are some interpretational difficulties with several of the facies in the three members which make up this formation.

The bulk of the Lower Fishing Point Member is made up of breccias of facies B_4 (the Gms facies of Miall, 1978; Rust, 1978) which laterally interfinger with the fine to medium sandstones of facies C_3 and the pebbly sandstones of facies C_1 (both massive and neither corresponding to any of the categories of either Miall, 1978 or Rust, 1978). Because of the deformation (mainly faulting of unknown throw) which is common in the breccias even the bedding planes are uncertain. There are infrequent sandy lenses, commonly containing the enigmatic traces described in Chapter 8, which may represent original bedding surfaces (their three dimensional orientation is unknown). Much of the void space is filled either with coarse sand or, in some cases with lenses of blocky calcite. The lack of any structure in the sediments implies deposition from debris flows but there is no sign of the massive clasts found floating in many such beds (Rust, 1978), Figure 2; Takahashi, 1981, Figure 1) although this is also a function of the size of clasts available for transport. Debris flows composed only of small clasts are known (Bull, 1977). The lack of matrix is harder to resolve. It mav be that breccias formed essentially as sieve deposits (Hooke, 1967, Bull, 1977, Figure 7) in which the matrix has been winnowed out by subsequent flow over and through the sediment. This would account for the primary void space which was filled by the blocky calcite. The lack of desert varnish which is common on debris flow deposits (Bull, 1977) because of the long periods between events on the same part of the fan (Beaty, 1970; Pierson, 1980) is absent here. It could have been altered and/or masked by the pervasive hematization which occurred. The clasts are all derived from a granitic source close to the deposit (Chapter 6): this is consistent with a debris flow model since debris flows generally do not travel long distances.

At the western end, 50 m east of the Pumper Hole, the breccias terminate abruptly against fine sands with an intercalated boundary approximately 30 m wide. This sudden change in facies is characteristic of alluvial fan deposition (Rust, 1978). A near vertical contact may result from the steady state balance existing between alluvial fans and the playa sediments of the basin (Hooke, 1968). The pebbly sandstones are composed of up to 30% granules in a fine sand matrix and occur as lenses with the massive, thick-bedded fine sandstone. The playa interpretation proposed above is based on the large amount of calcite in the matrix of the rock (Surdam and Wolfbauer, 1975) and its association with the breccias. Any sedimentary structures which were present may have been obliterated, possibly by bioturbation (Chapter 8) although a few preserved bedding plane surfaces do show warty, mud-draped structures similar to adhesion ripples (Reineck and Singh, 1975, p. 57). The coarser sediment is interpreted as deposited in small channels cut into the playa by exceptionally large debris flows. Unfortunately because of the deformation present it is impossible to correlate the granule lenses with the more prominent breccia tongues to the east.

The deep red sediments of the Fishing Point Member are cut into by the overlying Duck Cove Member. This member is made up of facies A_5 and A_6 (the latter equivalent to the Gp classification of Miall, 1978; Rust, 1978) as well as trough crossbedded coarse sand of facies C_2 (St facies of Miall and Rust) and parallel laminated medium grained sand of facies C_3 (Sh of Miall and Rust). Interbedded with these facies are red shales of both facies D_1 and D_2 (Fm and Fl of Miall and Rust).

The largest amount of conglomerate occurs in the lower part of the member and there appears to be an overall fining upward cycle in which the coarse sediments are present but the number and thickness of the beds is reduced. Associated with the thicker beds of the conglomerate are units of intraformational conglomerate with more than 80% shale clasts in a matrix of coarse sand and pebbles. The shales, where preserved, vary greatly in thickness however, on the east coast of Lepreau peninsula, they are traceable for over 600 m. The laminated shales are obviously a result of overbank spilling from the river(s) in the region, with layers of fine sand variable thickness scattered throughout the beds.

The overall environment of deposition of the member is one of a distal braided river such as the Donjek type of Miall (1978) or the G_{III} group of Rust (1978). This is based mainly on the absence of massive gravels in the conglomerates and the presence of both trough and planar tabular crossbeds. Fining upward cycles, as implied by the use of these models, have not been documented by detailed measured sections but preliminary field observation indicates that such cycles are present and that the shales become thicker upsection.

A major problem in this member is the abundance of trace fauna in all facies types except A_6 and D_2. These traces indicate an abundance of life which seems out of place on what was previously thought to be at least a semi-arid alluvial fan. The traces are effective in obscuring or totally eliminating the sedimentary structure in many of the beds, including the coarse sandstones. Obviously there was enough moisture in the region to support a rather diverse faunal assemblage of both small amphibians and various types of invertebrates (see Chapter 8 for further details). Their presence in the coarse sand, and the high numbers coupled with low diversity for individual beds indicates the area was populated by opportunistic species which were able to reproduce quickly in times when there was enough water, and to move to other areas or estivate in periods of drought.

This is confirmed by the presence of carbonate nodules, almost caliche, of facies D_1 (facies P of Miall, 1978). Reeves (1976) in his discussion on the genesis of these type of soil horizons pointed out they occur where there is proper balance between evaporation and precipitation. The optimum, "appears to be neither excessively arid or excessively humid" (p. 84), but there is a wide range of both precipitation and temperature in which these sediments can form. Part of the reason they are well formed here is the availability of carbonate.

Precambrian and possibly Windsor carbonates outcrop within 50 km of the area and their previous extent was undoubtedly larger. All the sediments in this formation contain calcite both as matrix and as fracture fill indicating it was available throughout the depositional history of the sediments.

Although paleocurrent data for this member are meager, it appears that the flow was from the northeast, the same general direction as the underlying member. If true, and the lack of the data here reduces everything to the realm of conjecture, the arid climate which produced the Fishing Point Member ameliorated somewhat which allowed the formation of a braided river complex on the fan. The continued decrease in grain size up section and the increase in the number and thickness of the redbeds indicate the overall climate became harsher toward the end of this time interval. The lack of any debris flow deposits also points to a period of little activity on the boundary faults and is probably associated with scarp retreat (Heward, 1978).

Moving upwards stratigraphically there is an increase in the amount of clast supported breccia, facies B_5. Beds of this facies thicken and coarsen upward through the Maces Bay Member. Both provenance and grain size distribution indicate sediment brought in from the north again. Therefore along with the decrease in the precipitation in the source area there was an uplift which increased the slope enough for the debris flows (equivalent to facies Gms of Miall and Rust) to reach further into the basin. Alternatively, since debris flow formation depends on the availability of mud to act as a matrix, the climate may have continued to get wetter and the debris flows formed as a result of the breakdown of the cataclasticly deformed Carboniferous sediments in the area. Certainly debris flows occur under all climatic conditions (e.g. Takahashi, 1981; Pierson, 1980) although they are most widely reported from semi-arid climates.

There is a gradual decrease upwards in the amount of sandstone interbedded with breccias until, just south of the Maces Bay wharf the sandstones disappear and the unit becomes completely dominated by breccia. As with the breccias in the Fishing Point Member bedding planes are hard to distinguish and faults are numerous. There are thin lenses of medium sand which were taken as indicators of bedding planes, since they appeared to 'drape' the top of the breccias they rested on. The sand lenses are interpreted as having been deposited from the slurry accompanying debris flow (Bull, 1977). At the same time the erosive capability of debris flows is seen in the thinner beds at the base of the formation, where scours are up to 50 cm deep (as thick as the deposit in some cases). Although much deeper cuts have been reported (Wasson, 1977; Pierson, 1980) they were either absent or not observed in this study. Overall there is a coarsening up cycle to this member probably the result of progradation of the fan (Heward, 1978).

5.3.7 Summary of Lepreau Formation:

The Fishing Point Member of the Lepreau Formation represents deposition of debris flows on a semi-arid or arid alluvial fan with the finer playa lake sediments in contact with the breccias. Flow was from the north based on the amount of granites in the deposit and the proximity of such outcrops to the area. This is overlain by braided river deposits of the Duck Cove Member. These include well developed redbed sequences probably formed in a semi-arid climate although the amount of bioturbation would, at first glance, appear to imply the opposite. Conglomerates occur throughout the member though the thickness of the beds decreases suggesting either a decrease in precipitation in the source area or scarp retreat and lowering of the fan slope increased the distance the sediment travelled over the fan surface.

The upper Maces Bay Member is distinguished by the presence of debris flow deposits which thicken and coarsen upward, possibly the result of fan progradation. The lack of any fine material in the upper section of the Maces Bay Member makes it extremely difficult to determine the cause of the progradation although either increased rainfall or tectonic uplift in the source area (or a combination of both) would produce this result (Heward, 1978).

Chapter 6

Petrology

6.1 Introduction:

Petrology makes up a minor part of this study, primarily because there has already been an extensive investigation by Klein (1962). During the course of the field investigations pebble counts were taken at different sites in many of the formations to determine if there was any systematic change in lithology through the stratigraphic section. The types of clasts were noted in an attempt to trace them outcrop if in fact any such rock types existed in the area. There was not systematic study of the rocks in thin section. Hand specimens were taken from several locations with various formations and thin sections prepared, in order to investigate particular points of interest, such as the origin of facies C_4 in the Honeycomb Point Formation at St. Martins, or of facies C_3 in the Fishing Point Member of Lepreau Formation. In addition several samples from facies C_4 were prepared and analysed under the scanning electron microscope.

6.2 Pebble Counts:

6.2.1 Introduction:

Visual inspection of the Quaco Formation during the early part of the summer showed what appeared to be a progressive change in abundances of certain clast types. To check this, stations at various intervals were located on air photos and the number of clasts of each type present in a one square metre grid were counted. Although pebble counts were primarily restricted to this formation they were extended, at the end of the field season to several other formations as well. Generally only clasts greater than 2 cm in diameter were counted although in the case of the Berry Beach Member the smaller overall grain size caused this lower limit to be reduced to 1 cm. The relative percentages of the constituents of each count for each station are presented here in table form and histograms of the data are shown in Appendix C.

6.2.2 Honeycomb Point Formation:

Visual inspection of the breccias showed them to be composed mainly of gray sandstones and pebbly sandstones, at least in the western parts of the exposures. A single pebble count at Robinson Cove, Figure 6.1, in a relatively fine-grained conglomerate, showed 68% of the clasts were sandstones of one type or another and 18% were quartz (Table 6.1, Figure C-1). These sandstones are easily traceable to the Carboniferous exposures in the western part of the basin between Emerson Brook and Robinson Cove. Although a detailed examination of the coarse sediments at Browns Beach was not carried out preliminary work did not find any clasts which were derived from the Carboniferous fault block immediately to the north. This generally westward source is consistant with the observed paleocurrent directions from the upper half of the formation (see Chapter 7).

6.2.3 Quaco Formation:

In all 11 locations were sampled (Figure 6.2) with the results shown in Table 6.2 and Figures C-2 to C-12.

Figure 6.1 Location map for the pebble count at Robinson Cove.

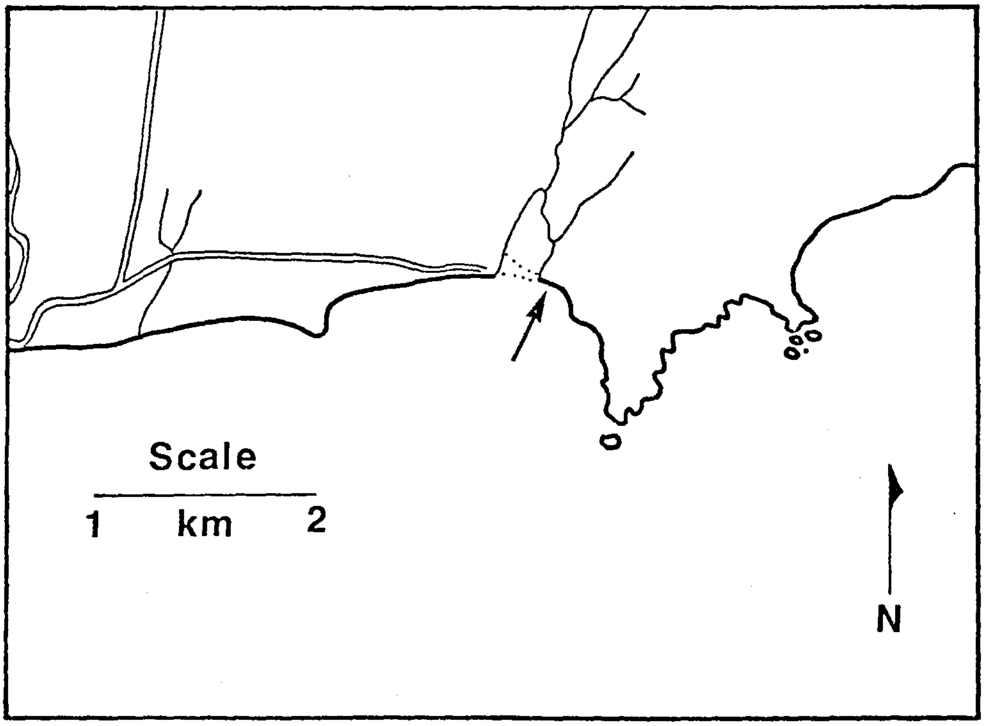

Scale
1 km 2
N

Table 6.1 Pebble count from Honeycomb Point Formation

Station	Elevation (m above base)	Sample Size	volcanics	feldspar	quartz	granite	sandstone	others
		181	3.9%	2.7%	18.2%	1.1%	68.0	11.6%

Table 6.2 Pebble count from Quaco Formation

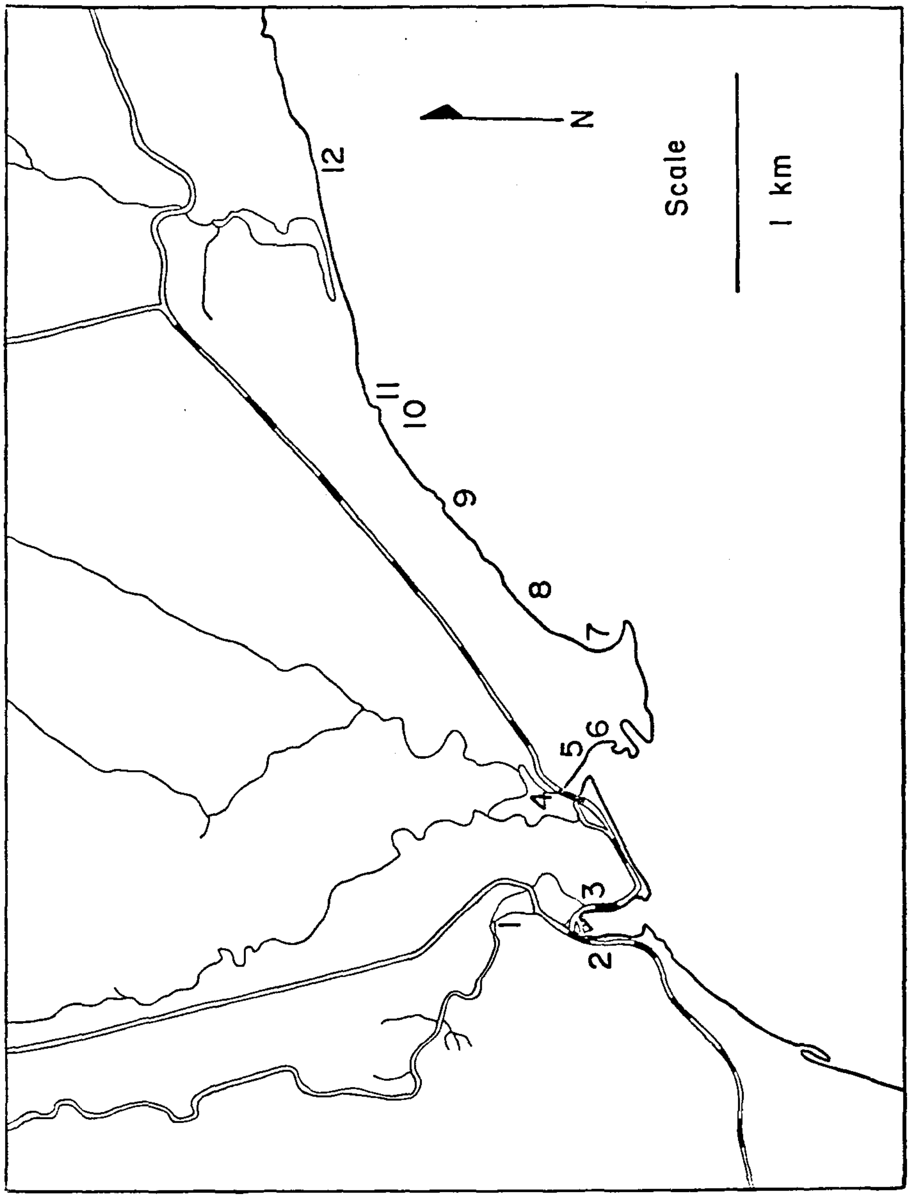
Station	Elevation (m above base)	Sample Size	quartzite	quartz	sandstone	granite	volcanics	epidote	others
1	0.0	377	67.1%	4.2%	12.7%	1.6%	1.1%	0.3%	13.1%
2	0.0	390	48.2	8.2	19.7	6.7	17.0	0.0	0.0
3	25.8	299	58.9	4.7	6.0	8.4	23.0	0.0	0.0
4	59.2	373	51.2	6.7	12.6	12.9	4.8	1.3	10.5
5	59.2	219	52.1	4.1	21.0	8.2	14.6	0.0	0.0
6	70.9	185	54.6	7.6	16.2	10.8	10.8	0.0	0.0
7	87.9	263	49.4	4.9	16.7	6.8	21.7	0.0	0.4
8	142.8	368	65.2	4.1	9.0	6.8	1.9	5.2	7.9
9	180.6	267	24.0	5.2	0.4	10.9	58.8	0.7	0.0
10	190.6	386	25.6	8.0	2.6	27.9	40.0	1.2	2.3
11	215.5	327	51.4	16.8	9.0	11.6	12.2	0.0	0.0
Mean		314	49.8	6.8	11.3	9.2	18.7	0.8	3.1
S.D.		72.2	13.8	3.7	6.8	4.2	17.3	1.6	4.9

Although there appears to be an overall decrease in the amount of quartzite up section there are several exceptions: stations 2, 8, and 11. A simple regression fitted to a plot of percent quartzite vs. distance from the base of the formation yielded a correlation coefficient r, of -0.567 (with the notable exceptions omitted, r = -0.988). Similar plots of percent sandstone vs height yielded r = -0.645, granite had r = 0.591 and volcanics r = 0.467. The large standard deviations in the sandstone and volcanic measurements appears to indicate a more random process introducing these components into the system than was the case for quartzite, granite and possibly quartz.

This implies the bedload of the river was carrying quartzite and granite (and maybe quartz) into the area while other sources, the alluvial fans draining the scarps to the north of the river system, were responsible for the introduction of the other components. The periodic influxes of epidote and volcanics may have been the result of either fluctuation in hydraulic conditions on the lower fan or variable erosion of a particular fan by the main river.

The most distinctive lithology of the formation is the light brown-gray banded quartzite. All attempts to locate this outcrop failed. Geologists at the Department of Natural Resources in Sussex who were familiar with the regional geology also could not identify the source. The epidote, volcanics and perhaps some of the quartz are easily traceable to metamorphosed volcanics and volcaniclastic sediments which make up the Caledonia Highlands to the north.

Figure 6.2 Location map for the pebble count stations in the Quaco Formation.


N
Scale
1 km
1
2
3
4
5
6
7
8
9
10
11
12

6.2.4 Echo Cove Formation:

The conglomerates of this formation are generally much finer than the underlying sediments. The only pebble count was taken on the east side of Berry Beach (station 12 of Figure 6.2) approximately 200 m above station 11 of the previous survey. The results are shown in Table 6.3, Figure C-13. The amount of quartzite has fallen to 13.7% with sandstone up to 22.6% and quartz and granite down to 9.3 and 4.9% respectively. In additon 9.7% of the count was made up of red shale clasts.

It appears the fan or fans which covered the fluvial gravels of the Quaco Formation were draining a source more rich in volcanic rocks. There seems to have been at least partial entrenchment of the fan, judging by the large number of shale (and sandstone) clasts present.

Although no detailed count was taken in the Melvin Beach Member of this formation the rock types present are mainly volcanics. The sediments contain rather abundant banded rhyolite, of a type which was found in outcops in the Irish River in the pre-Carboniferous highlands to the north of St. Martins.

6.2.5 Lepreau Formation:

6.2.5.1 Fishing Point Member: The breccias in this member are made up exclusively of various types of granites (Table 6.4; Figures C-14, C-15). Only 2 stations were counted, stations 1 and 2 on Figure 6.3, because of the uniformity of the composition. No systematic attempt to trace the different types of clast was undertaken but they are visible in outcrop along roads within 15-20 km of the region, situated to the north-

Figure 6.3 Location of pebble counts in the Lepreau Formation. Letters A to D correspond to Figures 13-16 of Appendix C. Other characters explained on page 192.

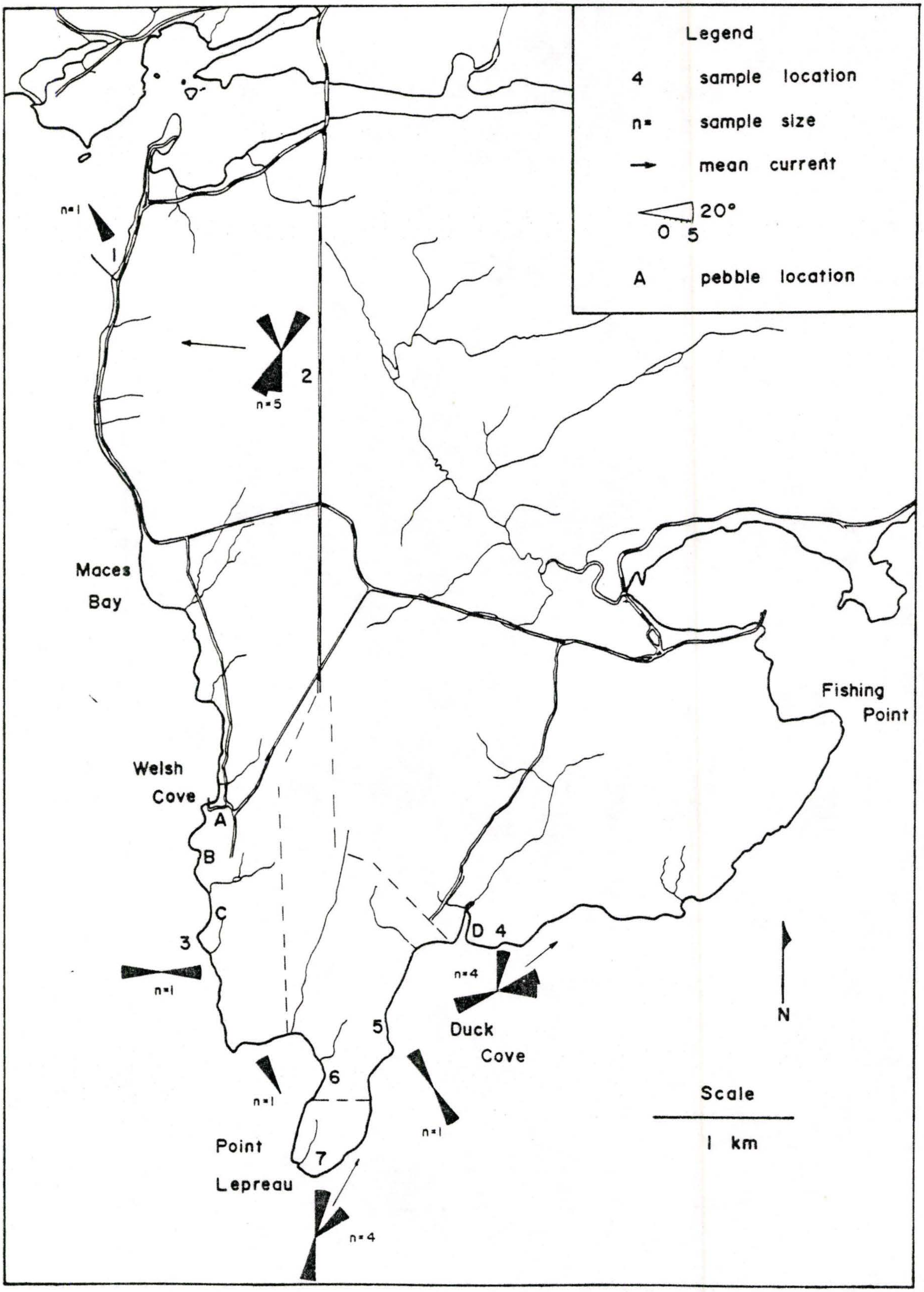

Legend
4 sample location
n= sample size
mean current
20°
0 5
A pebble location
n=1
1
2
n=5
Maces
Bay
Welsh
Cove
A
B
C
3
n=1
D 4
n=4
Duck
Cove
5
6
n=1
n=1
Point
Lepreau
7
n=4
Fishing
Point
N
Scale
1 km

Table 6.3: Pebble Counts from Echo Cove Formation

Elevation (m above base)	Sample Size	quartzite	quartz	granite	volcanics	epidote	others
200 m	226	13.7%	9.3%	4.9%	39.4%	0.0%	10.2%

Table 6.4: Lepreau Formation (Fishing Point Member)

Elevation	Sample Size	granite
30 m(?)	293	100%
80 m(?)	220	100

Table 6.5: Lepreau Formation (Duck Cove Member)

Elevation	Sample Size	volcanics	feldspar	quartz	granite	others
44 m	253	69.2%	15.8%	13.0%	0.8%	2.0%
1170 m	337	76.0	1.9	9.5	4.5	7.1
1191 m	473	75.7	2.1	8.4	5.1	7.6
Mean	354	73.6	6.6	10.3	3.5	5.6
S.D.	111	3.8	7.9	2.4	2.3	3.1

Table 6.6: Lepreau Formation (Maces Bay Member)

Elevation	Sample Size	volcanics	feldspar	quartz	granite	cataclastic sandstone	others
0.0	355	0.8%	25.9%	2.3%	23.3%	39.4%	8.2%

east or northwest. These sediments probably represent the proximal deposits of alluvial fans spreading southward from the boundary fault. The uniformity of the clast lithologies suggests either a very restricted basin as a source or that the granites were, at that time, exposed over a much larger area. Of the two the restricted basin is more likely given the rather small extent of this member.

6.2.5.2 Duck Cove Member: This sequence contains the distinctive gray-green, aphanitic volcanic clasts. Again only two stations were counted here (numbers 3 and 4 in Figure 6.3) and the data shown in Table 6.5 and Figures C-16 and C-17. Attempts to find the source of the volcanic clasts both by limited field excursions and conversations with government geologists who had mapped the local area failed (S. McCutcheon, pers comm.).

The presence of the volcanic clasts from areas at the top and bottom of the member (plus field observations of the clasts from points in between) are a good indication that the source area of the sediment reamined unchanged throughout the depositional history of the sediments. The amounts of both quartz and feldspar present show that granitic terrains were still being eroded quite close to the depositional site. The matrix of these conglomerates contains abundant feldspar and quartz as well. These consistently indicate a source area to the north and perhaps the growth of the limited drainage basin(s) of the previous member into those which could sustain a fair sized river system flowing for much of the year. It appears these conglomerates are the result of progressive erosion of the scarp and highlands probably creating a large, low-angle fan.

6.2.5.3 Maces Bay Member: Only one station (number 5 on Figure 6.3) was counted. This represents the occurrence of the breccias of this member in the column. The results are summarized in Table 6.6 and Figure C-18.

The sudden and marked increase in the amount of cataclastic sandstone and the virtual elimination of the volcanics is characteristic of this breccia type (facies B_5). The continued presence of both granite and feldspar in significant quantities implies that the granitic terrain to the north was still supplying sediment. Although there were no other counts carried out in this member, observations along the coast, particularly around the wharf at Maces Bay, show the cataclastic sediments make up a dominant lithology with the amount and size of granite clasts increases up section. The sediments can be found in outcrop in roadcuts on the north shore of the Little Lepreau Basin, a distance of 3-5 km from the outcrops along the coast, which indicates: a) that the sediments was carried in from the north, and b) that the source area was close to the known deposits. This is consistent with the explanation offered in Chapter 5 that these breccias are the result of debris flows coming in from the highlands to the north.

6.3 Thin section analysis:

6.3.1 Introduction:

Thin sections were cut from hand specimens of several different rock types although not every formation or facies was represented. Most attention was focused on facies C_4 because of its probable eolian origin. The previous work on the lithology of the sediments in both formations was done by Magnusson (1955) and Klein (1962) and a repetition of this work was not attempted. Instead samples were studied mainly from areas which have previously been interpreted differently. The sections involved both stained and unstained and some, notably from facies C_4, were so friable they were impregnated with blue resin prior to the sections being cut.

Staining of the sections was done only to determine the amount of potash feldspars present. This was done following the method described by Hutchison (1974, p. 17-18). The uncovered sections were placed face down over a beaker filled with 48% HF and were allowed to etch for 15 seconds. They were then placed in a saturated solution of sodium cobaltinitrate for 30 seconds, removed and rinsed gently in distilled water to remove excess solution.

The sections were point counted for major constituents. The counts were taken in groups of 50 with at least 6 runs per slide generally moving from top to bottom, left to right in a regular fashion. This enabled a statistically significant sample to be taken in each run and the amount of variance through the slide could also be calculated. The data is presented as tables in Appendix D with the sample location and formation as well as the mean and standard deviation for each constituent of each run and the sample overall.

6.3.2 Honeycomb Point Formation:

Three thin sections were cut from hand specimens of facies C_4 in this formation, two from Robinson Cove and one from Quaco Head. The hypothesis presented in Chapter 5 is that these beds formed from wind sorting of debris shed from a source area in the west. In this case the degree of sorting should be greatest in the central portion, i.e. at Quaco Head. Comparison of Tables D-1, 2 and 3 show virtually no change in sorting, possibly because the distances involved are too small. The eolian sands are in fact the normal water laid sediments shown in Table D-4 which would be expected if not extensively reworked by wind action.

In general sediments from this formation appear to lack potash feldspars almost entirely and are low in plagioclase. The cement may be either quartz or calcite but in the case of the latter sands are very friable and easily weathered. All grains show hematite rims but these are relatively thin. The degree of alteration of the grains varies markedly throughout individual slides. In some, the feldspars appear fresh while in others they are etched or altered to sericite with only faint remnant polysynthetic twinning. Chert is present (10-13%), however, too few sections there were examined to determine provenance.

6.3.3 Lepreau Formation:

6.3.3.1 Fishing Point Member: Because of the problem of determining the depositional environment of the fine grained rocks of the lower member of the Lepreau Formation thin sections were cut from both the irregularly bedded fine-grained sandstone and the sand and granule facies. Tables D-6 and D-7 are from the fine grained sediments while Table D-8 shows results obtained from the coarser material.

The common features of these sections are the extensive hematite rims on all grains and the amount of alteration present. The cement is calcite and void spaces are non-existent (the few noted occurrences of voids are the result of fractures). The finer grained sediment contains approximately 20% calcite which may reflect the amount of primary cement. The coarse grained example has an increased amount of quartz and decreased calcite percentage with the hematite staining staying within the bounds of the other two samples.

The grains appear to be angular to subangular in all three slides indicating the amount of transport was negligible. The fine material may have been deposited either by eolian or weak fluvial flows. If wind did transport sand and silt into these beds it did not form distinctive large-scale cross-lamination, but it may have resulted in the formation of the 'warty' adhesion ripples described in Chapter 5.

Another sample, shown in Table D-9, was cut to examine the sediment associated with the trace fossils in the breccias of this member. The amount of calcite counted in this sample however is biased by the presence of blocky carbonate at the base of the trace, the lower boundary of which is rather diffuse. Aside from this the sediments here appears much the same as in the fine-grained samples with a lower amount of quartz and extensive hematite alterations.

In all slides the feldspar content was low and almost exclusively plagioclase. Only one grain of K-feldspar was found in sample 01-01-02 (Table D-7).

6.3.3.2 Duck Cove Member: Because of the relative inaccessibility of the outcrop few samples of this member were taken and of these none were cut for thin section analysis. However the sample discussed below for the upper member of this formation is from the sandstone facies C_3 which may be considered equivalent to the sands in upper part of this member.

6.3.3.3 Maces Bay Member: Only one thin section from this member was studied. The sample came from a coastal exposure approximately 400 m south of Maces Bay. The sandstone was parallel laminated (facies C_3) and was interbedded with breccias of facies B_5 (at this point approximately 50-50). From point counts it is apparent the sand is dominated by quartz (Table D-5). Staining did not reveal any K-feldspar. There was a significant amount (average 20%) of void space in the sample probably due to a combination of grain plucking and dissolution of calcite during exposure. The relative percentage of components more or less agrees with Klein (1962). He classed the sediments from this formation (as a whole) as either low to high rank greywackes or arkoses (his Figure 5). This sample would be considered a low rank greywacke on the basis of the lack of feldspars.

No thin sections were made from any of the breccia units in this member.

6.4 Scanning Electron Microscopy:

6.4.1 Introduction:

The introduction of high resolution scanning electron microscopes (hereafter referred to as SEM) in the mid 1960's enabled researchers to study the microtextures of individual grains. Samples of medium to coarse quartz sand grains from known environments was collected and studied to determine what, if any, characteristic textures were present.

Krinsley and Doornkamp (1973), distinguished seven different groups of surface textures: 1) bedrock, 2) diagenetic, 3) glacial, 4) littoral, 5) glacial and littoral combined, 6) eolian, and 7) high energy chemical. Higgs (1979) in a compilation of his data and a literature review published a table 30 textures related to fluvial, deltaic, marine, eolian, glacial, pedologic and subsurface diagenesis. He further subdivided the fluvial and deltaic environments on the basis of energy input into the system. This is probably reading too much into the data since the deltaic environment has elements of both the fluvial and marine types as a matter of course. This study follows the criteria of Krinsley and Doornkamp (1973) in determining environment of deposition.

Krinsley et al. (1976) noted four characteristics which they found in sands from modern hot deserts. These were:

i) upturned plates which appear in more or less parallel ridges. These range from 0.5-10 um long and occur mainly on grains 400-500 um in diameter. Their formation is inferred to be the result of grain-grain collisions in the saltating layer which results in abrasion fatigue and plates forming on cleavage scarps. The consensus of opinion, based on the regularity of the spacing, and experimental studies into their formation (Margolis and Krinsley, 1971; Wellendorf and Krinsley, 1980) is that these plates represent the surface expression of internal cleavage patterns.

ii) Equi-dimensional or elongate depressions 20-250 um in length. These form as the result of direct, rather than glancing, impacts of grains in the saltating layer. The impacts break off (or spall off) large pieces from angular grains. Wellendorf and Krinsley (1980) also found this contributed significantly to the initial rapid rounding of the grains in an eolian environment.

iii) Smooth surfaces on grains 90-400 um in diameter due to the precipitation of silica. This feature also contributes to the rounding of quartz grains. The cause is thought to be due to moisture, either as infrequent rainfall or dew, evaporating from the surface of the grain. The concentration of dissolved salts raises the pH of the solution and dissolves quartz from sharp boundaries (such as upturned plates) reprecipitating it elsewhere. The extent to which this process operates in a function of the climate, but also depends on how often the grain is moved. Impact from saltating grains renews the formation of the upturned plates and the process begins over again.

iv) Arcuate, circular or polygonal cracks on the smaller grains, ranging in size from 90-150 um. These are the result of either chemical or physical weathering occurring while the grain is buried.

By contrast Krinsley et al. (1976) found coastal dunes showed upturned plates only in small patches on any given grain. This is probably a result of a combination of increased moisture, which allows chemical reactions to proceed at a faster pace, and less frequent movement of the grains due to the wetting of the surface. Similarly, periglacial dunes show only small patches of upturned plates. The equidimensional or elongate depressions occur more often in periglacial dunes than in those from the coast although neither are as common as in the hot desert climate.

The logical extension of these studies is application to the stratigraphic record. The problem of diagenetic modification of the textures has been and is the largest obstacle. The formation and morphology of quartz overgrowths has been discussed by Pittman (1972), Krinsley and Doornkamp (1973) and Marzolf (1976) among others. Because of the high initial porosity of eolian sands (Marzolf, 1976; Doe and Dott, 1980) groundwater can move through the sediment relatively easily speeding up the diagenetic processes. Both Sanderson (1973) and Marzolf (1976) did note that the entire surface of a grain is seldom completely covered and frosted primary surfaces did occur. Krinsley et al. (1976) stated most sediments older than Tertiary are too modified by diagenesis to determine the surface textures. There was one example cited, however, in which eolian sands from the Triassic of England were found to retain most of their initial characteristics (see discussion).

6.4.2 Sample Preparation:

One sample of a sand from the Browns Beach Member of the Honeycomb Point Formation at Robinson Cove was chosen for study. This sand is thought from field evidence (Chapter 5) to be eolian. The sample was well sorted, medium to fine grained and bright red in color. The preparation followed the procedure suggested by Krinsley and Doornkamp (1973). A part of the sample was first boiled for approximately 10 minutes in concentrated HCl and then boiled in a saturated solution of stannous chloride for 20 minutes to remove the iron oxides. The disaggregated grains were then washed in distilled water and dried.

Twenty-five grains of each of the medium and fine grain sizes were selected at random and mounted on an aluminum stub with two-sided tape. In addition, 25 medium and fine grains from the remainder of the untreated samples were also mounted along with a treated and untreated aggregate. The individual grains were then 'mapped' with the aid of a binocular microscope and their shapes and positions on the stubs recorded to facilitate identification under the SEM. The samples were then gold plated and viewed under a Phillips SEM.

6.4.3 Discussion:

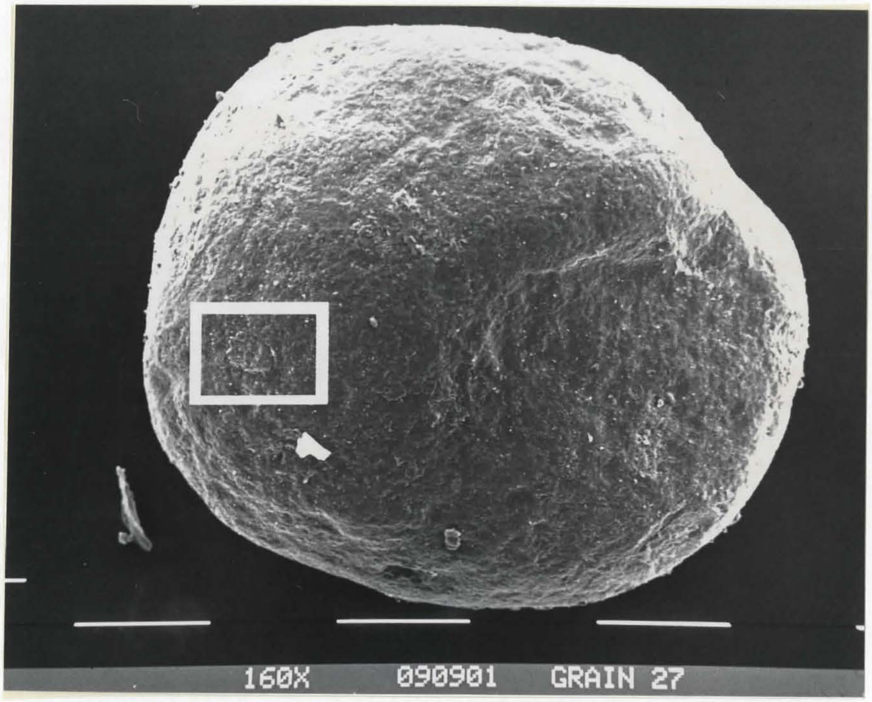
The main features seen on the grains, both treated and untreated, were; i) the general roundness of the surfaces, ii) a pervasive diagenetic overgrowth, iii) upturned plates, and iv) elongate depressions. In addition the complete absence of any V-shaped pits, whether fluvial or high energy chemical, was noticed.

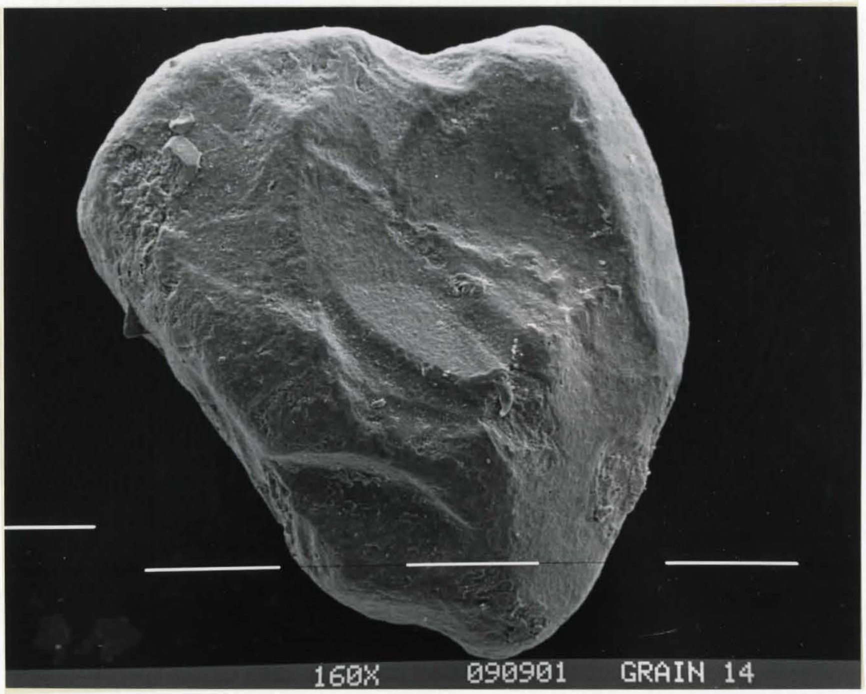
Figure 6.4 shows an extreme case of rounding while Figure 6.5 shows a typical grain outline. Such examples indicate either a shallow marine or eolian origin of the grains and, since there are no marine units within any of the formations studied, the eolian interpretation is favoured. It is barely possible that some of the grains may have inherited their shape as the result of reworking of older sediments. The Carboniferous sediments, however, are for the most part fluvial (with lacustrine further to the northeast) and not known to contain well-rounded sand grains. Pre-Carboniferous formations do include marine intervals but are polydeformed.

The elongate depressions of Figure 6.5 are comparable to Figure

Figure 6.4 Well rounded grain from facies C_4 viewed under the SEM. Horizontal field width is 0.75 mm.

Figure 6.5 Elongate depression in quartz and grrain from facies C_4 viewed under the SEM. Horizontal field width is 0.79 mm.


160X 090901 GRAIN 27


160X 090901 GRAIN 14

2a of Krinsley et al. (1976) also indicating an eolian setting. Similarly the presence of upturned plates, although modified by diagenesis, in Figures 6.6 and 6.7 compare well with Figure 2b of Krinsley et al. (1976) and plates 70-72 of Krinsley and Doornkamp (1973).

Although smooth patches are cited as common in eolian grains by Krinsley et al. (1976) and shown in plates 73-75 of Krinsley and Doornkamp (1973) they do not resemble the smooth areas of the grains studied. Although much of the quartz overgrowth forms a roughened crust over the grain there are areas where apparently opaline silica has formed (Figures 6.8a, b and 6.9a, b, c). The silica was probably derived from pressure solution at grain contacts (Figure 6.10 as shown by Pittman, 1972), Figure 7a). The differences between the silica overgrowths in this study and that of Krinsley et al. (1976) may be due to the early diagenesis of the material in the St. Martins area. Both examples are from the Triassic and therefore more or less equivalent in age however the colour of the English sample was described as brownish-yellow. The studies of Walker (1967, 1978) and Walker et al. (1976) indicate a colour change is a function of the breakdown of iron-bearing clays and silicate minerals such as hornblende with time. First a limonitic coating (yellowish) and finally a hematitic coating is formed on the grains as the breakdown advances. The degree to which this occurs (and the speed) is a function of the amount of oxygen-rich water available in the watertable as well as the availability of iron-bearing materials for oxidation. From the descriptions given it would appear the sample in this study has undergone more complete alteration. The coating of the

Figure 6.6 Upturned plates on quartz grains from facies C_4. Horizontal field with 187.5 um.

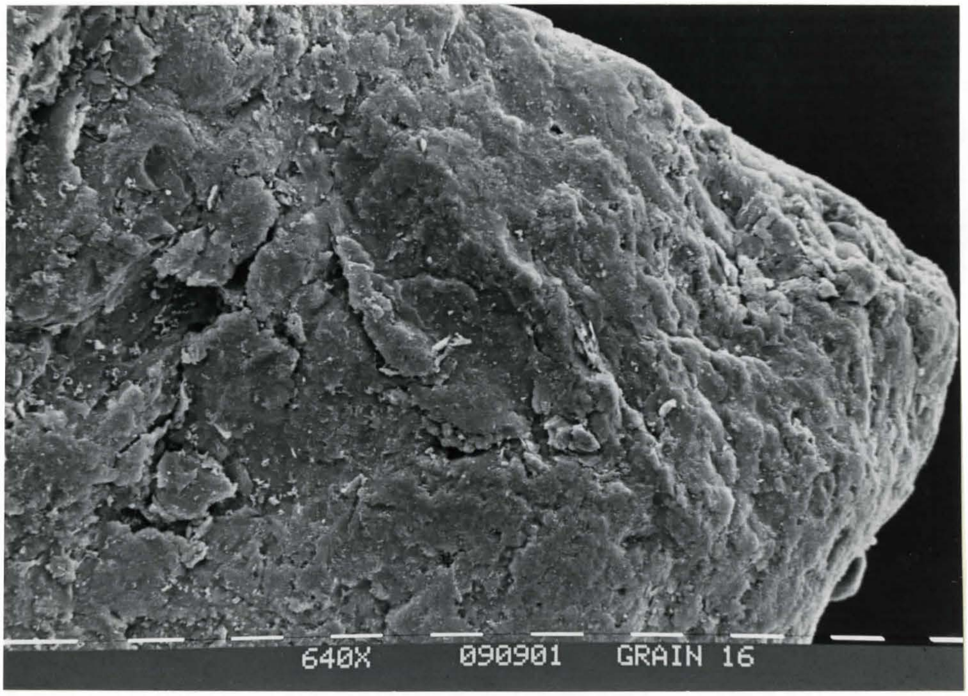
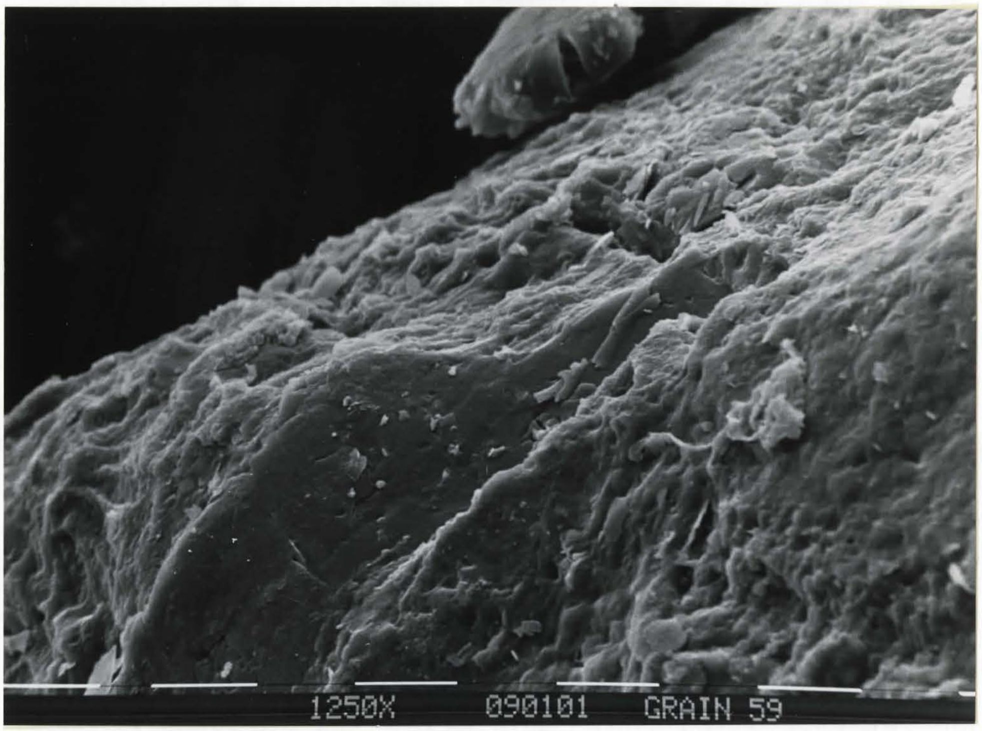

640X 090901 GRAIN 16

Figure 6.7 Upturned plates on quartz grains from facies C_4. This has undergone more silica precipitation than in Figure 6.7 considerably enhancing the cleavage plane. Horizontal field width is 96 um.

Figure 6.8a Opaline (?) silica coating part of the eolian quartz grain. Its formation in patches may be a function of the amount of clay present on the surface of the grain prior to diagenesis. Horizontal field width is 187.5 um.


1250X 090101 GRAIN 59

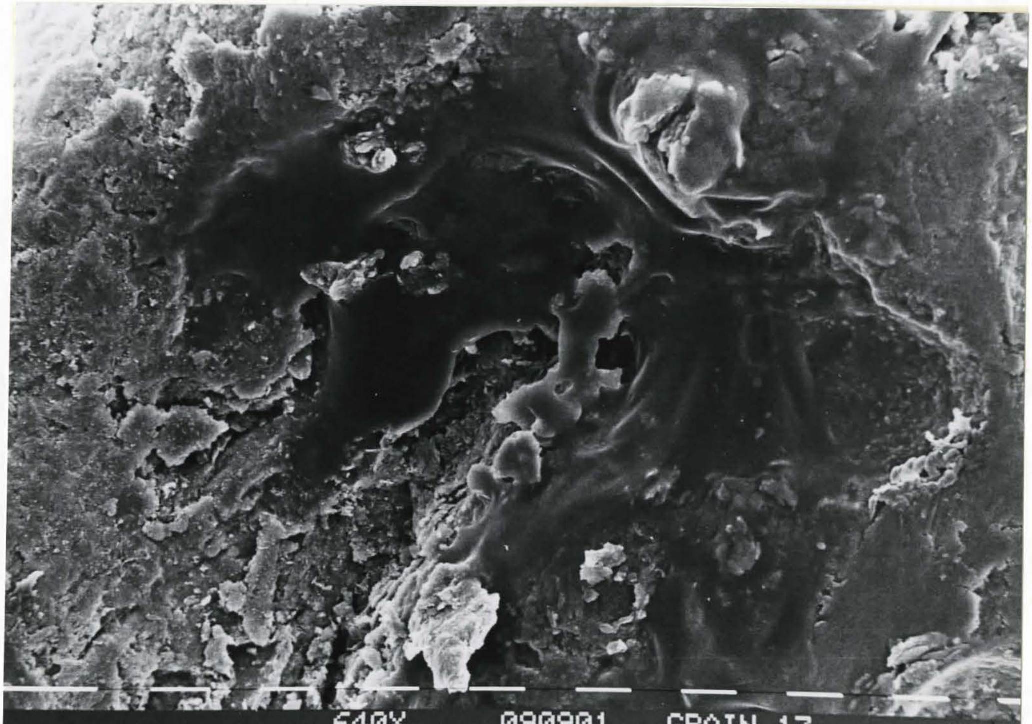
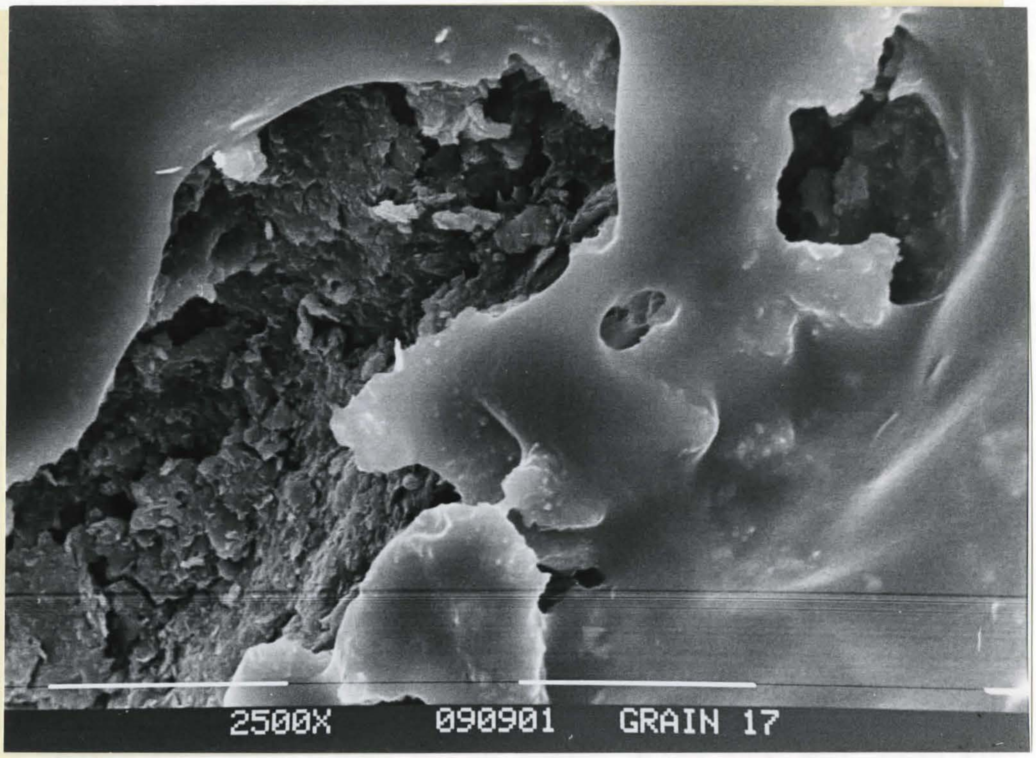

640X 090901 GRAIN 17

Figure 6.8b An enlargement of part 6.9a. Horizontal field width is 48 um.

Figure 6.9a Silica crust (in part opaline ?) coating a quartz grain from faices C_4. Horizontal field width is 187.5 um.


2500X 090901 GRAIN 17

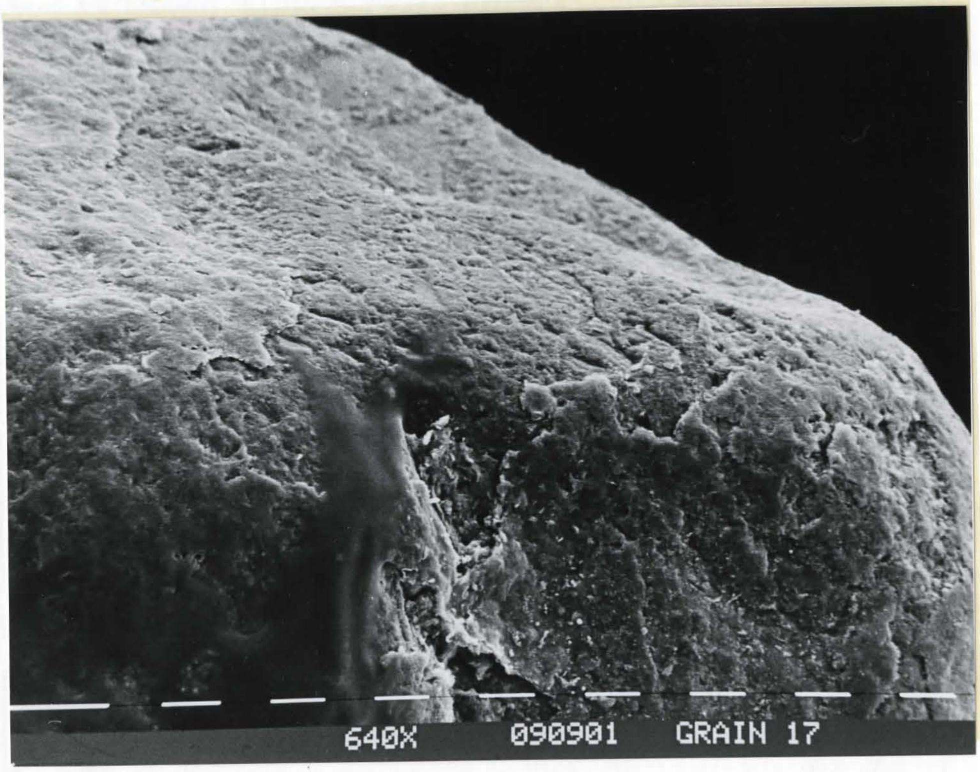
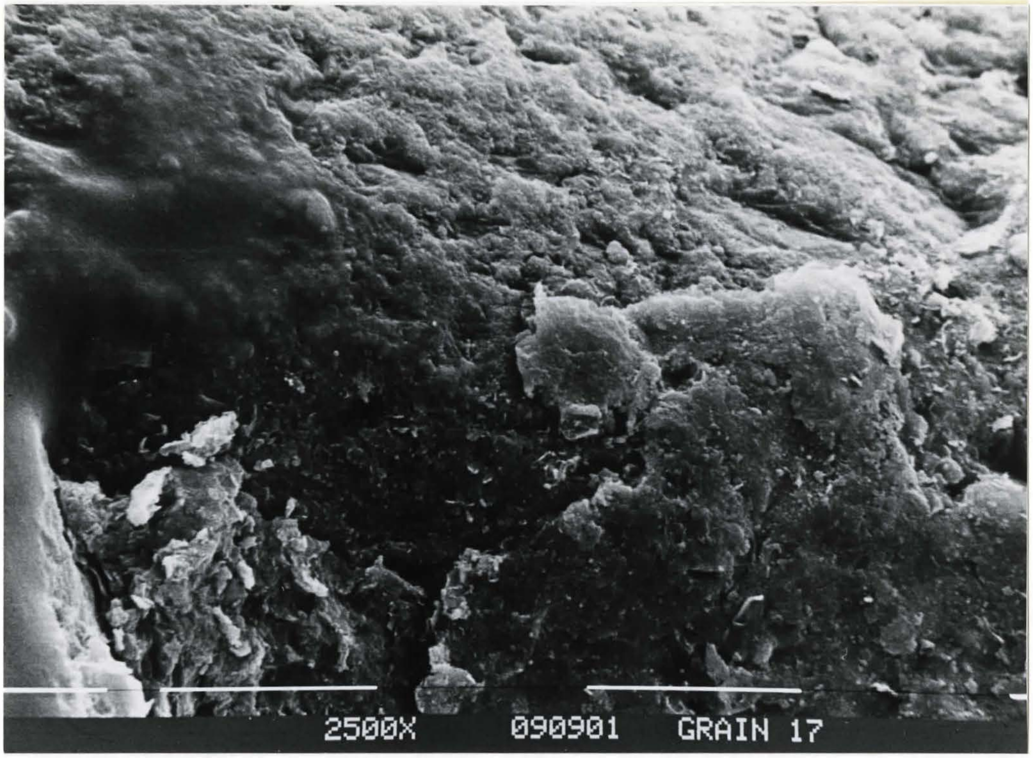

640X 090901 GRAIN 17

Figure 6.9b Enlargment of Figure 6.10a. Horizontal field width is 48 um.

Figure 6.9c Enlargement of Figure 6.10b. Horizontal field width is 12 um.


2500X 090901 GRAIN 17

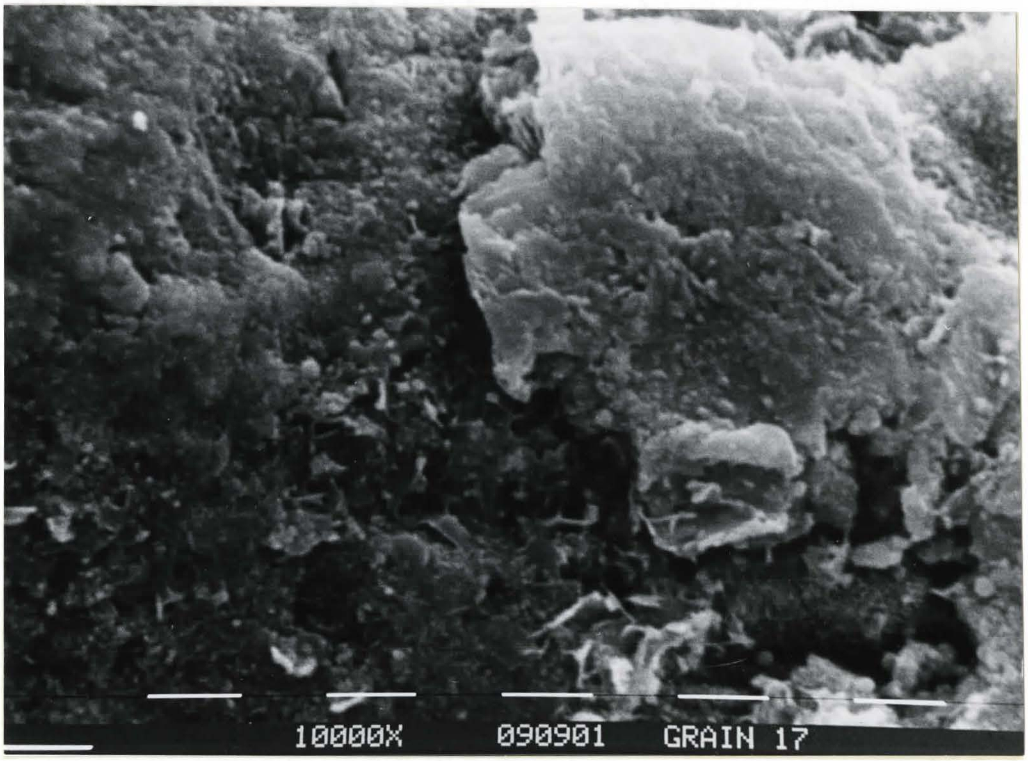
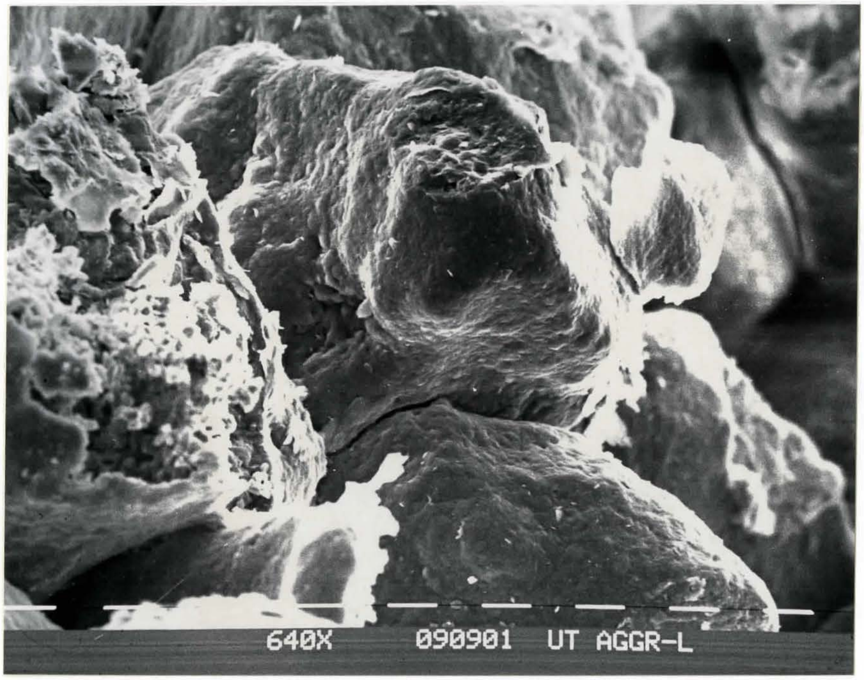

10000X 090901 GRAIN 17

Figure 6.10 Pressure solution pit on an untreated quartz aggregate from facies C_4. Horizontal field width is 0.75 mm.


640X 090901 UT AGGR-L

surface of the grains with clays and hematite may have affected the growth of silica by reducing possible nucleation sites (Pittman, 1972).

Overall therefore it appears the sediment sample is the product of reworking in an eolian environment both from direct evidence, the presence of upturned plates and elongate depressions, and from indirect evidence, the absence of V-shaped pits characteristic of a fluvial or marine environment.

Chapter 7

Paleocurrent Measurements

7.1 Introduction

The only previous work which incorporated any paleocurrent data from these two areas was that done by Klein (1963a). His outcrop locations were, however, limited to what Alcock (1938) had referred to as the Triassic. Therefore during the course of field mapping and measurement of detailed sections, all available paleocurrent information was recorded.

7.2 Method

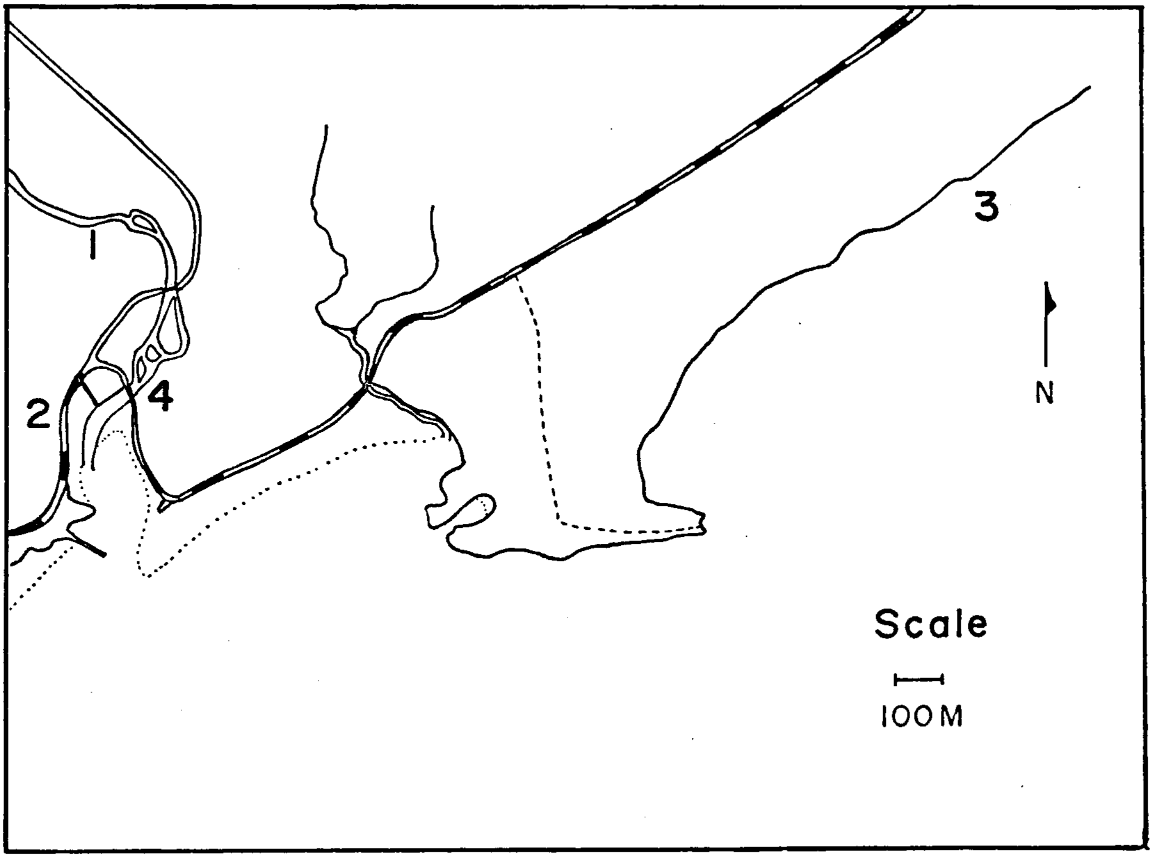
Exposures of all four formations are best along the coast but because of the jointing of the cliffs the outcrops tend to have smooth, flush surfaces which make determining paleocurrent direction, other than sense only, virtually impossible. Similarly outcrops in streams always seem to be covered with several meters of water or with the moss and slime which effectively masks all structures.

Where good exposures were present, or where there were only bi-directional features such as current lineation present, all available measurements were taken. For the shallow dipping beds (up to approximately 20°) this was done by visually rotating the beds to horizontal and measuring the azimuth directly. Where the beds were more steeply dipping, and the angle was never more than 25-30°, a clipboard was placed on the rock surface, the line tracing the current direction was drawn on it and then the board was rotated back to horizontal and the reading taken. A more accurate method is to measure the rake of the structure and correct the direction via a stereonet, however, it seemed with the low dip of the beds, and the simple nature of the structure that the errors were no more than would be expected from the uncertainty in the measurements.

In the Quaco Formation, where there were few sedimentary structures to measure, clast orientations were taken at several places in the section (Figure 7.1). Here the strike and dip of the AB plane, the A-axis direction and the measurement of the three principal axes were taken. The strike and dip of the bedding at each location was recorded and the AB plane and A-axis were subsequently corrected for tectonic dip with a stereonet.

The corrected data was then plotted on rose diagrams for each type of current indicator in each group. The groups were made up on the basis of extent of outcrop and amount of data. The Honeycomb Point Formation for example, is represented by data from McCumber Point only and was classed as a single group while the extensive outcrop of the Fownes Head Member necessitated splitting the member into three groups on the basis of geographical position. For each rose diagram the data was analysed using the method proposed by Curray (1956) in which a vector mean, strength and amount of dispersion was calculated. Then from each group a 'grand mean' was found by using the vector strength of each type as the 'n' value and grouping all types into one current rose. The calculations described above were then carried out again to give an estimate of the flow direction overall as well as the amount of deviation from the mean.

Figure 7.1 Location map for the clast orientation stations. Measurements listed in Appendix B.


1
2
4
3
N
Scale
100 M

The bi-directional data, such as current lineations, were weighted first in one quadrant and then the opposite and the amount of dispersion calculated in both cases. The fit with the least dispersion was taken to be the direction of flow (this was also checked with other current indicators to ensure the direction was not absurd). The grouped data is presented in Appendix A. The treatment of the clast orientations was somewhat different and will be described in the discussion of the Quaco Formation.

Because of the varying nature of the current directions in each group, the results will be discussed on a formation-by-formation basis.

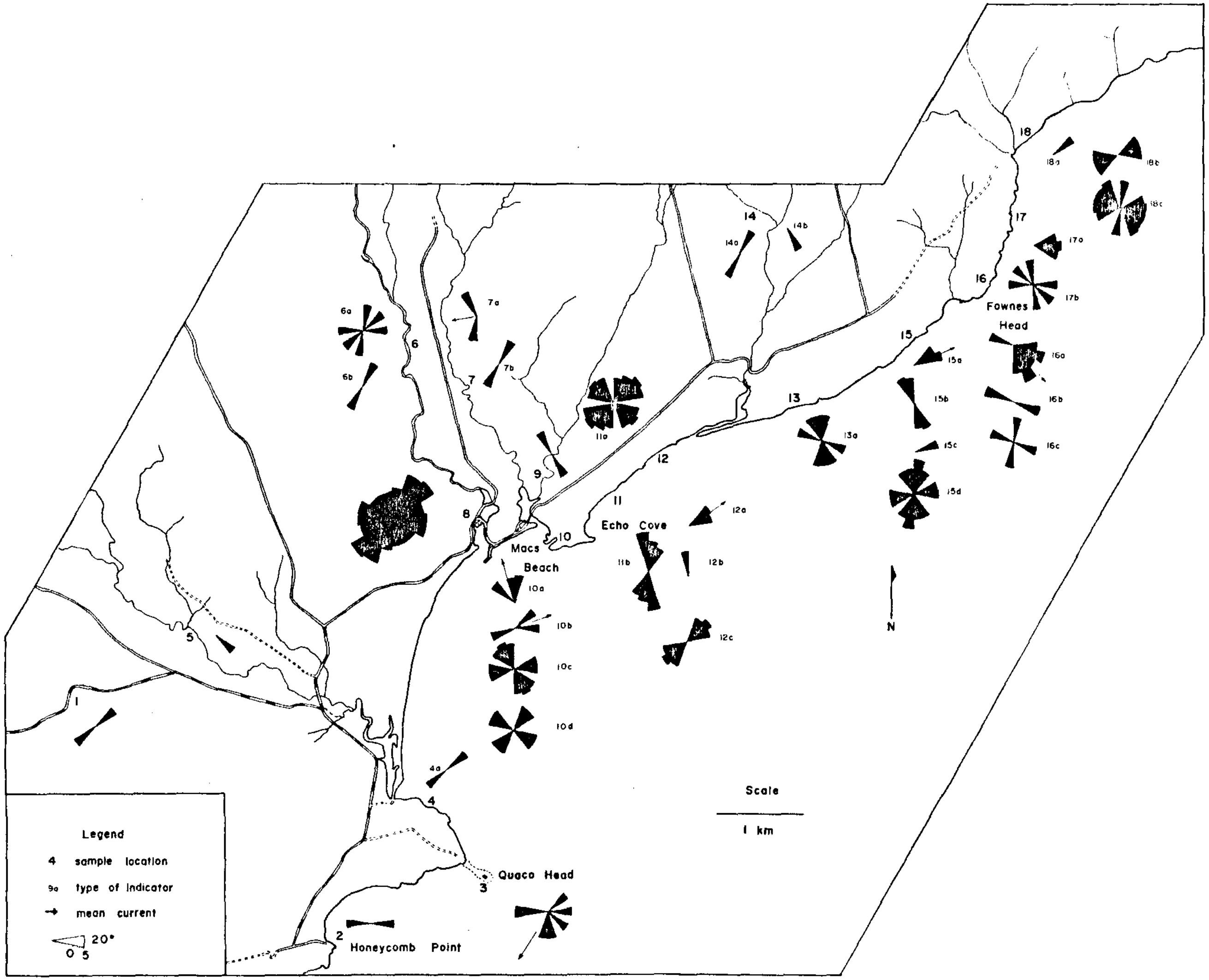
7.3 Honeycomb Point Formation:

From the facies descriptions it has been concluded that this formation can be divided into water and wind borne sediments. These will be discussed separately.

The water-laid sediments, where coarse, show little in the way of structures other than occasional pebble imbrication. The presence of isolated planar tabular cross-sets indicates this may be a function of the exposure and the large grain size rather than any inherent property of the sediment. Because only the portion immediately underlying the Quaco Formation at McCumber Point is contiguous with the rest of the formations in the area only paleocurrents from this region will be discussed in this group. The number and type of indicators are given in Figure 7.2 and Table 7.1.

The direction of the grand mean in this case is approximately 090° with the dispersion (L) = 63%. The lack of any distinct channels

Figure 7.2 Paleocurrent measurements in the St. Martins area. Numbers refer to the location numbers in Table 7.1. Current roses are in increments of 1, sample size listed in Table 7.1



Legend
4 sample location
9a type of indicator
mean current
20°
0 5
Scale
1 km
N
Quaco Head
Honeycomb Point
Macs Beach
Echo Cove
Fownes Head
1
2
3
4
4a
5
6
6a
6b
7
7a
7b
8
9
10
10a
10b
10c
10d
11
11a
11b
12
12a
12b
12c
13
13a
14
14a
14b
15
15a
15b
15c
15d
16
16a
16b
16c
17
17a
17b
18
18a
18b
18c

Table 7.1: Paleocurrent vectors from the St. Martins area

Location	Formation	Sample Size	Type of Indicator
1	Honeycomb Point	1	current lineation
2	" "	1	" "
3	" "	12	troughs (eolian)
4	" "	1	180° troughs
5	" "	1	imbrication
6a	Echo Cove	3	current lineation
6b	" "	1	tool mark
7a	Honeycomb Point	2	imbrication
7b	" "	1	current lineation
8	Quaco	50	A-axis (clasts)
9	Echo Cove	1	current lineation
10a	Honeycomb Point	5	troughs
10b	" "	3	ripples
10c	" "	6	current lineation
10d	" "	4	grooves
11a	Quaco	20	A-axis (clasts)
11b	"	11	180° troughs
12a	"	1	ripples
12b	"	3	planar tabular troughs
12c	"	5	current lineation
13	Echo Cove	4	" "
14a	" "	1	" "
14b	" "	1	imbrication
15a	" "	4	troughs
15b	" "	3	180° troughs
15c	" "	1	ripples
15d	" "	10	current lineation
16a	" "	18	troughs
16b	" "	3	180° troughs
16c	" "	2	current lineation

Table: 7.1 (cont.)

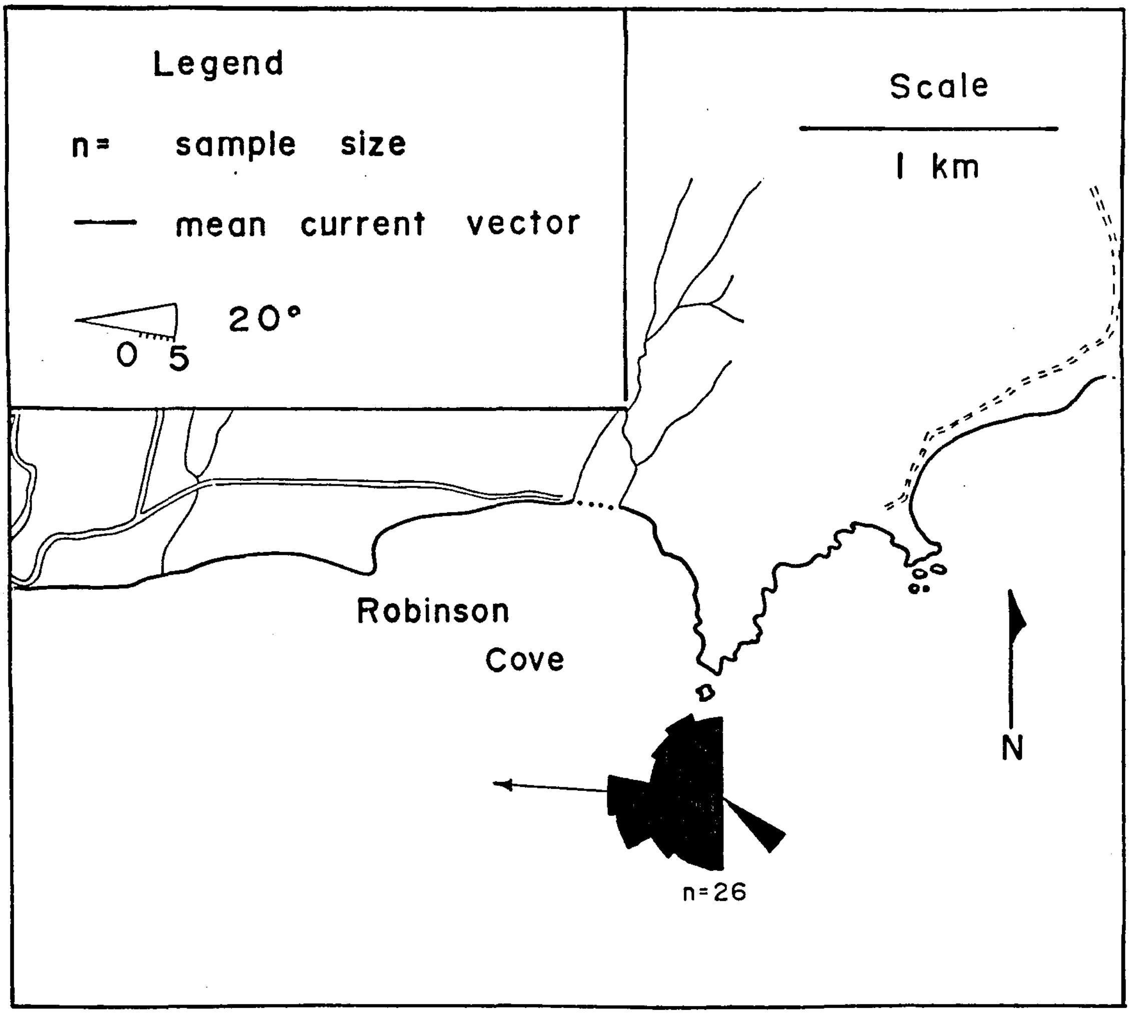
Location	Formation	Sample Size	Type of Indicator
17a	Echo Cove	6	troughs
17b	" "	3	current lineation
18a	" "	1	imbrication
18b	" "	3	grooves
18c	" "	12	current lineation

in any of the exposures and the presence of very small planar tabular crossbeds in the pebbly sandstone indicates this was formed by shallow, probably braided, streams. If this is the case the current indicators which would be expected to give the most accurate flow direction would be the current lineation, ripples and imbrication with trough cross-beds occurring at a high angle to the mean flow path (Williams and Rust, 1969; Rust, 1972; Bluck, 1975). This was found to be the case. This also fits in with the structural evidence (Chapter 2) which places the boundary fault on the north side of the basin and implies that the sediments were probably derived from the Caledonia Highlands to the north and west.

The wind-laid sediments occur at a lower stratigraphic level than those discussed above (Chapter 5) and are best exposed in sections at Robinson Cove, Browns Beach (Figure 7.3) and Quaco Head (location 3 on Figure 7.2). The data were treated in the same manner as the fluvial sediments but were kept separate for obvious reasons. The data and results shown in Figures 7.2 and 7.3 and calculations shown in Tables A-2 to A-4. The amount of dispersion in all three cases is quite high but is comparable to that in modern dune fields. McKee and Bigarella (1979a, b) note that paleocurrent readings for barchanoid dunes (which these are presumed to be, see Chapter 5) show a predominantly uni-directional wind, as these do, but individual readings may vary up to 140°. The total spread of readings is 220° at Robinson Cove, 160° at Browns Beach and 140° at Quaco Head.

The larger than normal spread in azimuths may be partly due to the proximity of the bounding fault. The effect of the scarp and the

Figure 7.3 Location map for paleocurrent measurements from facies C_4 at Robinson Cove. Sample size is 26.


Legend
n= sample size
mean current vector
20°
0 5
Scale
1 km
Robinson
Cove
N
n=26

stream valleys cut into it would be to disperse the wind patterns more than is found in open desert conditions. Topographic deflections of the winds may have been responsible for the formation of the dunes as well. Fryberger and Ahlbrandt (1979) cite this as one of the reasons for the accumulation of eolian sands.

The grand mean calculated for the three areas was 262° with a dispersion of L = 93%. This corresponds surprisingly well with the paleowind direction found by Hubert and Mertz (1980) in the Triassic of Nova Scotia. Their examples, which are on a much larger scale, head toward 225°. In this study area the amount of dispersion in the grand mean could be reduced still further if the mean of the Quaco Head cross-beds was rotated clockwise. The fact that there is a major fault (or faults) separating this exposure from similar sediments at Browns Beach indicates rotation may have occurred (although it is possible rotation has taken place in all three examples).

This formation then was formed in an area which was at least semi-arid with alluvial fans spreading eastward from the fault scarp interbedded, in the lower portion, with eolian sands piled up by winds moving west-south-west but deflected in part by the scarp. A similar example was described by Clemminson (1977) from the Triassic of Greenland. He chose to interpret the variability of paleocurrent measurements in the eolian sands as due to two opposing principle wind directions blowing at different times of the year. This is not found to be the case in any of the modern dune fields which have been studied (McKee and Bigarella, 1979a; Fryberger, 1979).

7.4 Quaco Formation

This formation poses the greatest difficulties in paleocurrent analysis because of the scarcity of data. The exposures are spectacular but much of the outcrop is out of reach. Initially the data for the entire formation were lumped together because of this defect but subsequently the data were divided into two groups with the dividing line arbitrarily chosen as the middle of the formation. The grand mean for the lower section was 015° (L = 96%) and for the upper portion, 044° (L = 95%).

On the surface it would appear the paleocurrents in the lower part of the formation were almost due north while in the upper part they had shifted to the northeast. However, closer examination of the raw data shows most of the indicators in the bottom group are the axes of cross-bedding troughs. The environment is thought to be a gravelly, braided river system and examples from the literature (e.g. Eynon and Walker, 1974; Williams and Rust, 1969) note that the troughs are always at a high angle to the mean flow direction. Much better indicators of the general flow direction according to Bluck (1975) are the small-scale structures and current lineations. These are present in the upper portion trending 050°. Planar tabular crossbeds in the upper group also head in the same direction.

This means that the subdivision of the unit may be entirely artificial. If in fact flow throughout the entire unit was northeast, the orientation of the troughs would be expected to be either to the north or southeast with the planar tabular beds either at a high angle to flow, similar to the troughs, or parallel to flow (Eynon and Walker, 1974). The fact the troughs in the lower half of the formation have a low dispersion (L = 95%) is offset by the low number of measurements (n = 11).

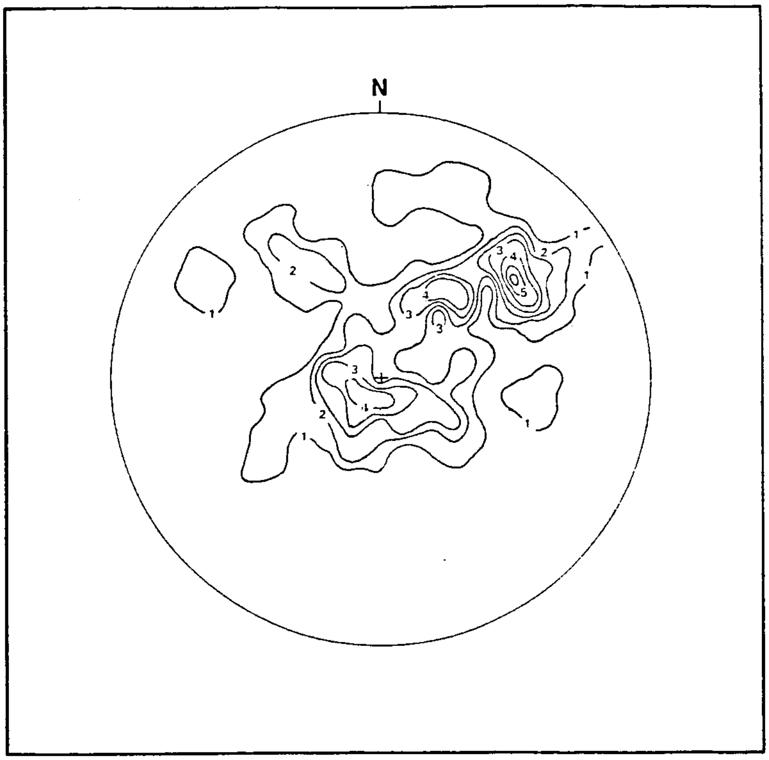
These uncertainties may possibly be resolved by the study of pebble orientation. Both Bluck (1975) and Rust (1972) found pebble orientations showed good correlation with the mean current direction. The pebble measurements in this study are limited and, unfortunately the only sample with at least 50 measurements is also from the upper portion of the formation. Figures 7.4 to 7.7 show the concentrations of poles normal to the AB plane plotted on a Schmitt net and then contoured using a Kalsbeek counting net. Figure 7.7 is included for completeness; however, the low number of readings prevents any conclusions being drawn from it.

Figure 7.4 (n = 50) clearly shows a northeast trend of steeply dipping clasts, a southwest trend of shallow dipping clasts and a still weaker trend off to the northwest. These trends are also seen in Figures 7.5 and 7.6 although to a lesser degree because of the fewer readings. The northeast trend is thought to represent the main flow direction of the river with the other groups due to pebble alignment on the lee slope of bars in the channels (Johansson, 1976). The clast size is large (A-axis in Figure 7.4 varies from 5.2-13.6 cm) and there is a lack of data concerning the behavior of these sizes in natural or experimental flows.

As a check on the validity of the assessment, the orientations of the A-axes of the clasts were plotted for all four sample sites as

Figure 7.4 Contoured poles to the AB plane of clasts from station 1 (n = 50). Contours in increments of 1.

Figure 7.5 Contoured poles to the AB plane of clasts from station 2 (n = 21) Contours in increments of 1.


N
1
2
3
4
5

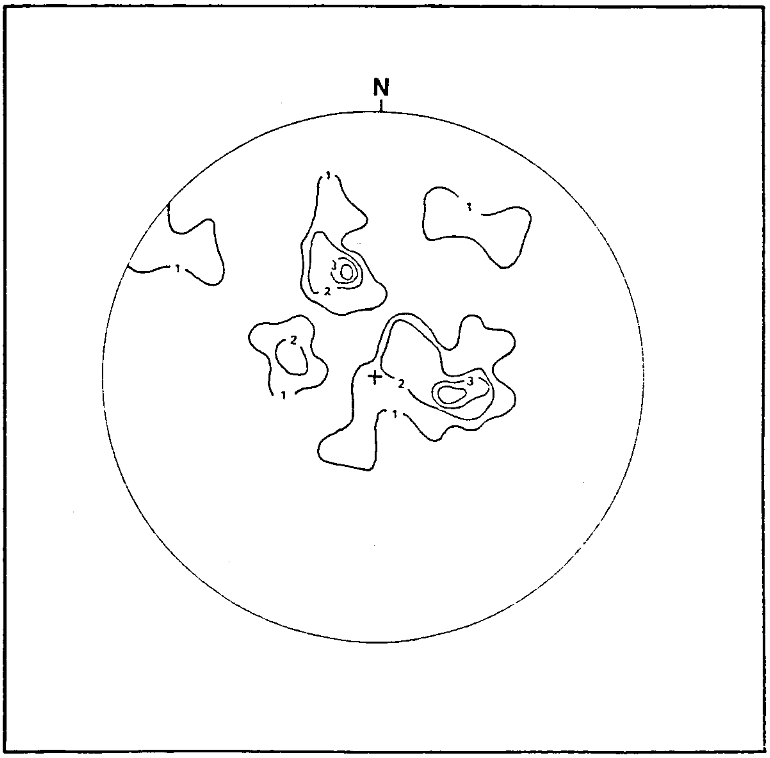
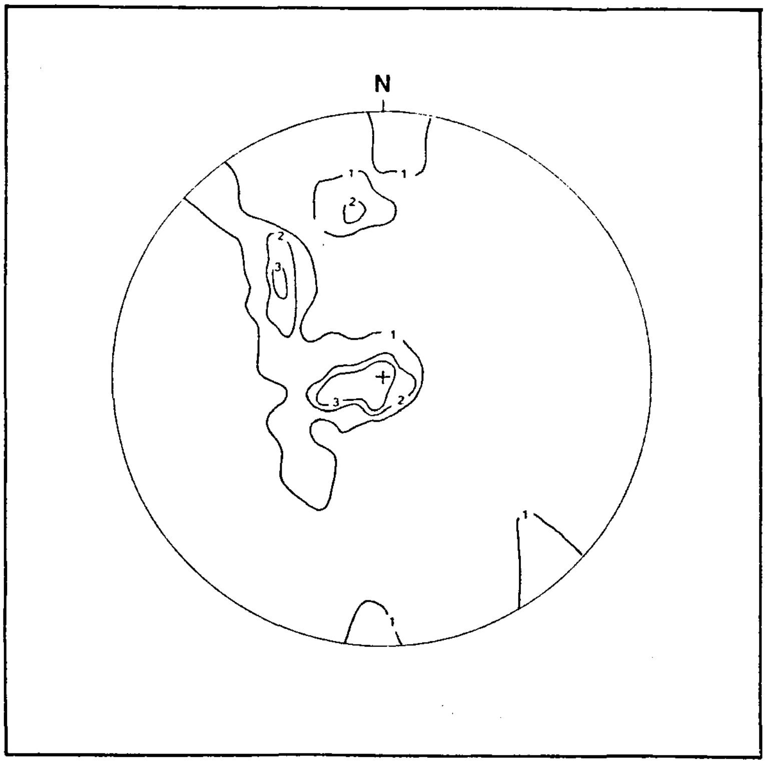
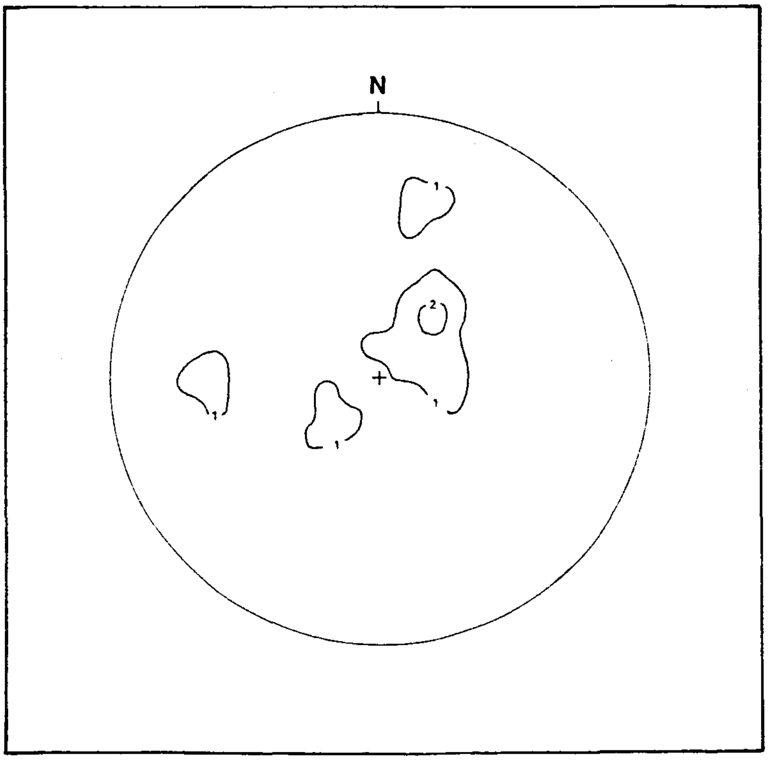

N
1
2
3

Figure 7.6 Contoured poles to the AB plane of clasts from station 3 (n = 20). Contours in increments of 1.

Figure 7.7 Contoured poles to the AB plane of clasts from station 4 (n = 7) Contours in increments of 1.


N
1
1
2
2
3
1
3
2
1
1


N
1
2
1
1
1

well. This was done two ways, first the direction of the axis and the dip of the AB plane were considered. The results are shown in Tables B-1 to B-4. Then the direction of the A-axis alone was taken, as shown in Tables B-5 to B-9. The results seem to confirm the observations of Rust (1972) who found that for A-axes greater than 5 cm and with clasts covering more than 90% of the bed there were three modes, transverse, parallel and at 45° to the channel trend. The size and shape of the clasts and hydrodynamics of the river play a large part in controlling the clast orientation both through the type of bedforms present and their rate of migration and the interaction between the clasts and flow. Johannson(1963, 1976), for example, noted the asymmetry of the clasts allowed them to pivot about a point and align themselves parallel to the current. The figures in this instance show a predominance of A-axis parallel to flow although whether this is due to the effects of isolated, very large clasts or to the asymmetry of the clasts themselves is not known.

It appears, therefore the Quaco Formation is the result of a single braided river system flowing approximately northeast throughout the history of the deposit, but which may have been deflected farther toward the northeast in the upper half of the unit by the sediments of the Echo Cove Formation.

7.5 Echo Cove Formation:

7.5.1 Berry Beach Member:

This immediately overlies the Quaco Formation and consists of redbeds which give way to trough cross-bedded pebbly sandstones. The data given in Table 7.1 are shown in more detail in Tables A-5 and A-6. The average flow direction is toward 113° but once again the dispersion is fairly high, L = 82%. This is thought to be similar to, and may have resulted from a resurgence of, the fan or fans below the Quaco conglomerate. The primary difference is the increase of the competency of the flows. Here they form a thick section of trough cross-beds in sets up to 1 m thick which are only sporadically interbedded with red shales. This implies a change in the precipitation received in the drainage basin from a semi-arid to humid condition.

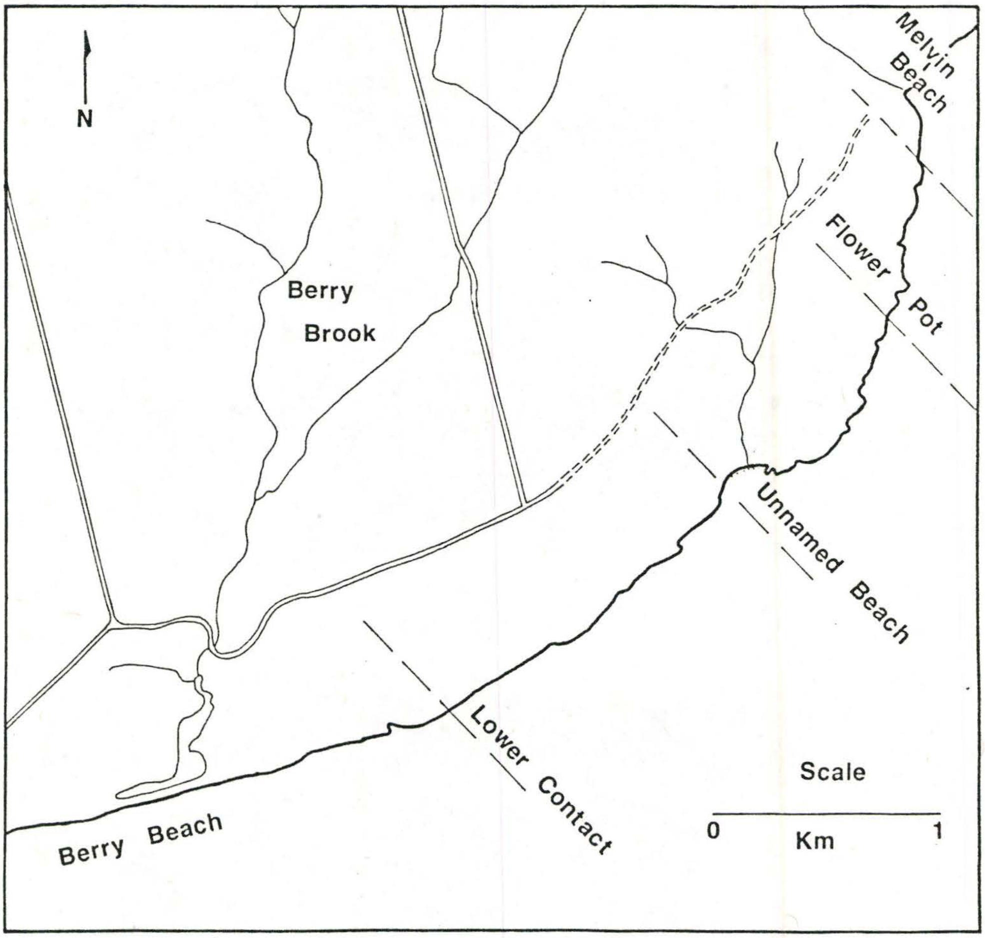
The current lineations here trend 150° while grooves on the base of beds trend 110°. The troughs measured were oriented towards 070 and 110°. The result is a braided river system flowing more or less towards the east-southeast with a fairly wide dispersion in current vectors.

7.5.2 Fownes Head Member:

This member was divided into three geographical units because of the large amount of outcrop along the coast. These are from the lower transition to the west end of the unnamed beach immediately west of Fownes Head, from the east end of the beach to the 'flower pot' (an informal name given to a detached section of cliff with trees growing on the top. It is also visible on air photos), and from the flower pot to the upper transition (Figure 7.8).

Unfortunately because of the nature of the exposure the number of measurements taken in this member, particularly in the lower unit, is sparse. The grouped means for the three units are shown in Tables A-7 to

Figure 7.8 Informal division of the Fownes Head Member for paleocurrent analysis. Unit 1 extends from the lower contact to the unnamed beach; unit 2 extends from the unnamed beach to the flower pot; and unit 3 extends from the flower pot to the upper contact.


N
Melvin Beach
Flower Pot
Berry Brook
Unnamed Beach
Lower Contact
Scale
0 Km 1
Berry Beach

A-11.

The large amount of bi-directional indicators in the lower unit increases the ambiguity of the interpretation. If these are weighted so that they are southerly (Table A-7) the mean direction is 153° with L = 63%. If they are weighted to the north (Table A-8) the mean is 20° with L = 82%. Following the criteria established previously the accepted value should be 020°. This is a sharp change in direction from the lower member (113°) and from the next unit in this member (131°).

There are two alternatives. First the northerly flow may be correct in which case this could be viewed as the influence of the northerly flowing river system seen in the Quaco Formation. This is partly supported by the presence of a thick (2 m) bed of conglomerate of facies A_2 near the base of the unit. On the other hand, if the southerly flow is correct, it may simply mean a change in depositional site on the fan. The change in lithology and colour indicates a general increase in rainfall in the source area (Chapter 8) which may have triggered the change in deposition (similar to switching the suprafan lobes in the submarine fans).

The next group of measurements (Table A-9) shows the mean flow heading toward 131° with L = 99%. Although planar tabular cross-sets were seldom exposed in sufficient detail to be measured their sense of direction was either east or west. If the previous unit was heading toward the north this change in direction would be the result of the fan(s) once again deflecting the river system and overriding it as was the case in the transition between the Quaco and Echo Cove Formations. If the flow was to the south there appears to have been an eastward shift in average current direction.

The upper group has a mean current direction of 102° with L = 95%. Here again there appears to be an eastward shift in the flow direction. An example of just such a system is the modern Kosi River in India which consists of a large braided river which progressively moves over the surface of the fan (Gole and Chitale, 1966). A more detailed look at this member is needed before any definite conclusions can be drawn (particularly in the lower unit).

7.5.3 Melvin Beach Member:

Here too, there is a gradational lower contact but in this case it forms as the result of coarser and coarser material being brought in along with the re-introduction of redbed facies similar to the Berry Beach Member.

The current data obtained from the limited outcrop available were mainly bi-directional features, which, when tabulated gave an average direction of 089° (L = 93%) or 284° (L = 83%). The fact the imbrication dips toward 050° must be treated with caution. The presence of poorly defined planar tabular cross-beds means the imbrication may in fact show the trend of the cross-bedding rather than the flow direction. The 089° average is preferred on the basis of direction of all the other flows in the area. The data for this group are presented in Table A-11.

7.6 Summary for St. Martins:

From the observations during this study it would appear the lower formation formed as the result of alluvial fans flowing generally eastward from the Caledonia Highlands in a semi-arid environment (Table 7.2). Small dunes formed by winds blowing west-southwest covered the outer fringes of the fan during periods when the fan was inactive and were planed off by renewed sedimentation. The fan(s) was then covered by a northward flowing braided, gravel river where deposits were in turn overlain by further alluvial fan sediments deposited by flows to the east-south-east. This fan may have shifted its deposition centre due to an increase in precipitation in the highlands or, a separate fan may have prograded over the previous one, forming the Fownes Head Member. The flow directions on this fan appear to have moved steadily eastward from 153° to 102°. The Melvin Beach Member may be a continuation of the same fan system as the preceeding member with a return to more arid conditions and an uplift of source area to account for the coarsening clast size. In this case the fan continued its eastward migration. Alternatively, the Melvin Beach Member may be part of the fan system which deposited the Berry Beach Member and had now re-established itself.

The presence of extensive coarse fanglomerate deposits of the Stony Brook Member of the Echo Cove Formation to the northwest makes presence of streams flowing to the east and southeast and transporting finer sediment even more probable although Klein (1963a) thought the opposite occurred:

" The Wolfville of New Brunswick contains mean

Table 7.2: Grouped mean paleocurrent directions for St. Martins

Formation	Sample Size	Current Direction	L
Honeycomb Point (Macs Beach)	28	084	56.2%
Honeycomb Point (Eolian)	23	259	91.6
Quaco (lower half)	12	018	92.4
Quaco (upper half)	10	045	95.3
Echo Cove (Berry Beach Member)	13	137	61.7
Echo Cove (Fownes Head Member)	18 (lower)	158 (020)	66.6
	23 (middle)	130	99.1
	9 (upper)	102	93.8
Echo Cove (Melvin Beach Member)	16	089	93.0

> azimuths that are parallel to the overlying Quaco and Echo Cove formations of the St. Martins area, suggesting that the drainage pattern was unchanged during sediment deposition in this area during Upper Triassic time." (p. 803)

His observations, however, did not include anything beyond the Berry Beach Member of the Echo Cove Formation in the immediate area of St. Martins. Along with the fluvial data he also grouped the eolian data (which can be seen as the strong westward component in his Figure 2, map 3).

7.7 Lepreau Formation:

Less time was spent covering this formation than any of the others and consequently the data here are meager (Figure 7.9, Table 7.3). Nevertheless, there are trends which seem to contradict the conclusions of Klein (1963a) and so they will be discussed here member-by-member.

7.7.1 Fishing Point Member:

No paleocurrent vectors were measured from this member, primarily because of the nature of the sediments (coarse breccias). Nevertheless some inferences can be made on the basis of the lithology of the clasts (see Chapter 6). The granites which make up the bulk of the pebbles in this member can be found within 10 km of the outcrop to the northwest and northeast. It is therefore reasonable to assume they were brought in by currents flowing generally southward.

7.7.2 Duck Cove Member:

The measured indicators in this formation are primarily ripples

Figure 7.9 Location map for paleocurrent data from the Lepreau Formation. Numbers refer to table 7.2. Sample sizes given in Table 7.2.

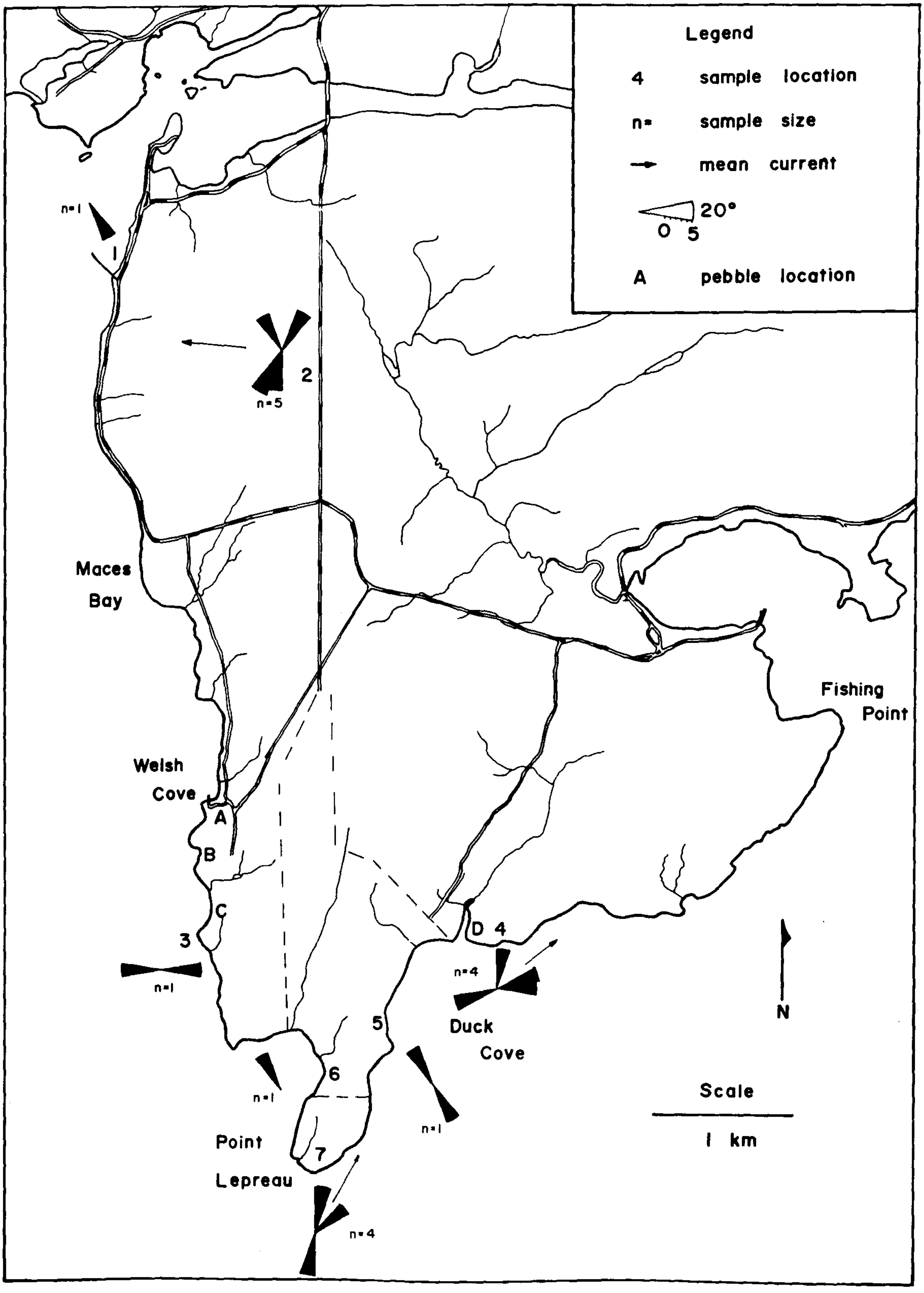

Legend
4 sample location
n= sample size
mean current
20°
0 5
A pebble location
n=1
1
2
n=5
Maces Bay
Fishing Point
Welsh Cove
A
B
C
3
n=1
D 4
n=4
Duck Cove
5
6
n=1
n=1
Point Lepreau
7
n=4
N
Scale
1 km

Table 7.3: Paleocurrent data from the Lepreau Formation

Location	Sample Size	Type of Indicator
1	1	imbrication
2	4	"
3a	4	current lineation
3b	1	tool mark
4	2	ripples
5a	1	groove
5b	1	ripples
5c	2	current lineation
6	1	" "
7	1	ripples
8a	1	"
8b	1	current lineation
9a	1	ripples
9b	1	current lineation
10	1	" "
11a	2	" "
11b	2	ripples

and current lineations. As a general rule it appears that the current lineations are oriented more or less north-south while the ripples are either northeast or northwest. Again the problem of which to weight with the most importance comes in. If the current lineations are weighted to the north the average direction is 045° (L = 68%) (Table A-12), while if they are weighted to the west the result is an average of 134° with L = 24% (Table A-13). Field observations, however, indicated that both trough and planar tabular cross-beds were trending either south or southwest, never north. This may mean that the ripples were the result of wind interaction with small ponds of water or that they were formed on the edges of rather large pools by eddies flowing in the opposite direction. If the current lineations are taken by themselves, the average direction becomes 208°, L = 82%. When one considers other lineations measured in the upper member of this formation (but formed by the same processes) the grand mean becomes 232° with L = 78%. Since the source direction was probably in the north it seems reasonable to conclude the main flow direction was to the southwest and that the ripples were formed by a counter-current of some type.

7.7.3 Maces Bay Member:

The bulk of the measured vectors in this member actually belong to the Duck Cove Member. The only data which come exclusively form this unit are a few scattered imbrications. This gives a grand mean of 200°, L = 25% (Table A-14) but over only eight readings. Once again, however, the clasts of this member are of a lithology which is found 2-5 km to the north of the outcrop locations and it is reasonable to assume the source lay in this direction. The granitic clasts just north of the Maces Bay wharf are up to 1.6 m in diameter, indicating a close proximity to the source.

7.8 Summary for Lepreau:

The only previous work on the paleocurrents in this area was that of Klein (1963a). On the basis of 46 measurements from all three members he concluded flow was toward the northwest for all four locations, (Figure 2, Map 4). The results of this study both from provenence and vector measurement however indicate that the flow was to the southwest. With the major boundary fault to the northeast it is apparent that the simplest interpretation is that the sediments were derived from the northeast.

Chapter 8

Paleontology

8.1 Introduction

Deposition of the Triassic sediments of New Brunswick took place in a terrestrial environment. Therefore, few fossils have been preserved compared with their abundance in most sediments. In terrestrial environments, oxidation of both plant and animal remains is rapid with the result that often only traces and spores are left as a record of the populations which inhabited the area. The bulk of the fossils previously reported from the Triassic in New Brunswick were poorly preserved plants, which were rather tentatively correlated with the Keuper of Europe (see Chapter 3). A further attempt by Magnusson (1955) to have plants from the Fownes Head Member identified was not successful because of the poor state of preservation. No attempt was made in this study to identify any megascopic plant fragments. Several lithological samples were, however, collected from around the better preserved plants for pollen analysis. An abundant and diverse pollen flora was discovered. In addition, bioturbation and trace fossils proved to be more abundant than was originally expected, and a preliminary description is given in this chapter.

The first reported work on the fossils in this area was by Dawson (1878) who identified poorly preserved, silicified plant remains from St. Martins as belonging to the genus _Peuce_ or _Pinites_ both of which were Triassic. Subsequent work northeast of the St. Martins exposures by Holden (1913) confirmed Dawson's analysis and further extended the correlation to the Keuper beds of Germany and the Triassic of Eastern U.S. In a comprehensive work on the Triassic palymorphs Cornet (1977) left out the south coast of the Bay of Fundy because:

> "For example, the Echo Cove and Quaco Formations are omitted because of palynological evidence indicating an Early-Middle Triassic age (Traverse, personal communication, 1974) and the Lepreau Formation is omitted because of palynological evidence indicating that at least part of it is of a Late Devonian-Early Mississippian age (Traverse, personal communication, 1976)."(p. 5).

Subsequent inquiries, based on mapping reported in this thesis, indicates that the evidence from the Lepre~~q~~au Formation came from a Carboniferous inlier rather than the Triassic as stated above (Traverse, pers. comm., 1980).

Because of the extension of the Echo Cove Formation farther north than previously studied, several samples of the green beds were taken to the Atlantic Geoscience Centre for palynological analysis by Dr. J. Bujak. It was thought that this aspect was important because there was no firm data which placed the redbeds in either the Lepreau or St. Martins area in the Triassic. At best, earlier work indicated that they were post-Pennsylvanian.

8.2 Trace Fossils:

8.2.1 Introduction:

The trace fossils in the St. Martins area are rather scarce.

There are, however, several beds with well-preserved ichnofauna and descriptions of the traces (along with photographs) are included because of their importance in environmental interpretation.

8.2.2 Honeycomb Point Formation:

Because of the coarse grain size of most of the sediment and the previous interpretations of this formation as semi-arid it appeared unlikely that trace fossils would be found in these beds. Nevertheless, at least two areas, Robinson Cove and Browns Beach, traces were found in the eolian sediments. The examples from the Brown Beach exposure will be described here.

The traces are located at the west end of the beach, on the base of a small bed of eolian sandstone. The traces are, unfortunately, just out of reach with the result that all descriptions are from the photos. The sands in which the traces are found are well-sorted, so there is no preservation of internal structures (Figures 8.1 and 8.2). Some of the external morphologies, however, are very similar to traces found in modern deserts.

A recent summary of bioturbation in modern deserts by Ahlbrandt et al. (1978) showed, by means of photographs and line diagrams (Figures 8.3 and 8.4), the diversity possible in dune as well as interdune regions in deserts. The scale for all the invertebrates, 15-50 cm is the same as is found in the examples shown in Figures 8.1 and 8.2. Without closer examination identification of the traces is tenuous at best; the bulbous ends of the digger wasp of Figure 8.4 are, however, quite similar to the terminations visible in Figure 8.1, while Figure 8.4 is similar to the

Figure 8.1 Traces from facies C_4 at the west end of Browns Beach. Note bulbous ends on many of the burrows (arrow). Base of photo is approximately 1.5 m across.

Figure 8.2 Traces from the same location on Figure 8.3 Note the branching trace (arrow) similar to those in Figure 5A of Ahlbrandt et al. (1978). Outcrop is approximately 2 m across at base of photo.

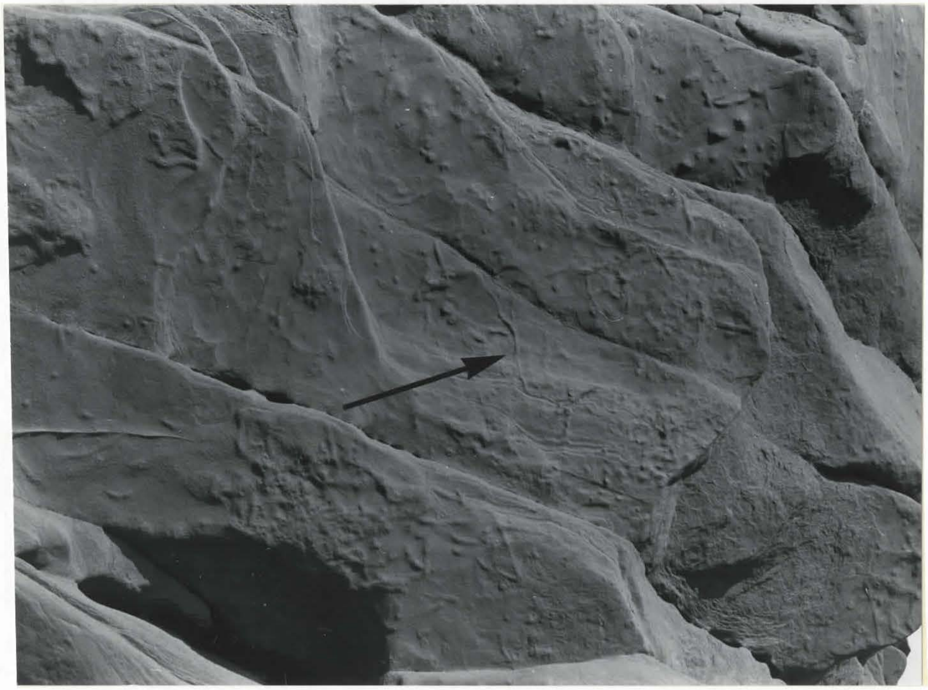
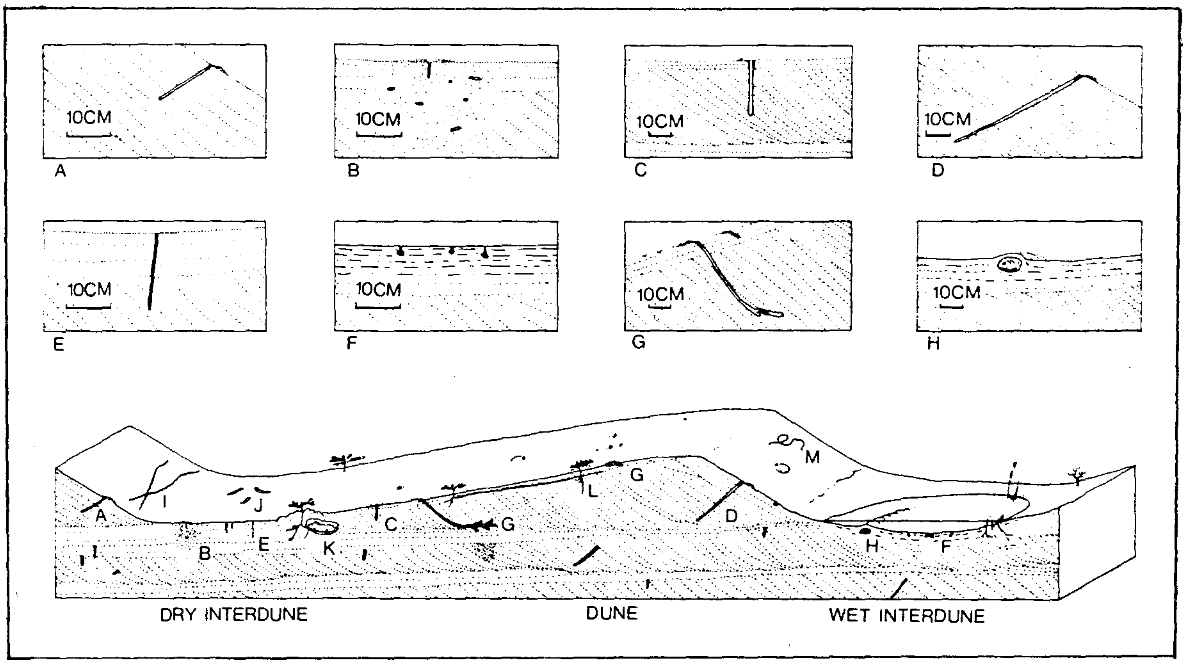


Figure 8.3 Diagram of commonly observed bioturbation traces in eolian deposits (block diagram not to scale): A. Beetle burrow, B. Burrowing and disruption of sediment by ants, C. Wolf spider burrow with web collar and reinforced burrow walls, D. Sand-treader camel cricket, in slipface deposit, with back-filled entrance, E. Tiger beetle larva burrow, F. Aestivating gastropods, G. From left to right, two trial burrows, a nesting burrow, and a sleeping burrow of a sand wasp, H. Toad burrow, I. Crane fly larva burrow, J. Root molds (dikaka), K. Gopher burrow with disruption of sediment by plant roots, M. A second type of crane fly larva burrow (from Ahlbrandt et al., 1978).

Figure 8.4 Examples of variation in digger wasp nesting burrows (Sphecidea): A. *Bembicinus neglectus*, B. *Sticta carolina*, C. *Bicyrtes fondiens*, D. *Microbembex monodonta*, E. *Alysson mellus*, F. *Hoplisoides nebulosus* (from Ahlbrandt et al., 1978).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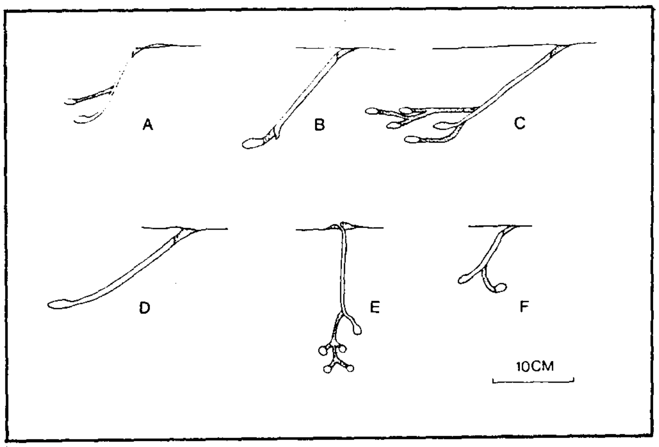
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curved trace in Figure of Ahlbnant et al (1980). The similarities are thought to be close enough to confirm that the markings were made by burrowing invertebrates, insects such as digger wasps and crane fly larvae.

In their discussion of the preservation of traces in dunes Ahlbrandt et al. (1978) noted that traces are preserved if: a) the sand is cohesive when burrowed, b) the organism reinforces the burrow with cement or, c) if the trace is rapidly buried. The rapid burial criteria fits the preferential preservation of traces on the slip faces rather than on the stoss sides of the dunes. Whether the sand was cohesive or the burrows were lined cannot be determined here, but the extensive reworking of the sediment would seem to indicate at least periodic wetting to allow the insects to survive.

There were also other isolated occurrences of traces in this formation which can be seen in the exposures at McCumber Point. Unfortunately the bedding planes on which these are exposed are situated at the back of the wave cut caves in the area which hampers both observation and photography. No description will be given other than to note that the traces occur on the surface of large ripples which then appear to have been covered by a mud drape, perhaps indicating a period of water ponding which allowed the invertebrates to move over the surface and the mud to settle out of suspension.

8.2.3 Echo Cove Formation:

8.2.3.1 Berry Beach Member: No trace fauna was found *in situ* in this member; however, in the rubble at the foot of the cliffs at Echo

Cove the sands of some of the redbeds did show traces, mainly vertical burrows, on some surfaces. The burrows appeared to be in medium sand, circular and 3-5 mm in diameter. Because of the limited amount present no environmental determination for these fauna was attempted.

8.2.3.2 Melvin Beach Member: This member has slightly more trace fauna than the lower member. They are present as calcite filled burrows in shales, Figure 8.5, which have irregularly shaped walls and cut through the sediment at an oblique angle, are up to 15 cm long and 7 mm wide, and are probably the result of a resting rather than a feeding burrow. Other, smaller, structures are relatively straight-walled, penetrate the sediment vertically and are 4-6 cm long and 2-3 cm wide. Most of the traces are preserved in the thickest bed of red shales.

One other bed with traces was found, in the middle of a parallel laminated sandstone unit. Once again it was situated at the back of a small cave where photography proved impossible. Two trails were seen, one formed a circular spiral with trace cutting itself one. The other was straighter but still undulatory. The former was 5-8 mm wide and the circle it formed approximately 30 cm in diameter. The latter was also the same width with a relief of 1-2 mm. Because of the uniformity of the sand and the weathering, the outcrop had undergone no details of the traces were preserved. Both trails end and start abruptly leading to the conclusion the animal was a deposit feed invertebrate. On discovering no organic matter on one bedding plane the feeding animal dug its way into another. The bedding planes above and below this particular one all showed current lineations. It is thought that these trails were

Figure 8.5 Calcite-filled burrow from red shales (facies D_2) of the Melvin Beach Member. Lens cap is 5.7 cm in diameter.

Figure 8.6 Large, branching calcareous tracing in breccias of Fishing Point Member of the Lepreau Formation, Photo taken approximately 150 m west of Fishing Point. Hammer for scale is 33 cm long.


Nikon

formed after deposition and probably prior to the deposition of the next unit which in this case is a breccia.

8.2.4 Lepreau Formation:

8.2.4.1 Fishing Point Member: Traces in this member are found in both the breccias and the fine sands. In the breccias there are a number of curious branching and curved calcareous deposits (Figure 8.6) which appear to lie in the same plane as the bedding (bearing in mind the difficulty in determining the bedding here). They were immediately taken for traces in the field, although they do not appear to incorporate any finer sediment in the calcite when viewed in thin sections. They occur associated with small lenses of finer sediment within the breccias and were observed to enter and exit the breccias seemingly at random. The size varies but is generally 6 cm wide and 2 cm deep giving them a rather ovoid cross-section. Whether this shape was primary or due to compaction could not be determined. The lack of any clastic grains in the limestone suggest that the traces were originally cavities formed after the sediment was deposited and subsequently infilled by percolating ground waters. The lack of any apparent vertical orientations of these traces was puzzling and the best suggestion as to their origin was given by J. Cortes (pers. comm.) who felt they may represent casts of branches which rotted after deposition, with the voids then filled by calcite. Given that trees such as pines existed at this time, this is a reasonable hypothesis which fits all known aspects of the traces.

In the fine grained sediment farther to the west, traces are only exposed on bedding planes which also have a thin veneer of mud preserved on the upper surface. It is the contrast between this mud and the underlying micaceous sands which shows up the traces. It was thought the massive nature of the beds of this unit may have been the result of bioturbation, but x-radiographs and thin sections cut through samples failed to show any signs of this activity.

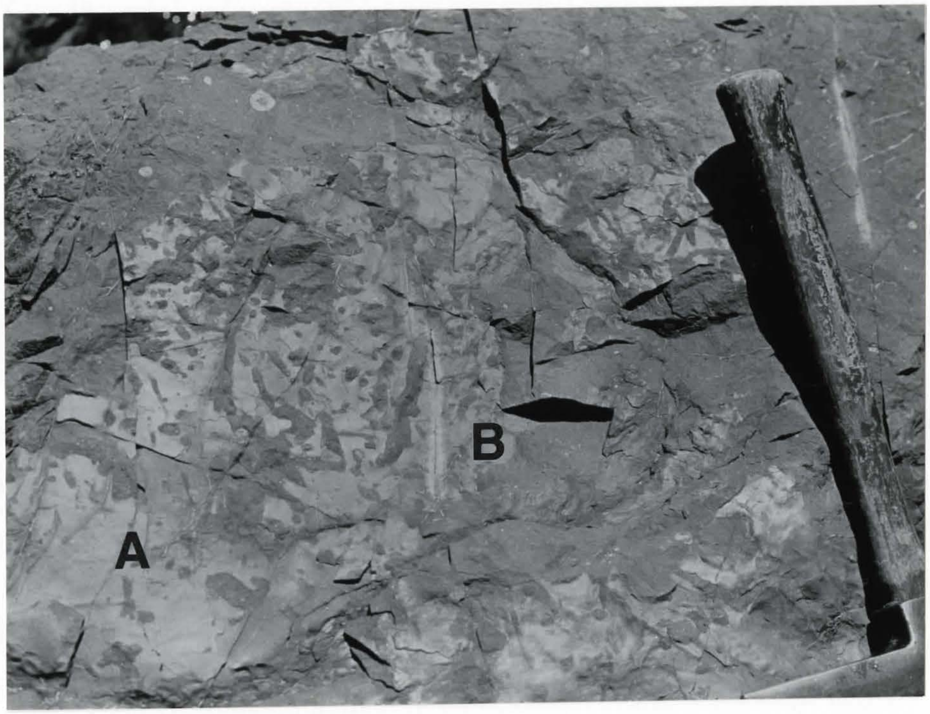
Because of the lack of contrast between the sediment composing these fine beds and that filling the burros and trails, no internal strutures were preserved. The morphology of the traces however was easily subdivided into two general categories; A) circular traces whose outlines were either irregular or smooth and approximately 1-2 cm in diameter and B) stubby oblong traces with two rounded ends which are 1.5 cm wide and vary from 5-15 cm long (Figure 8.7).

The circular burrows may either have been formed for shelter or may have been the passageways for larger deposit feeders which mined the lower sediment levels (see Stanley and Fagerstrom, 1974; Bromley and Asgaard, 1979). The shorter stubby traces are thought to represent either the accidental penetration of the animal through the sediment interface it was restricted to, or the bottom of U-shaped burrows which penetrated from above. From observations made in other sections within the same formation (but not the same member) the latter explanation is preferred.

8.2.4.2 Duck Cove Member: Most of the preserved traces found in the area were found in this member. The frequency and diversity was surprising given the arid climatic interpretation suggested most of the other evidence. In order to give a rough description of the types

Figure 8.7 Poorly preserved traces on the bedding plane surface of the massive sandstones of the Fishing Point Member. Hammer handle is 29 cm long.

Figure 8.8 Four types of traces on the upper surface of a coarse sandstone. Duck Cove Member of the Lepreau Formation. Photo taken at Lepreau Light. Quarter for scale.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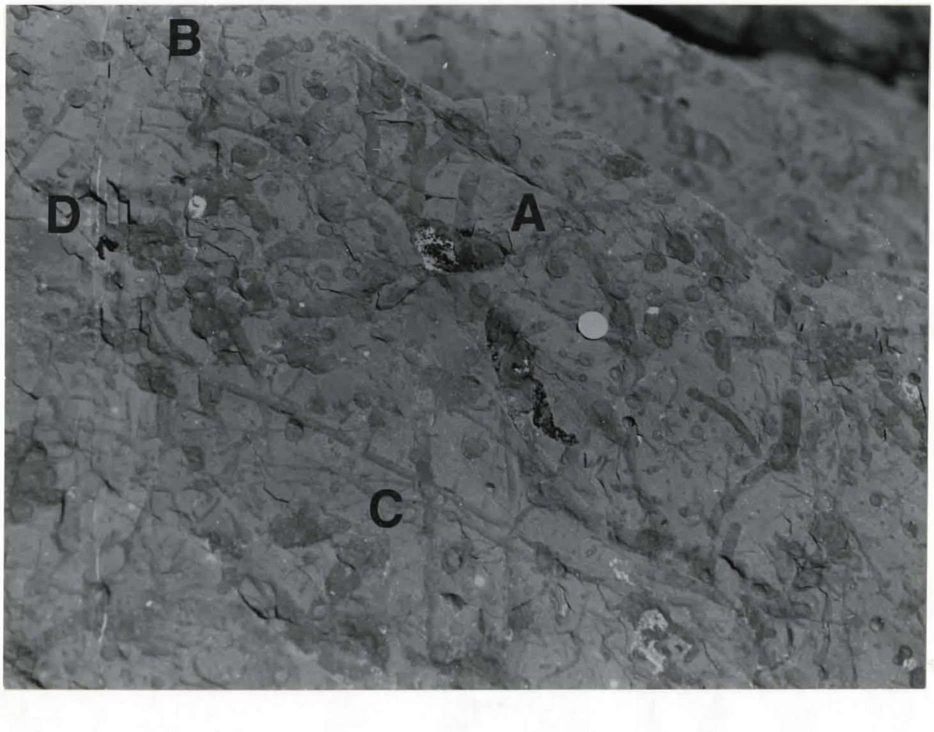
A


B
D
A
C

present each will be given a letter designation as in the previous member which will correspond to that shown on the accompanying plates.

A) Arcuate horizontal traces with sharp, distinct, and usually straight side walls and having doubly rounded ends (similar to type A in the previous section). Size ranges from 6.9-7 cm long and 1.2-1.7 cm wide with the latter giving a much stubbier, cigar-shaped appearance to the trace. They occur in both medium and coarse sands and are generally more prominent where there is a mud drape covering the bedding plane as with the previous examples. As with those found in the Fishing Point Member these are thought to be the bases of U-tubes (Figure 8.8).

B) Circular burrows ranging in size from 0.4-2.3 cm in diameter and usually found in association with trace A (Figure 8.8). The smaller samples are more nearly circular with the larger ones markedly asymmetric. These are numerically the most abundant traces, outnumbering all others by nearly 2:1. They are similar in shape to the trace B of the Fishing Point Member and were probably formed in the same way. The difference in sizes may either reflect differences in the body diameter of different species of insects, or it may be caused by the co-existence of different age populations of the same species (Stanley and Fagerstrom, 1974; Trewin, 1976).

C) Straight trails with sharp, distinct edges, up to 62 cm in length and 0.6 cm wide. The lengths but not the diameter varies in different examples. These appear to be too straight to be feeding trails and are probably made by invertebrates moving from one feeding location to another (Figure 8.9).

D) Small undulatory or Y-shaped traces with sharp, distinct walls and infilled with sediment similar to the surrounding rock. Widths vary from 0.29-0.38 cm and lengths from 9.2-11.5 cm. These appear from and disappear into other traces. This may be completely fortuitous but is is thought to indicate that they simply connect feeding traces (Figure 8.9).

All these traces occur in the same beds in medium to coarse sandstones. The best exposures are along the coast just south of the lighthouse at Point Lepreau. As indicated earlier the diversity does not necessarily imply species diversity but the number of traces present suggests the sediment was heavily reworked.

E) A roughly cyclindrical, calcite-filled burrow with rough walls which is curved toward the base. The example shown in Figure 8.9 is roughly 2.4-3.6 cm wide and at least 29 cm long. It was formed in red shales of facies D_1 and the infilling is a combination of coarse sand and calcite with the latter predominating. This is thought to be a resting burrow (domichnia).

F) Small cylinders which appear to be horizontal with doubly tapering ends and distinct straight walls similar to type A. Their length ranges from 2.9-4.4 cm and the width is fairly constant at 0.7 cm. The examples shown in Figure 8.10 were formed in coarse sand which had cut into medium sandstone with the traces highlighted by remnants of the underlying bed. The infilling of the burrows is the same as the surrounding sediment indicating formation by deposit feeders. The method of formation was probably the sames as for type A but the much coarser grain size in this

Figure 8.9 Burrow in red shales (Facies D_2) of the Duck Cove member of the Lepreau Formation. Photo taken approximately 100 m southeast of the reactor site. Hammer handle is approximately 28 cm long.

Figure 8.10 Traces exposed on the base of a block of coarse sandstone of the Duck Cove Member. Traces of highlighted by the presence of medium sand. Hammer head is 18 cm long.


E


F

case warranted its inclusion in a separate category.

G) Vertical to subvertical burrows with rounded ends, cut into facies D_2 and subsequently filled with coarse sands from the overlying facies A_6. The side walls are straight and smooth and, although the entire burrow is not visible, the length/width ratio in this exposure is remarkably constant at 4:1. The fine laminations of the shale to not appear to have been disturbed by whatever animal excavated the burrow (Figure 8.11). It would appear, therefore, that this was constructed as a resting rather than a feeding burrow, probably by an invertebrate which was accustomed to a subaerial rather than a subaqueous environment.

H) Cyclindrical, stubby, inclined traces with only one end exposed. The ends are well rounded and protrude from coarse into medium and fine sands. Those shown in Figure 8.12 are approximately 2 cm long and 0.5 cm wide. They are infilled with coarse sand and have sharply defined walls. These may be the remnants of burrows eroded by the influx of coarse sediment, or more likely, they were formed by organisms which were mining the organic matter out of the coarse sands and accidently penetrated the finer material in the process.

I) Trails which are preserved as epichnial grooves but which may or may not have the clay 'slick' associated with larger trails (type N). They are undulatory or Y-shaped with lengths up to 35.1 cm and widths varying from 0.7 to 0.9 cm (Figure 8.13).

J) Raised epichnial ridges with sharp but irregular boundaries, in a current lineated, medium grained sandstone. They occur as straight to arctuate or Y-shaped trails which intersect each other frequently. The

Figure 8.11 Burrow into redbeds (facies D_1) of the Duck Cove Member. Overlying bed is conglomerate with coarse sand matrix. Approximately two-thirds actual size.

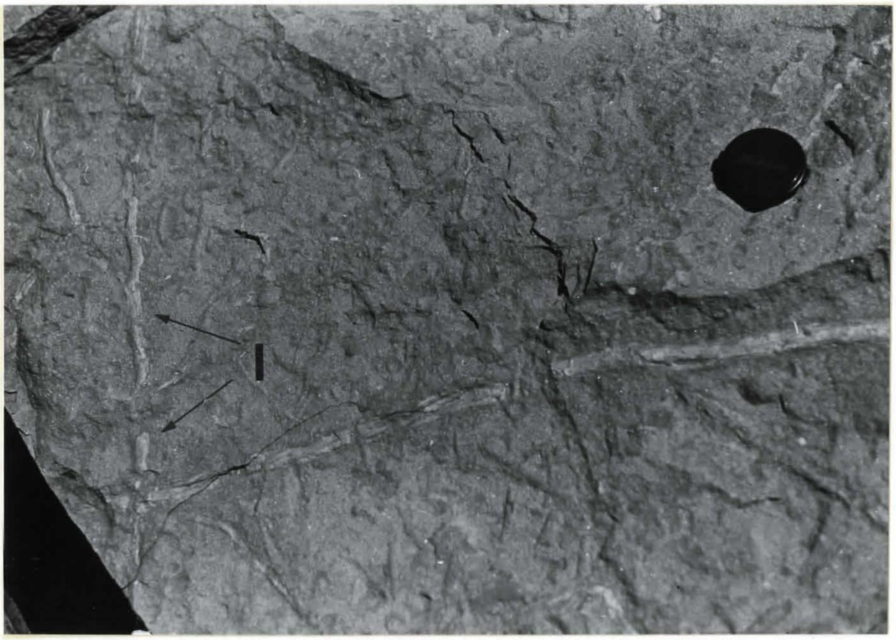
Figure 8.12 Burrows in the base of a coarse sandstone bed of the Duck Cove Member. Scale is 7 cm long


G


H

Figure 8.13 Small undolatory trails on the surface (?) of coarse sandstone of the Duck Cove Member. Note the presence of the clay 'slick' which enhances the trace. Lens cap is 5.7 cm in diameter. Location is the southeast end of Indian Cove.

Figure 8.14 Poorly preserved traces on the surfaces of parallel laminated medium grained sandstone of the Duck Cove Member. Location is approximately 100 m southeast of reactor site. Lens cap for scale.


I


J
Nikon

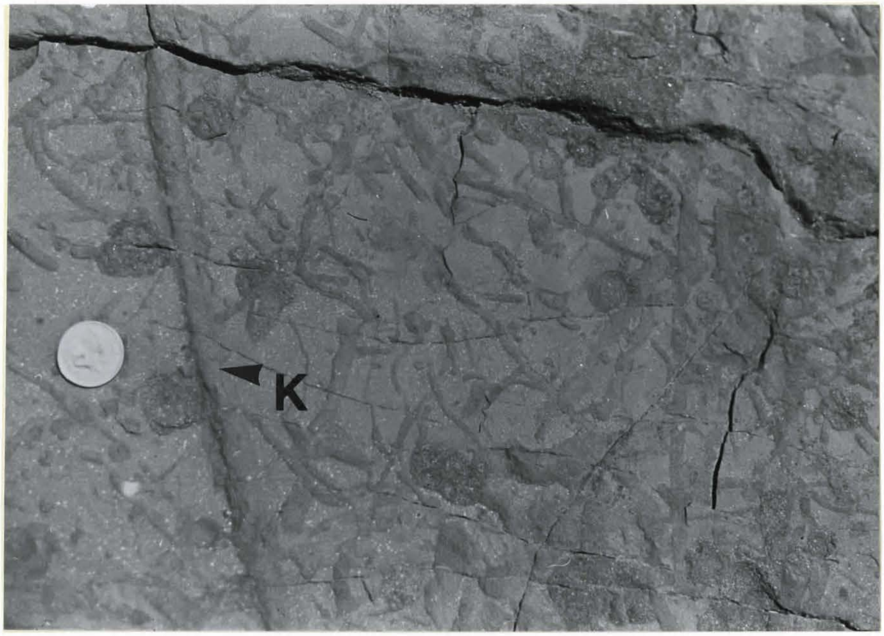
examples in Figure 8.14 vary from 10.8 to 13.5 cm in length and 0.7 to 1.4 cm in width. As is obvious from the photo the preservation of these traces is poor. The fact that they occur in sand similar to that with traces at Melvin Beach is, unfortunately, no assurance the same organism formed both sets.

K) A raised epichnial ridge, in the coarse sandstone facies (Figure 8.15). The length is 18.9 cm and the width is approximately 1.1 cm. The width is in the same range as type J and the extra length may simply be a function of preservation.

L) Horizontal to inclined feeding trails, forming a complex braided pattern in the coarse sand to which they are restricted. They vary from straight to undulatory and have a maximum length of 16.2 cm before being truncated by another trace of the same type. The widths are fairly uniform at 1.1 cm. Some of the traces have bulbous ends, especially where they penetrate the base of the sandstone. In the rocks where these are found the sediment tends to be completely bioturbated producing a massive sandstone. The evidence of bioturbation is apparent only on weathered surfaces because the sand infilling the burrows in the same as the matrix. Nevertheless the burrows stand out in relief on weathered surfaces indicating that they were probably agglutinated by secretions from the invertebrates as they pushed through the sand. Similar traces are found in identical rocks to the southeast of the Nuclear Power Plant, along the coast, where they form cylindrical burrows roughly 3.5 cm long and 0.4 cm wide (Figure 8.16). The presence of a completely bioturbated zone, produced presumably by only one type of invertebrate, indicates a

Figure 8.15 Large raised trail through coarse sand in the Duck Cove Member. Lens cap is 5.7 cm in diameter. Location is immediately south of Lepreau light. Quarter for scale.

Figure 8.16 Horizontal to inclined traces in coarse sandstone. Thes occur in the Duck Cove and Maces Bay Members and completely bioturbate the sediment. Lens cap (center right of photo) is 5.7 cm in diameter.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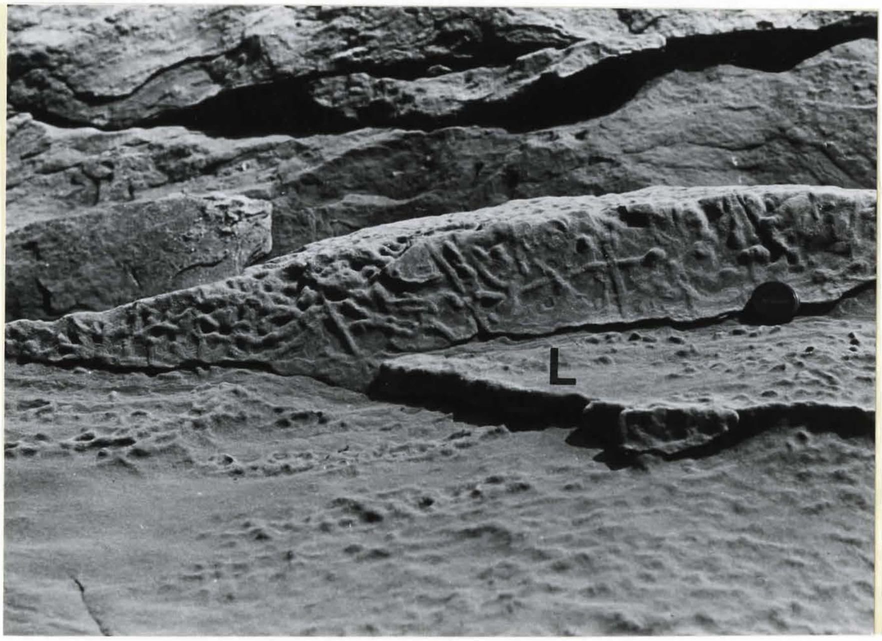
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rather harsh climate in which periodic influxes of water induce 'blooms' of life. The fact that the coarse sand was the one reworked may be because this sediment would lie in the bottom of the channels, probably covered with finer sediment. In this case the water would be kept in the sand longer and would retain the organic matter as well as remain mobile and damp enough to be reworked.

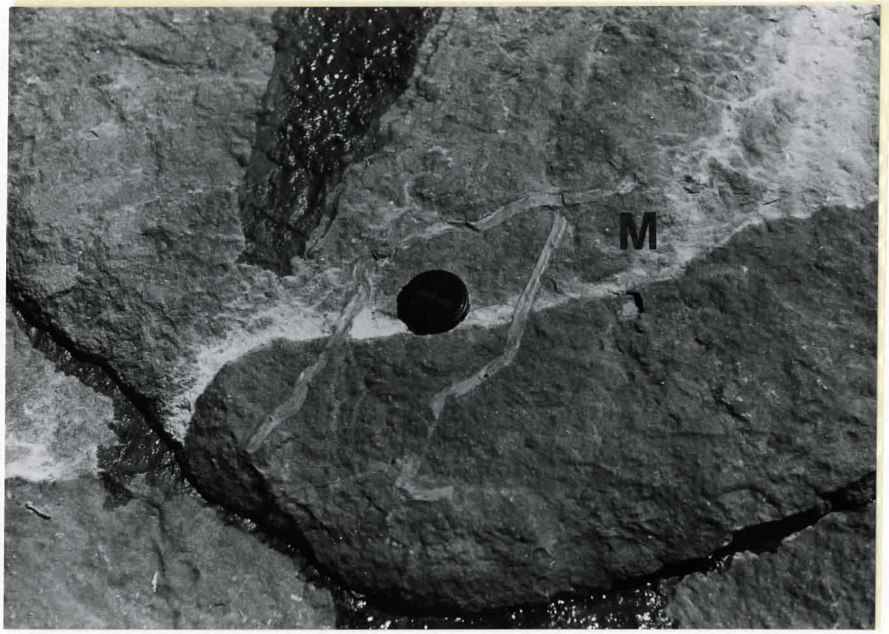
M) Arctuate, branching horizontal trails which are 2-3.3 cm wide and 3.3-39.6 cm long (Figure 8.17). These are probably a smaller version of type N.

N) Trails on the upper surfaces of coarse sands, which are picked out by striated clay 'slick' which covers the trace. These may be gently arcuate with sharp boundaries, and generally occur where the underlying sand has been bioturbated (given the amount of bioturbation in this member as a whole it would perhaps be surprising only if this did not occur). They are up to 4.1 cm wide and at least 3.5 m long. In all cases they are truncated by lack of exposures wide enough to view the entire trail. They are frequently cut by smaller traces of similar design and appearance. Most of the smaller traces, however, are undulatory or Y-shaped and 1.1-1.4 cm wide (Figure 8.18). It is not known what formed these trails or even if the animal was as wide as the trace or if this simply represents the drag marks of the tail or body of a small amphibian. No tracks were seen associated with these trails. They are best developed along the strike section on the east side of Indian Cove south of the Power Plant.

8.2.4.3 Maces Bay Member: This member contains sediments very

Figure 8.17 Curved and branching trails similar to type 1 in coarse sandstone of the Duck Cove Member at the south end of Indian Cove. Clay 'slick' preserves the trace. Lens cap for scale (5.7 cm in diameter).

Figure 8.18 Portion of a large (greater than 3 m long) trace in coarse sandstone of the Duck Cove Member. Same location as Figure 8.17. Lens cap for scale.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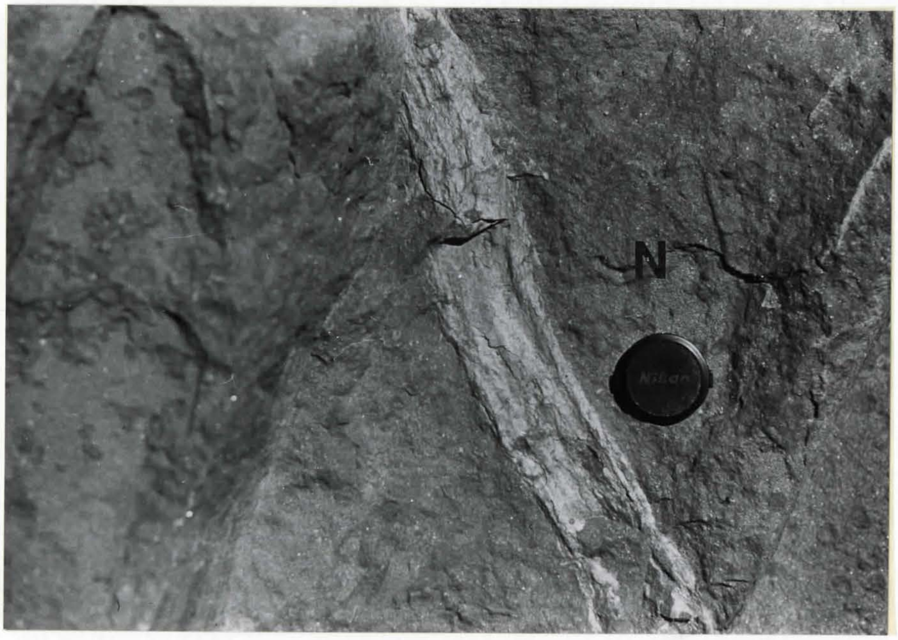
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similar to those of the Duck Cove Member, so the traces are the same as well. In particular, traces of type N and L are common although the former are generally smaller than can be found lower in the section and the latter are more restricted because of the decreasing amount of coarse sandstone further up-section. Cylindrical traces similar to type A and H are also found sporadically throughout this member.

In contrast to the breccias in the Fishing Point Member, no traces of any kind were seen in the breccias of this unit. These may be partly a function of the much poorer exposure of possible bedding plane surfaces in the coastal outcrops of this member.

8.2.5 Environmental Conclusions:

8.2.5.1 St. Martins: Because of the relative lack of traces throughout all three formations in this area definitive conclusions cannot be reached. In the lower formation the presence of abundant traces in probable eolian deposits shows that, while the climate was dry enough to form the dunes, there was enough moisture falling regularly to enable the various invertebrates (probably insects such as the modern sand wasp) to survive.

The traces present in the Melvin Beach Member are not common but they also show that if the climate was arid, there was still enough moisture for long enough periods to allow the growth of the organisms as well as form the red shale beds.

8.2.5.2 Lepreau Formation: Trace fauna are abundant throughout the Lepreau Formation. In the Fishing Point Member they are poorly preserved but the fact they are there at all was surprising. The low diversity of the traces, however, indicates a harsh climate which agrees with the petrographic data and facies analysis (Chapters 5 and 6). The Duck Cove Member which, from the facies analysis, appeared to be formed under a more humid climate than the basal member, contains the most abundant and diverse faunal assemblage. Although individual beds wre populated by relatively few species, this can probably be due to the periodic flooding of the river system rather than a harsh, semi-arid climate. Such flooding enables opportunistic species to repopulate areas quickly, before other species can become established. The traces in the Maces Bay Member are of the same variety as those in the Duck Cove Member and occur in the same facies as well.

From the trace fauna therefore it appears there was a more humid (or at least a less harsh) climate during the deposition of the Duck Cove Member. Whether or not this extends into the Maces Bay Member cannot be determined since there were no traces found in the breccias of the upper member.

8.3 Palynology:

As stated in the introduction to the St. Martins area, several pollen samples were taken from the Fownes Head Member of the Echo Cove Formation for analysis at the Bedford Institute of Oceanography.

Five samples were taken from the transition between the Fownes Head and Melvin Beach Members for analysis. Only the lowest was productive. One other sample contained plant debris (cuticular and wood fragments) but only rare bisaccate pollen which were not diagnostic (Bujak, pers. comm.) and three were barren. The remaining sample contained an abundant and diverse assemblage which was similar to the Chatham, Richmond, Taylorsville Groups of the Newark Supergroup described by Cornet (1977). Bujak (pers. comm.) found both striate and nonstriate bisaccates in the sample. Two of the striate species, Lunatisporites acutus Leschik and Striatoabietites aytugii Visscher, are present in the Carnian but not in the Norian assemblages. The presence of abundant nonstriate bisaccates along with the absence of species of Classopollis (present in the Lower Jurassic but absent below the Rhaetian) indicates a Middle-Late Carnian age for the sediments. This agrees with the earlier work of Holden (1913) who concluded the Triassic in southern New Brunswick was of Keuper age (equivalent to Carnian and Norian in North America; van Eysinga, 1978).

More detailed study of Fownes Head Member may be able to determine climatic variations in the sediments similar to those proposed for the southern U.S. basins of similar age by Cornet (1977, p. 61).

8.4 Correlation of St. Martins and Lepreau:

The only previous attempt to correlate the two basins was by Klein (1962, p. 1135) who stated that the two areas had similar conglomerates. No such similarity was found in this study. Nevertheless, the fact that both areas are the result of deposition on alluvial fans on the downthrown side of the same half graben and both begin and end with a semi-arid formation or member and have an intermediate 'pluvial' member, points to a possible correlation on physiographic and environmental grounds. The presence of mid-Late Triassic pollen from the Fownes Head Member and the Late Triassic footprints reported by Sarjeant and Stringer (1977) from the Lepreau Formation further substantiates this correlation. However, until the stratigraphic position of the redbeds along the Lepreau River can be established, or, until pollen can be obtained from the coastal exposures of the Lepreau Formation, such correlation will remain tentative.

Chapter Nine

Summary and Conclusions

The sediments in two small basins on either side of Saint John New Brunswick were studied but only the eastern basin, centered near St. Martins, were looked at in detail.

The St. Martins basin is divided into three formations (from base to top); the Honeycomb Point, Quaco and Echo Cove Formations. The basal formation was renamed and divided into two members. The Browns Beach Member is exposed in the western part of the basin. It consists of breccias interbedded with light red well-sorted sandstones. Although exposed only in disconnected fault blocks it is thought to be approximately 1,000 m thick. The lateral equivalent, the McCumber Point Member, is exposed in and around the town of St. Martins. This eastern member forms a coarsening and then fining upward sequence from medium grained sandstones into pebbly sandstones and back into medium sand. The total thickness exposed at St. Martins is approximately 925 m.

The Honeycomb Point Formation has an erosional upper contact and is overlain by the Quaco Formation (Klein, 1962). The conglomerates of the Quaco Formation are dominantly clast supported while the coarse sands are trough crossbedded. There is a slight fining upward trend which is accompanied by a change from clast to matrix support in the conglomerates. The formation varies from 190 m at Echo Cove to 380 m at Irish River. Additional outcrops of this formation were found in the western part of the basin which increased the lateral extent of the outcrop to at least 10 km.

The Quaco Formation is overlain by the Echo Cove Formation (Klein, 1962). In the western part of the basin the contact, although not exposed, is considered to be erosional because of the coarse nature of the overlying sediments in the area. These sediments, 1,350 m thick, composed of breccias and interbedded medium to coarse sandstones, form the Stony Brook Member of the Echo Cove Formation. Along the coast, east of St. Martins, this formation is divided into three members. Immediately overlying the Quaco Formation, with a gradational lower contact, are the red sands and shales of the Berry Beach Member which are approximately 170 m thick. The contact of this unit with the overlying Fownes Head Member is gradational. The Fownes Head Member consists of 570 m of gray-green sands, pebbly sandstones and conglomerates which contain abundant plant material. The upper contact is gradational into red breccias, sandstones and shales of the Melvin Beach Member. This unit is at least 170 m thick although the upper contact is faulted off against the Precambrian volcanics of the Caledonia Highlands.

The Lepreau Formation (Wright and Clements, 1943) is exposed along the coast from Dipper Harbour to the Little Lepreau Basin and inland in a narrow strip trending northeast from the mouth of the Lepreau River. Only the only the coastal section was examined. This series of sediments, 2,700 m thick, was divided into three members (from base to top); the Fishing Point, Duck Cove and Maces Bay Members.

The Fishing Point Member consists of deep red breccias which laterally grade into massive fine to medium grained sandstones. Although faulting is severe, the thickness is estimated to be approximately 350

m. The bottom contact is not exposed and the upper contact with the Duck Cove Member is erosional. The Duck Cove Member consists of a series of conglomerates, sandstones and shales. Only the latter have the same deep red hue found in the Fishing Point Member. The Duck Cove sediments gradually fine upward while the same time the number and thickness of shale increases. The total thickness of the unit is approximately 1,200 m. The upper contact is gradational and set at the first appearance of a clast supported breccia containing mainly cataclastically deformed sediments. The overlying Maces Bay Member consists of 1,175 m of sands and conglomerates (of the same type as the Duck Cove Member) and breccias. The latter thicken and coarsen upward until they form the entire unit. The upper contact is faulted against deformed Carboniferous sediments.

The facies analysis also concentrated on the St. Martins area. In general there were four main facies distinguished; conglomerates, breccias, sandstones and shale (Table 5.1). Each of these main types was further subdivided on the basis of grain size, lithology and/or structures present (Tables 5.2 to 5.6). The result of an integration of the facies analysis, paleocurrent data and petrographic studies was a re-interpretation of the environment of deposition.

In the Honeycomb Point Formation the breccias and sandstones of the Browns Beach and McCumber Point Members represent deposition on an alluvial fan. A general thinning and fining eastward of the breccias of the Browns Beach Member supports paleocurrent evidence from the McCumber Point Member which shows flow from the west. The sandstones which are interbedded with the breccias in the west, which, from petrographic (SEM) and structural data appear to be eolian, show a fairly uniform transport direction toward the southwest. This agrees closely with paleowind measurements in the Triassic of Nova Scotia.

The Quaco Formation was deposited by a major, north flowing gravelly river system. The clast lithologies indicate some were brought in from outside the basin (the banded quartzites) while others were probably derived from the western margin (the epidote clasts, for example). The lower half of the formation has paleocurrent data showing a northward flow while the upper half shows flow toward the northeast. This deflection is thought to be due to the renewal of fan building activity represented by the Echo Cove Formation.

In the western part of the basin the Stony Brook Member is interpreted as proximal fan deposits which are the lateral equivalent of at least the Berry Beach Member along the coast (but may include part of the Fownes Head Member). Paleocurrent data from the Berry Beach Member indicates flow from the west similar to the Honeycomb Point Formation. The overall coarsening upward sequence in this member is considered to be the result of progradation of the fan in response to uplift of the source area (with fault movement perhaps represented by the convolute laminations) and increased precipitation in the uplands. The latter resulted in the deposition of the gray-green beds of the Fownes Head Member.

Paleocurrent data in the Fownes Head Member show flow at the base was either north or south but further upsection this shifts progressively eastward until, by the upper contact, the braided river system which deposited these sediments was flowing almost due east. The sudden increase in grain size in the Melvin Beach Member is interpreted as the result of tectonic uplift of the source area and entrenchment of the fan. The flow directions are again almost due east with provenence of the breccias to the northwest of the town of St. Martins. A decrease in the amount of precipitation reaching the source area is indicated by the return of thick red shale beds and the lack of any plant fragments in the sandstones or breccias.

Pollen analysis of sediments from the upper portion of the Fownes Head Member yielded an age of Middle to Late Carnian. The suggested increase in precipitation during this time is consistent with deposits of similar age in the United States (Cornet, 1977).

The Lepreau Formation also consists of alluvial fan sediments. The breccias which make up the eastern end of the Fishing Point Member fine to the west and become a massive fine to medium grained sandstone. The granitic composition of all the clasts in the breccias and the general westward-fining trend taken together indicate transport from the north or northeast.

The Duck Cove Member erosionally overlies the finer sediments of the Fishing Point Member, and consists of conglomerates and sandstones of a large braided river system. Here, too, there is a change in colouration of the redbeds with only the shales in the Duck Cove Member as red as the sediments of the lower member. Paleocurrent data suggests flow from the north. The large number of trace fossils present throughout the entire member may indicate the climate was fairly humid. The general fining upward trend of the member (shown by the increase in number and thickness of shales) appears to have been accompanied by an increase in aridity, resulting in the formation of caliche deposits.

South of the Welsh Cove wharf the first clast supported breccias of the Maces Bay Member appear. These breccias consist dominantly of dark brown, cataclastically deformed Carboniferous sediment clasts. The lower half of the upper member contains sandstones and conglomerates which are similar in lithology and trace fossil content to the Duck Cove Member. Throughout the Maces Bay Member, however, the breccias continue to thicken and coarsen upward as the result of progradation of an alluvial fan dominated by deposition from debris flows. Flow directions appear to be from the northeast, similar to the underlying units.

No correlation of the two basins was possible. Although there are indications of a more humid interval separating arid climates in both areas and the Duck Cove and Fownes Head members may be coeval there is no proof, either lithological or palynological.

Deposition of these sediments was controlled to a large degree by the tectonics of the region, on both a large and small scale. The Fundy Basin, which extends into the Gulf of Maine, is a half graben with the flexure in Nova Scotia and the faulted margin close to the south shore of New Brunswick. The westerly paleoslope imposed on the area by this structure was responsible for confining the major north-flowing river system (which deposited the Quaco Formation) to the western part of the basin.

On a much larger scale, this basin was considered to be one of a series of grabens and half-grabens which stretched from South Carolina to offshore Newfoundland which began opening in the south during Mid-Late Carnian time. Pollen analysis from the Fownes Head Member, however, indicates the Fundy Basin is as old as the most southerly of the basins in the U.S. It is therefore suggested that there are in fact two rift systems. Both opened along the same line of weakness in the supercontinent (probably formed during the collision of Africa and North America in the Devonian). Both rifts began opening at their southern ends during the Middle to Late Carnian and gradually created new basins farther to the north (see Figure 2.14). The southern and northern boundaries of the U.S. rift are the Cape Fear-Cape Verde and the Kelvin-Canary Fracture Zones while the limits of the Canadian rift were controlled by the Kelvin-Canary Fracture in the south and the Newfoundland Fracture Zone in the north. This explains the lateral offset between the basins in the northeastern U.S. and southwestern Maritimes and why the same basins in the northern states, which are mostly Jurassic, do not contain any Triassic evaporites, which are present in the more easterly basins in Canada. The upward doming of the region around the Kelvin Fracture Zone due to the presence of a mantle hot spot created regional slopes to the south in the northern U.S. basins and to the north in the Fundy Basin which are reflected by the paleocurrent data.

By the end of the Triassic the spreading center shifted eastward and formed another, subparallel, series of basins along what is now the shelf edge. The limits of these basins appear to be the Newfoundland Fracture Zone in the north and the Bahamas-Guinea Fracture Zone in the south. The Kelvin-Canary and Cape Fear-Cape Verde Fracture Zones were apparently inactive by this time. This shift caused deformation of the older basins (now acting as part of the passive margin) and renewed basin subsidence in some cases. These shelfbreak basins contain mostly Jurassic evaporites and marine sediments. A final eastward shift in the spreading center to its present position caused further deformation in both series of basins to the west.

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Table: A-1

Formation: Honeycomb Point (McCumber Point Member)

Location: McCumber Point (180^{o} indicators weighted to the NW)

θ^{o}	n	$n\cos\theta^{o}$	$n\sin\theta^{o}$	type
10				
30	1.0	0.8661254	0.5	cur. cresents
50				
70	2.76	0.9439756	2.5935516	ripples
90				
110	2.0	-0.6840403	1.8793852	imbrication
130	1.0	-0.6427876	0.7660444	flutes
150	1.88	-1.6281278	0.94	imbrication
170				
190				
210				
230				
250	1.0	-0.3420201	-0.9396926	cur. lineation
270	3.02	0.0	-3.02	grooves
290	2.0	0.6840403	-1.8793852	1 cur. lineation 1 groove
310	4.91	3.1560872	-3.7612782	cur. lineation
330				
350	4.45	4.3823945	-0.7727344	troughs
N	24.02	6.7355472	-3.6941142	

$\tan\theta = -0.5484505$ $\theta = 331^{o}$

$R = (n\cos^{2} + n\sin^{2})^{\frac{1}{2}} = 7.68$

$L = R/N \times 100 = 32\%$

Table: A-2

Formation: Honeycomb Point (McCumber Point Member)

Location: McCumber Point (180^{0} indicators weighted to the NE)

θ^{0}	n	$n\cos\theta^{0}$	$n\sin\theta^{0}$	type
10				
30	1.0	0.8660254	0.5	cur. cresents
50				
70	3.76	1.2859957	3.5332443	2.76 ripples 1 cur. lineation
90	3.02	0.0	3.02	grooves
110	4.0	-1.3680806	3.7587705	1 cur. lineation 1 groove 2 imbrication
130	5.91	-3.7988748	4.5273227	1 flute 4.91 cur. lin.
150	1.88	-1.6281278	0.94	imbrication
170				
190				
210				
230				
250				
270				
290				
310				
330				
350	4.45	4.3823945	-0.7727344	troughs
N	24.02	-0.2606676	15.506603	

$\mathrm{Tan}\theta = -59.488034$ $\theta = 91^{0}$

R = 15.51

L = 64.6%

Table: A-3

Formation: Quaco

Location: Echo Cove (lower half of formation)

θ^o	n	$n\cos\theta^o$	$n\sin\theta^o$	type
10	10.49	10.326694	1.82087	troughs
30				
50				
70				
90	1.0	0.0	1.0	groove
110				
130				
150				
170				
190				
210				
230				
250				
270				
290				
310				
330				
350				
N	11.486	10.326694	2.82087	

$\tan\theta = 0.2731629$ $\theta = 15.3^o$

$R = 11.04$

$L = 96.1\%$

Table: A-4

Formation: Quaco

Location: Echo Cove (upper half of formation)

θ^o	n	$n\cos\theta^o$	$n\sin\theta^o$	type
10				
30				
50	7.84	5.0394549	6.0057884	5.84 cur. lin. 2 planar X-beds
70				
90				
110				
130				
150				
170				
190				
210				
230				
250				
270				
290				
310				
330				
350	1.0	0.9848078	-0.1736482	ripples
N	8.84	6.0242626	5.8321402	

$\tan\theta = 0.9681086$ $\theta = 44.1^o$

R = 8.38

L = 94.9%

Table: A-5

Formation: Echo Cove (Berry Beach Member)

Location: West end of Berry Beach

θ^o	n	$n\cos\theta^o$	$n\sin\theta^o$	type
10				
30				
50				
70	1.0	0.3420201	0.9396926	troughs
90	1.33	0.0	1.33	flutes
110	3.7	-1.2661586	3.4787421	grooves
130				
150	1.88	-1.6281278	0.9295	cur. lineation
170				
190				
210				
230				
250	1.0	-0.3420201	-0.9396926	ripples
270				
290				
310				
330				
350				
N	8.91	-2.8942863	5.7382221	

$\tan\theta = -1.9826214$ $\theta = 116.8^o$

R = 6.42

L = 72.1%

Table: A-6

Formation: Echo Cove (Berry Beach Member)

Location: West end of Berry Beach

θ^o	n	$n\cos\theta^o$	$n\sin\theta^o$	type
10				
30				
50				
70				
90				
110				
130				
150	3.8	-3.2934946	1.9	cur. lineation
170				
190				
210				
230				
250				
270				
290				
310				
330				
350				
N	3.8	-3.2934946	1.9	

$\tan\theta = -0.5773503$ $\theta = 150^o$

$R = 3.8$

$L = 100\%$

Table: A-7

Formation: Echo Cove (Fownes Head Member)

Location: Lower contact to unnamed beach (weighted to the SE)

θ^{o}	n	$n\cos\theta^{o}$	$n\sin\theta^{o}$	type
10				
30				
50				
70	4.95	1.6929997	4.6514785	3.95 troughs 1.0 ripples
90				
110				
130				
150	2.96	-2.5634352	1.48	180^{o} troughs
170				
190	8.4	-8.2723851	-1.4586447	cur. lineation
210				
230				
250				
270				
290				
310				
330				
350				
N	16.31	-9.1428206	4.6728338	

$\tan\theta = -0.5110932$ $\theta = 153^{o}$

R = 10.3

L = 63%

Table: A-8

Formation: Echo Cove (Fownes Head Member)

Location: Lower contact to unnamed beach (weighted to the N)

θ^o	n	$n\cos\theta^o$	$n\sin\theta^o$	type
10	8.4	8.2723851	1.4586447	cur. lineation
30				
50				
70	4.95	1.6929997	4.6514785	3.95 troughs 1.0 ripples
90				
110				
130				
150				
170				
190				
210				
230				
250				
270				
290				
310				
330	2.96	2.5634352	-1.48	180^o troughs
350				
N	16.31	12.52882	4.6301232	

$\tan\theta = 0.3695578$ $\theta = 20.3^o$

R = 13.4

L = 81.9%

Table: A-9

Formation: Echo Cove (Fownes Head Member)

Location: Unnamed beach to flower pot

θ^o	n	$n\cos\theta^o$	$n\sin\theta^o$	type
10				
30				
50				
70				
90				
110	1.0	-0.3420201	0.9396926	180^o troughs
130	14.73	-9.4682615	11.283835	troughs
150	1.53	-1.3250189	0.765	cur. lineation
170				
190				
210				
230				
250				
270				
290				
310				
330				
350				
N	17.26	-11.135301	12.988527	

$\tan\theta = -1.1664281$ $\theta = 130.6^o$

$R = 17.1$

$L = 99.1\%$

Table: A-10

Formation: Echo Cove (Fownes Head Member)

Location: Flower pot to upper contact

θ^{o}	n	$n\cos\theta^{o}$	$n\sin\theta^{o}$	type
10				
30				
50				
70				
90	5.83	0.0	5.83	troughs
110				
130	2.53	-1.6262527	1.9380924	cur. lineation
150				
170				
190				
210				
230				
250				
270				
290				
310				
330				
350				
N	8.36	-1.6262527	7.780924	

$\text{Tan}\theta = -4.7766822$ $\theta = 101.8^{o}$

$R = 7.9$

$L = 04.9\%$

Table: A- 11

Formation: Echo Cove (Melvin Beach Member)

Location: Melvin Beach

θ^o	n	$n\cos\theta^o$	$n\sin\theta^o$	type
10				
30				
50	1.0	0.6427876	0.7660444	imbrication
70	2.89	0.9884382	2.7157117	grooves
90				
110	8.5	-1.4760095	7.9873873	cur. lineation
130				
150				
170				
190				
210				
230				
250				
270				
290				
310				
330				
350				
N	12.39	0.1552163	11.469143	

$\tan\theta = 73.891353$ $\theta = 89.2^o$

$R = 11.47$

$L = 92.6\%$

Table: B-1

Fromation: Quaco

Location: West side of St. Martins harbour, south of Irish River dam

Description: A-axis orientations of clasts plotted in direction of dip of AB plane and calculated as other current vectors.

o	n	ncos o	nsin o
10	4	3.39231	0.6945927
30	3	2.5980762	1.5
50	2	1.2855752	1.5320889
70	4	1.3680806	3.7587705
90			
110	2	-0.6480403	1.8793852
130			
150	6	-5.1961524	3.0
170			
190	2	-1.9696155	-0.3472964
210	4	-3.4641016	-2.0
230	9	-5.7850885	-6.8944
250	5	-1.7101007	-4.6984631
270	2	0.0	-2.0
290	1	0.3420201	-0.9396926
310	3	1.9283628	-2.2981333
330	2	1.7320508	-1.0
350	1	0.9848079	-0.1736482
N	50	-4.6308945	-7.9867963

Tan = 1.72467 = 59.9 + 180 = 239.9^{o}

R = 9.23

L = 18.5%

Table: B-2

Formation: Quaco

Location: West side of St. Martins harbour

o	n	ncos o	nsin o
10			
30	2	1.7320508	1.0
50	1	0.6427876	0.7660444
70	3	1.0260604	2.8190779
90	1	0.0	1.0
110			
130	4	-2.5711504	3.0641778
150	2	-1.7320508	1.0
170	2	-1.9696155	0.3472964
190	1	-0.9848078	-0.1736482
210	1	-0.8660254	-0.5
230			
250			
270			
290	1	0.3420201	-0.9396926
310	1	0.6427876	-0.7660444
330			
350	2	1.9696155	-0.3472964
N	21	-1.7683278	7.2699148

Tan = -4.1112 = 103.7^{o}

R = 7.48

L = 35.6%

Table: B-3

Formation: Quaco

Location: Echo Cove, 40 m below upper contact

o	n	ncos o	nsin o
10	1	0.9848078	0.1736482
30			
50			
70			
90	1	0.0	1.0
110	2	-0.6840403	1.8793852
130	2	-1.2855752	1.5320889
150	2	-1.7320508	1.0
170	1	-0.9848078	0.1736482
190	1	-0.9848078	-0.1736482
210			
230	3	-1.9283628	-2.2981333
250	1	-0.3420201	-0.9396926
270	3	0.0	-3.0
290	2	0.6840403	-1.8793852
310			
330	1	0.8660254	-0.5
350			
N	20	-5.4067913	-2.0923963

Tan = 0.3869941 = 201.2^{o}

R = 5.8

L = 29%

Table: B-4

Formation: Quaco

Location: East side of St. Martins harbour

o	n	ncos o	nsin o
10			
30	1	0.8660254	0.5
50			
70			
90	1	0.0	1.0
119			
130			
150			
170			
190	1	-0.9848078	-0.1736482
210	1	-0.8660254	-0.5
230	2	-1.2855752	-1.5320889
250			
270	1	0.0	-1.0
390			
310			
330			
350			
N	7	-2.270383	-1.7057372

Tan = 0.7512993 = 217^{o}

R = 2.84

L = 40.6%

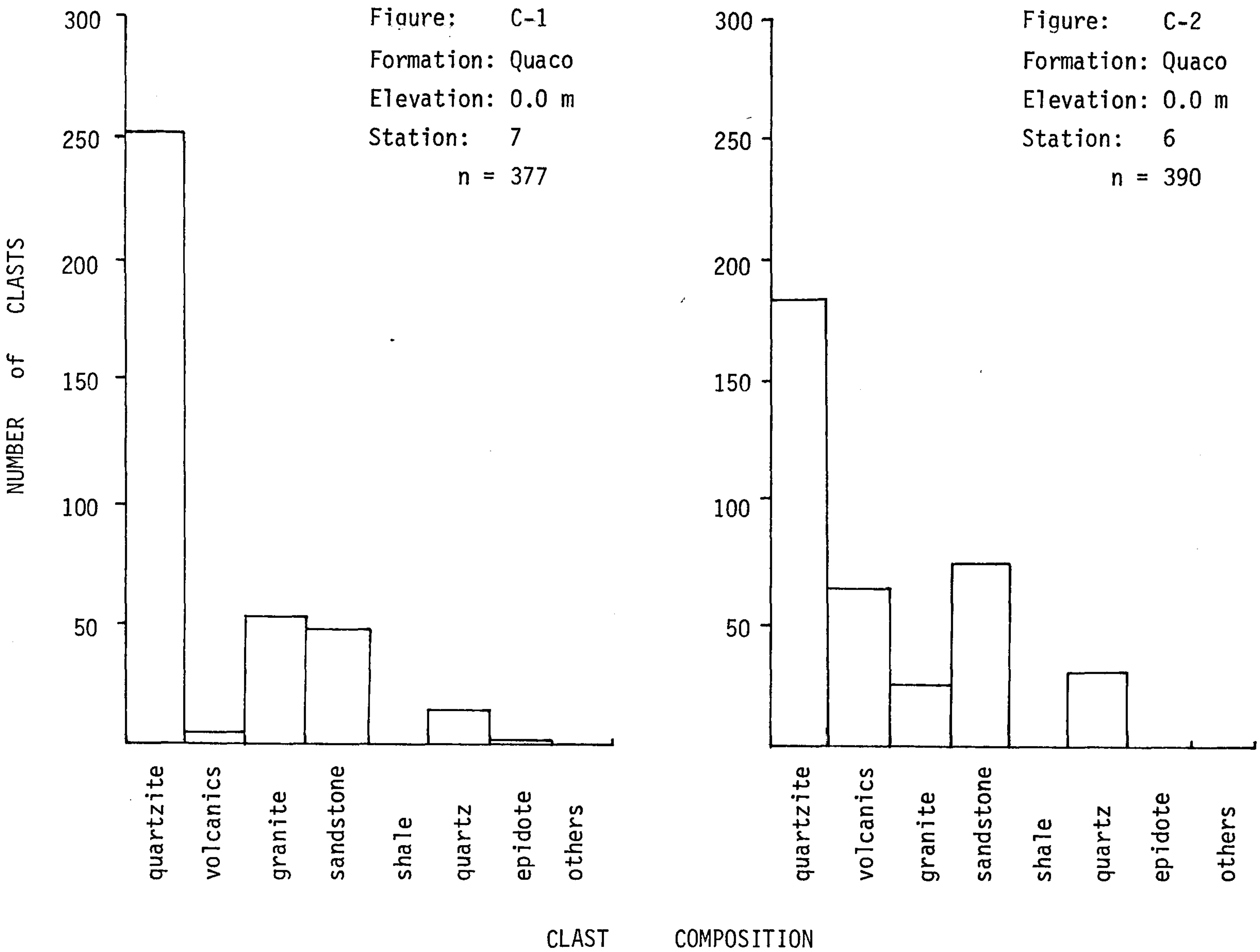


Figure: C-1
Formation: Quaco
Elevation: 0.0 m
Station: 7
n = 377
Figure: C-2
Formation: Quaco
Elevation: 0.0 m
Station: 6
n = 390
NUMBER of CLASTS
300
250
200
150
100
50
quartzite
volcanics
granite
sandstone
shale
quartz
epidote
others
CLAST COMPOSITION

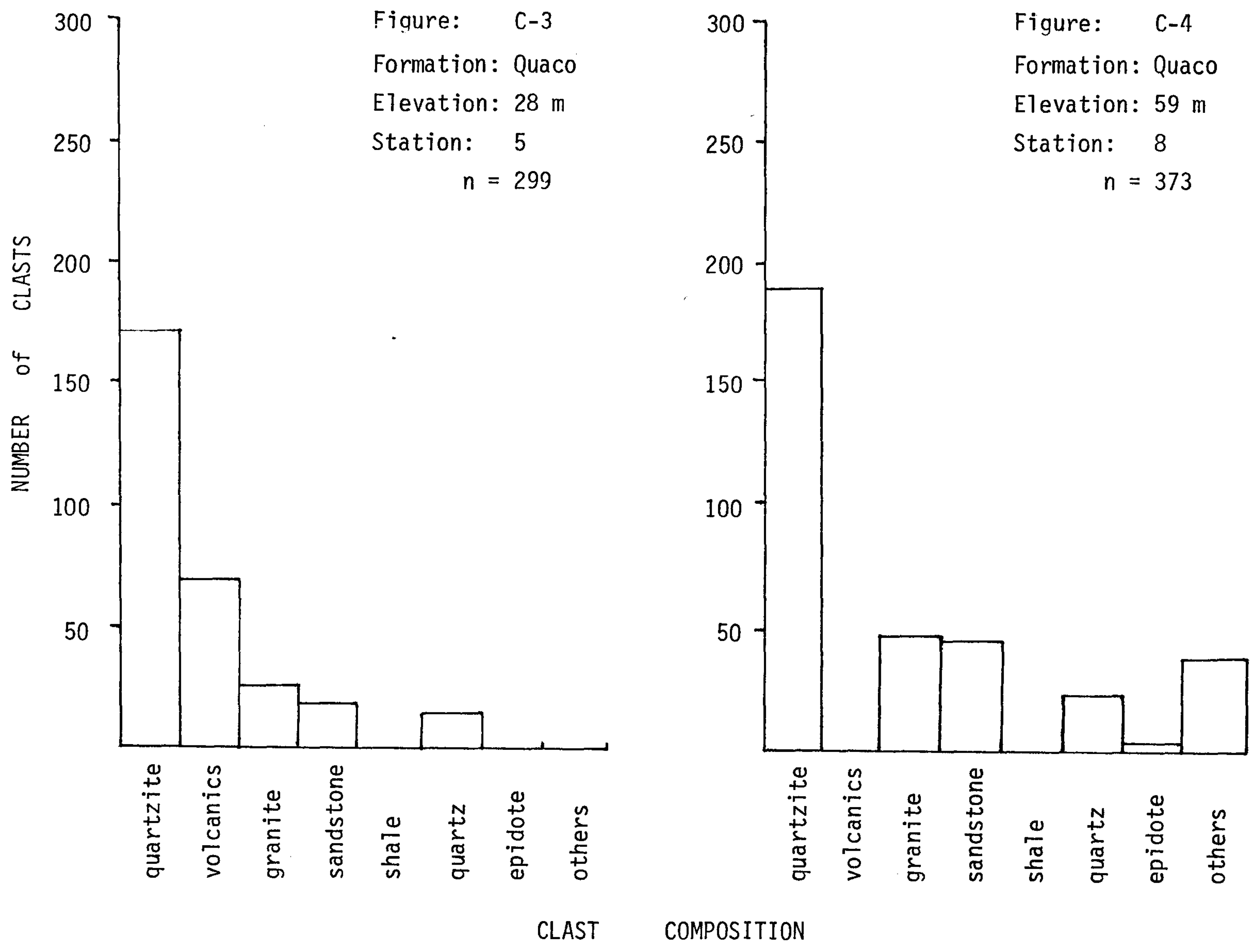


Figure: C-3
Formation: Quaco
Elevation: 28 m
Station: 5
n = 299
Figure: C-4
Formation: Quaco
Elevation: 59 m
Station: 8
n = 373
NUMBER of CLASTS
300
250
200
150
100
50
quartzite
volcanics
granite
sandstone
shale
quartz
epidote
others
CLAST COMPOSITION

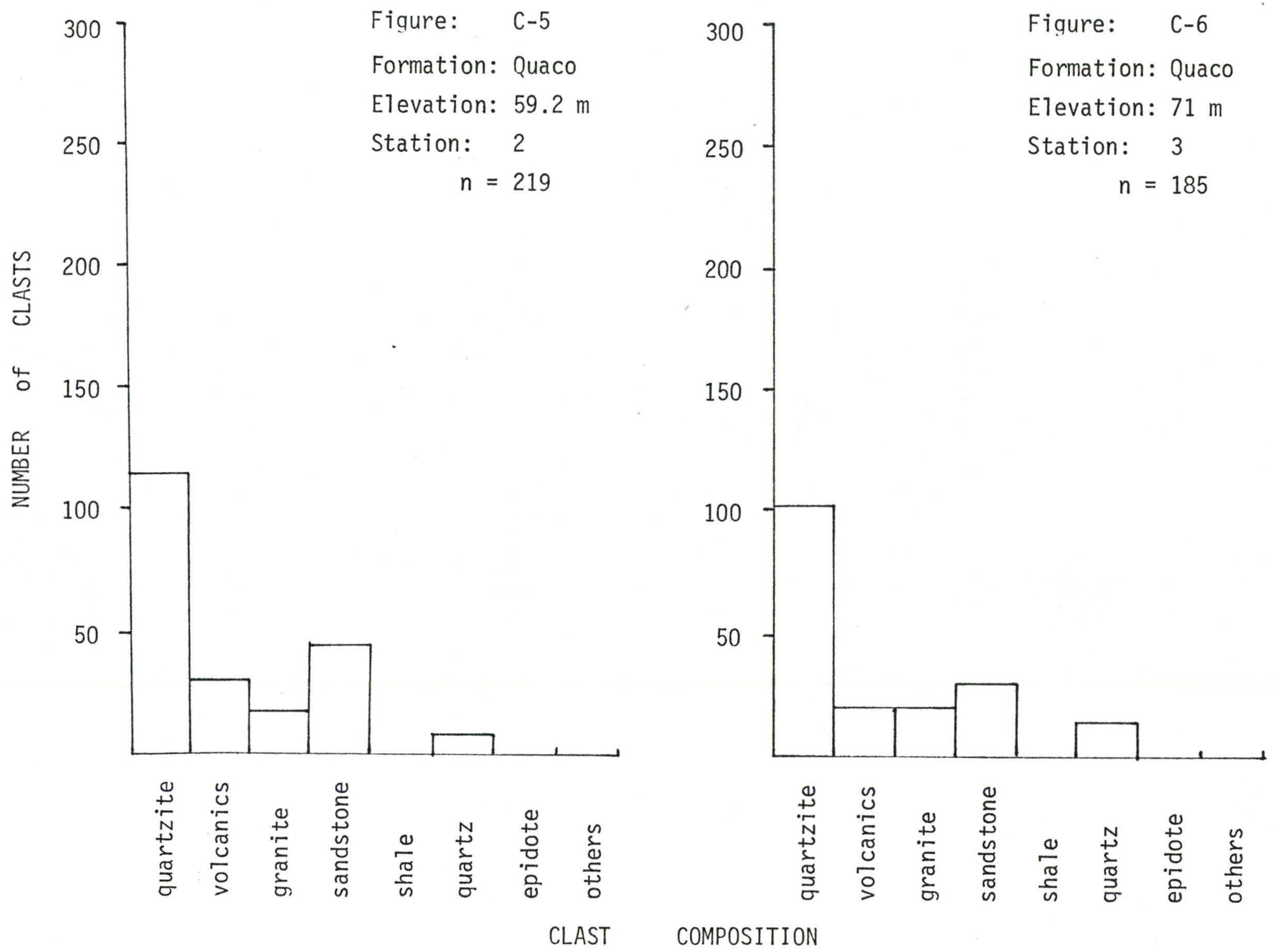
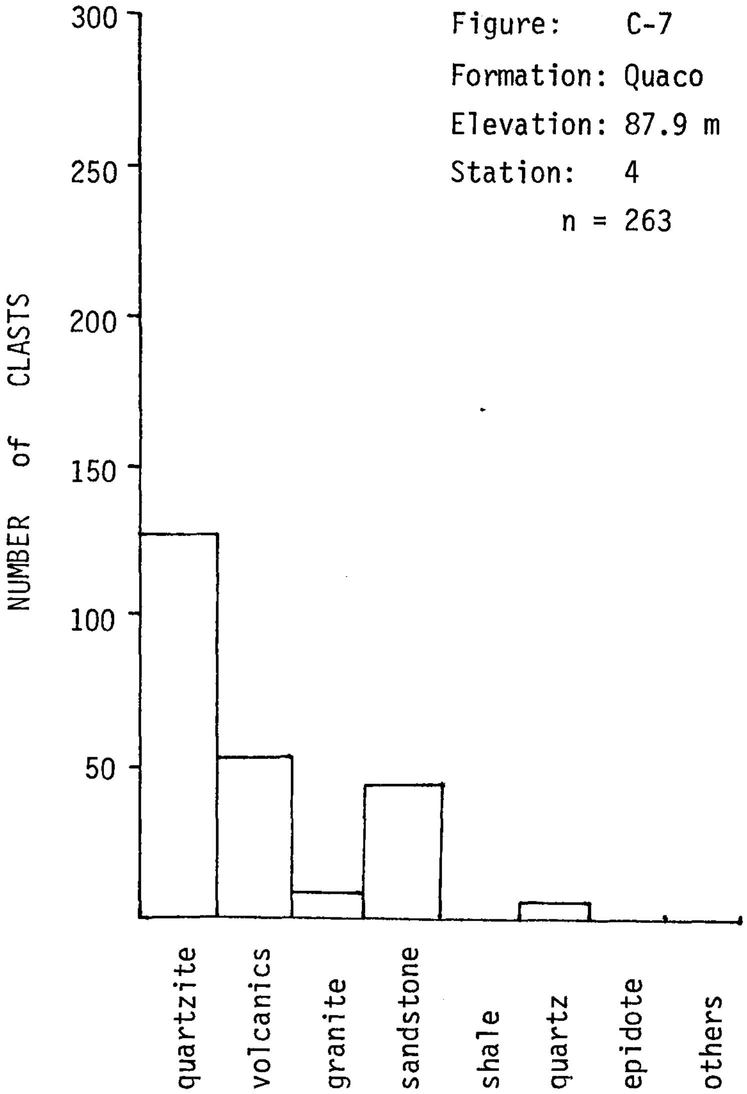
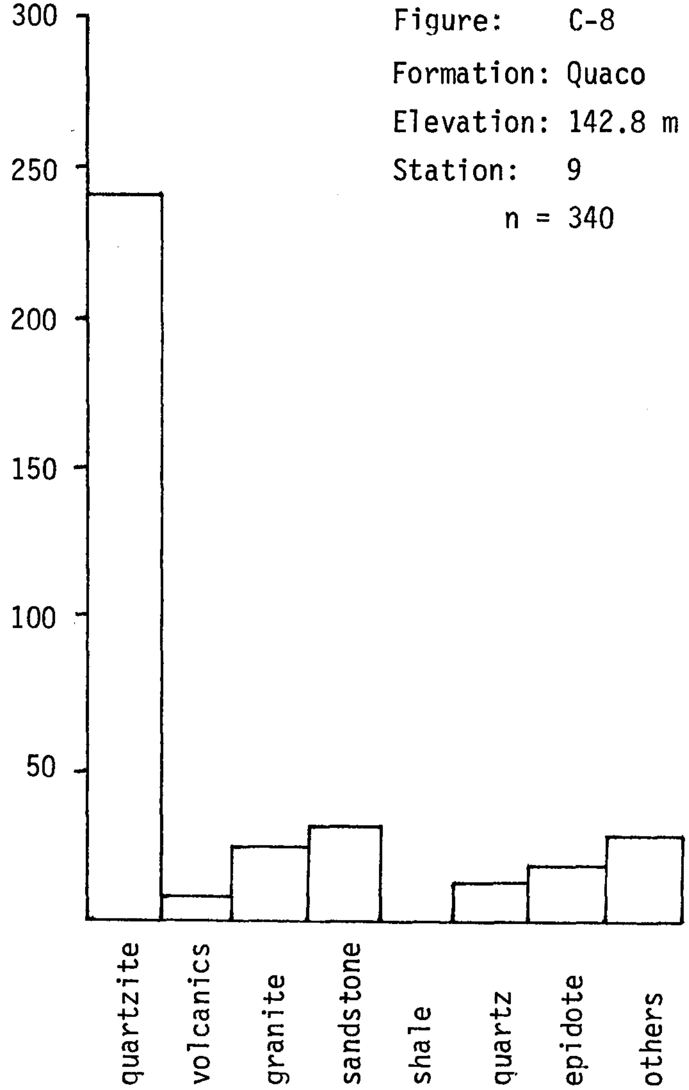


Figure: C-5
Formation: Quaco
Elevation: 59.2 m
Station: 2
n = 219
Figure: C-6
Formation: Quaco
Elevation: 71 m
Station: 3
n = 185
NUMBER of CLASTS
300
250
200
150
100
50
quartzite
volcanics
granite
sandstone
shale
quartz
epidote
others
CLAST COMPOSITION





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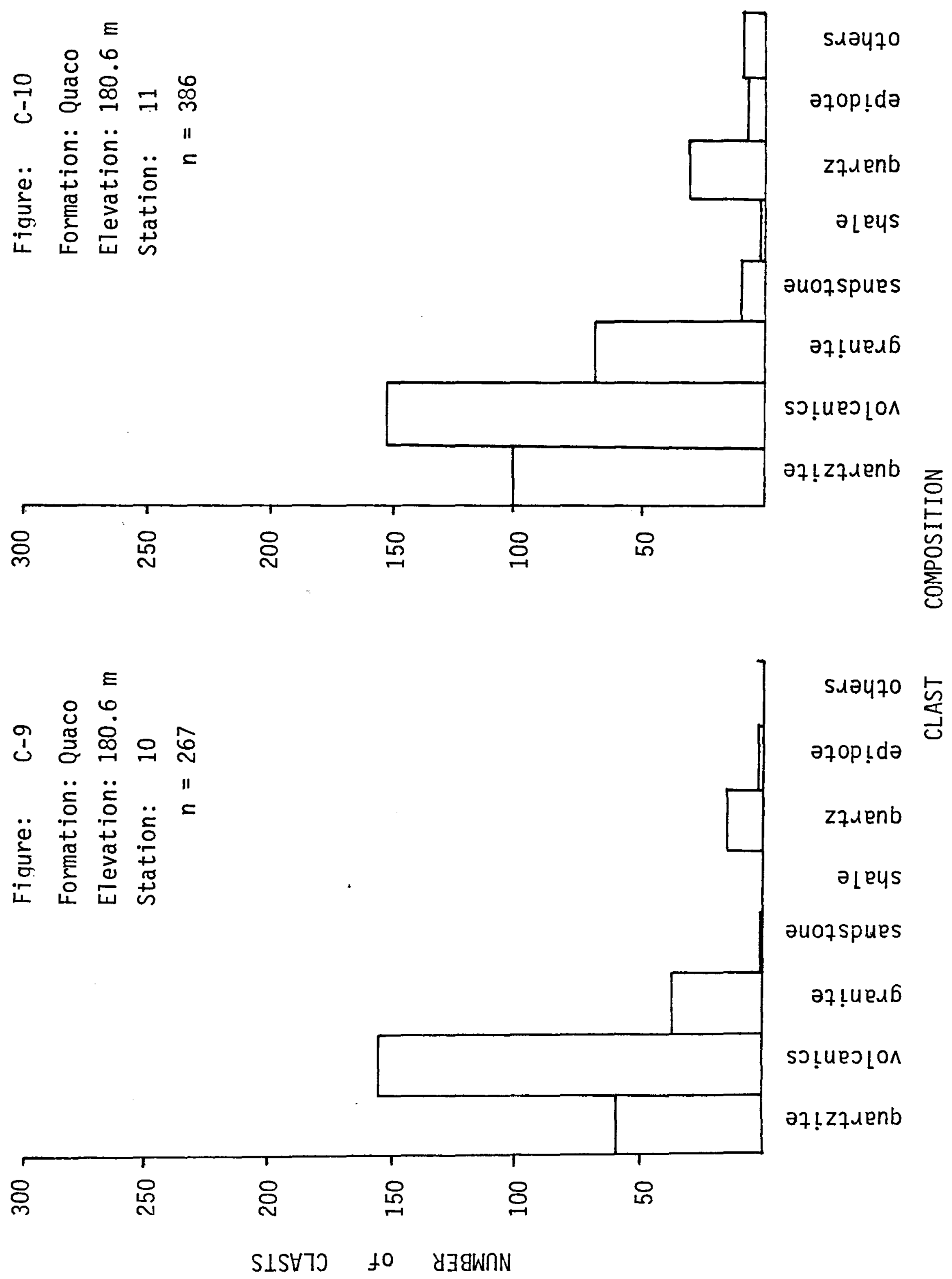
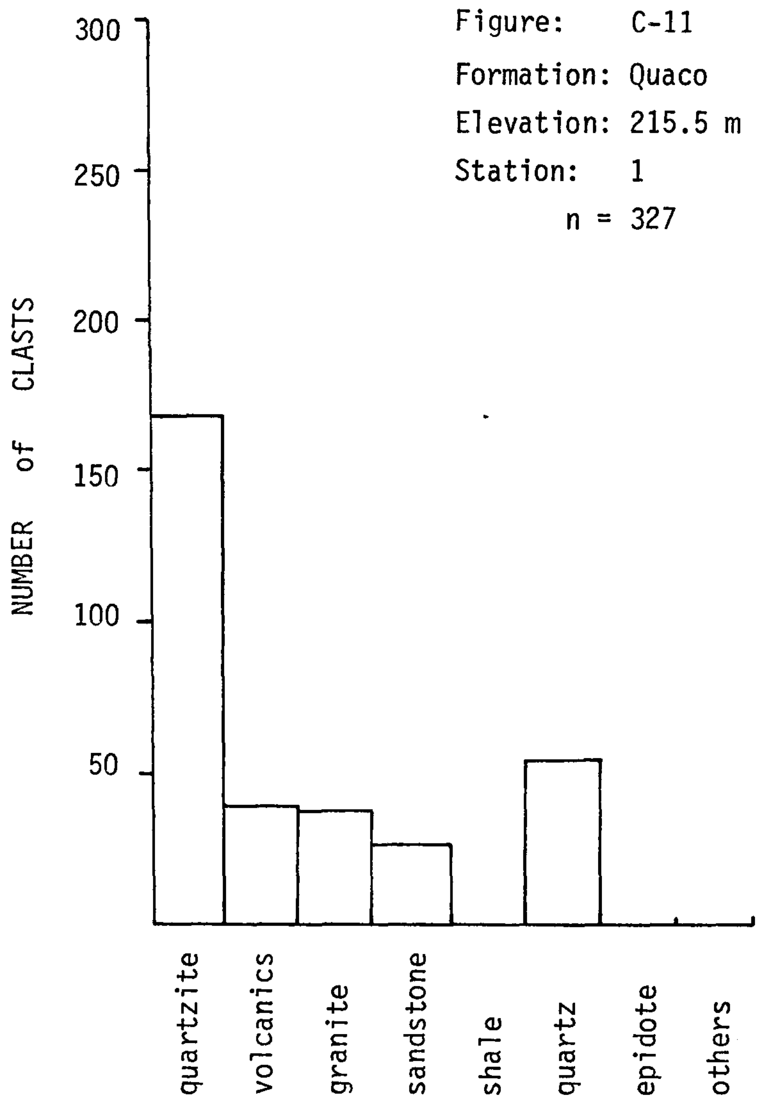
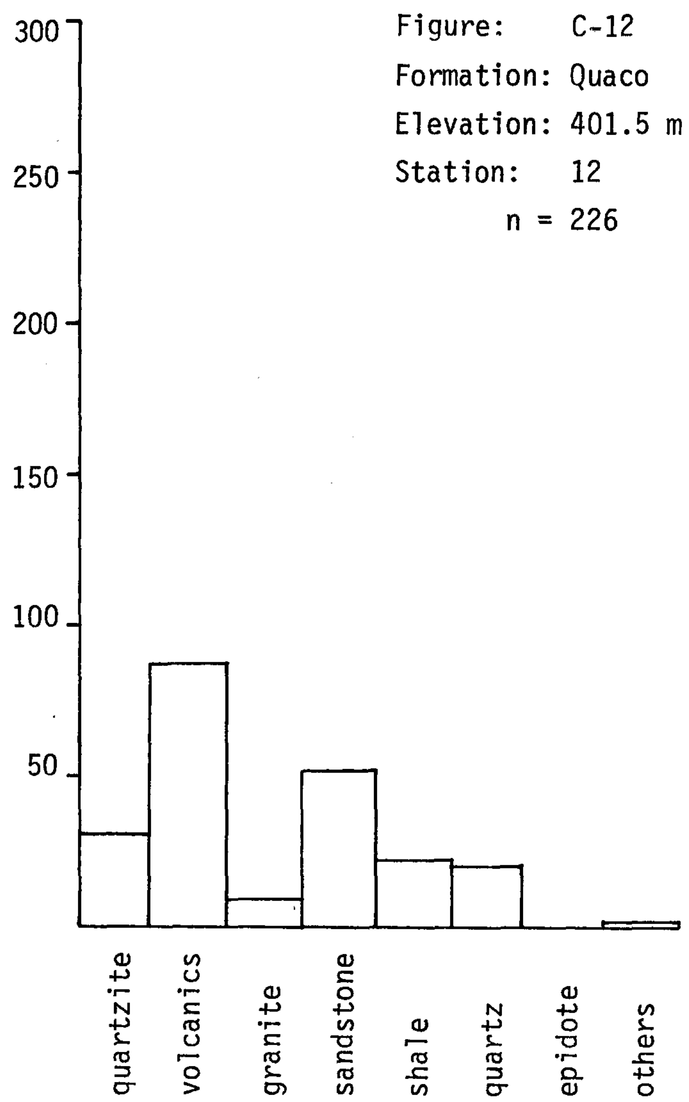


Figure: C-10
Formation: Quaco
Elevation: 180.6 m
Station: 11
n = 386
Figure: C-9
Formation: Quaco
Elevation: 180.6 m
Station: 10
n = 267
300
250
200
150
100
50
quartzite
volcanics
granite
sandstone
shale
quartz
epidote
others
NUMBER of CLASTS
CLAST COMPOSITION





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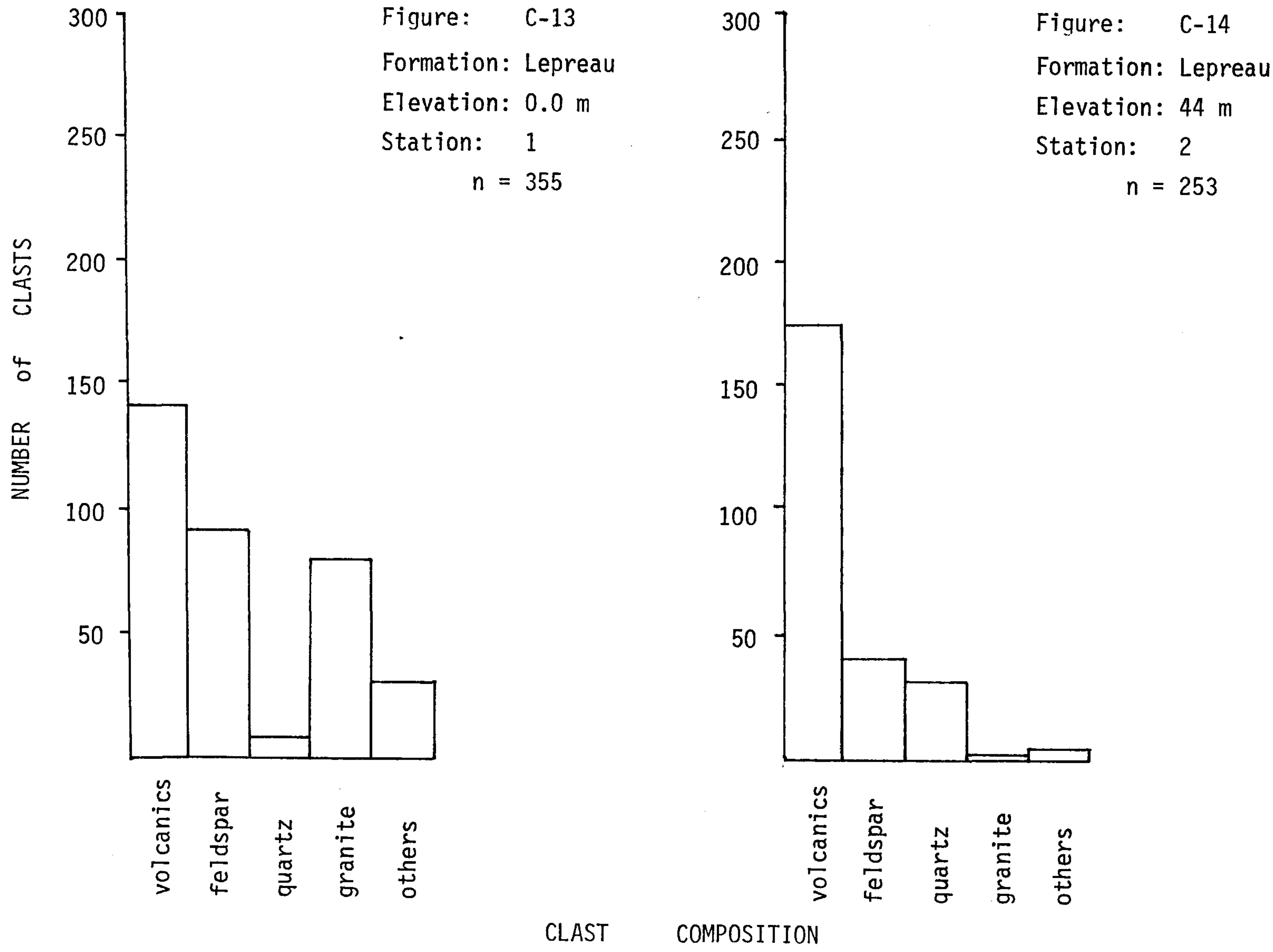
Figure: C-13
Formation: Lepreau
Elevation: 0.0 m
Station: 1
n = 355
Figure: C-14
Formation: Lepreau
Elevation: 44 m
Station: 2
n = 253
NUMBER of CLASTS
300
250
200
150
100
50
volcanics
feldspar
quartz
granite
others
CLAST COMPOSITION

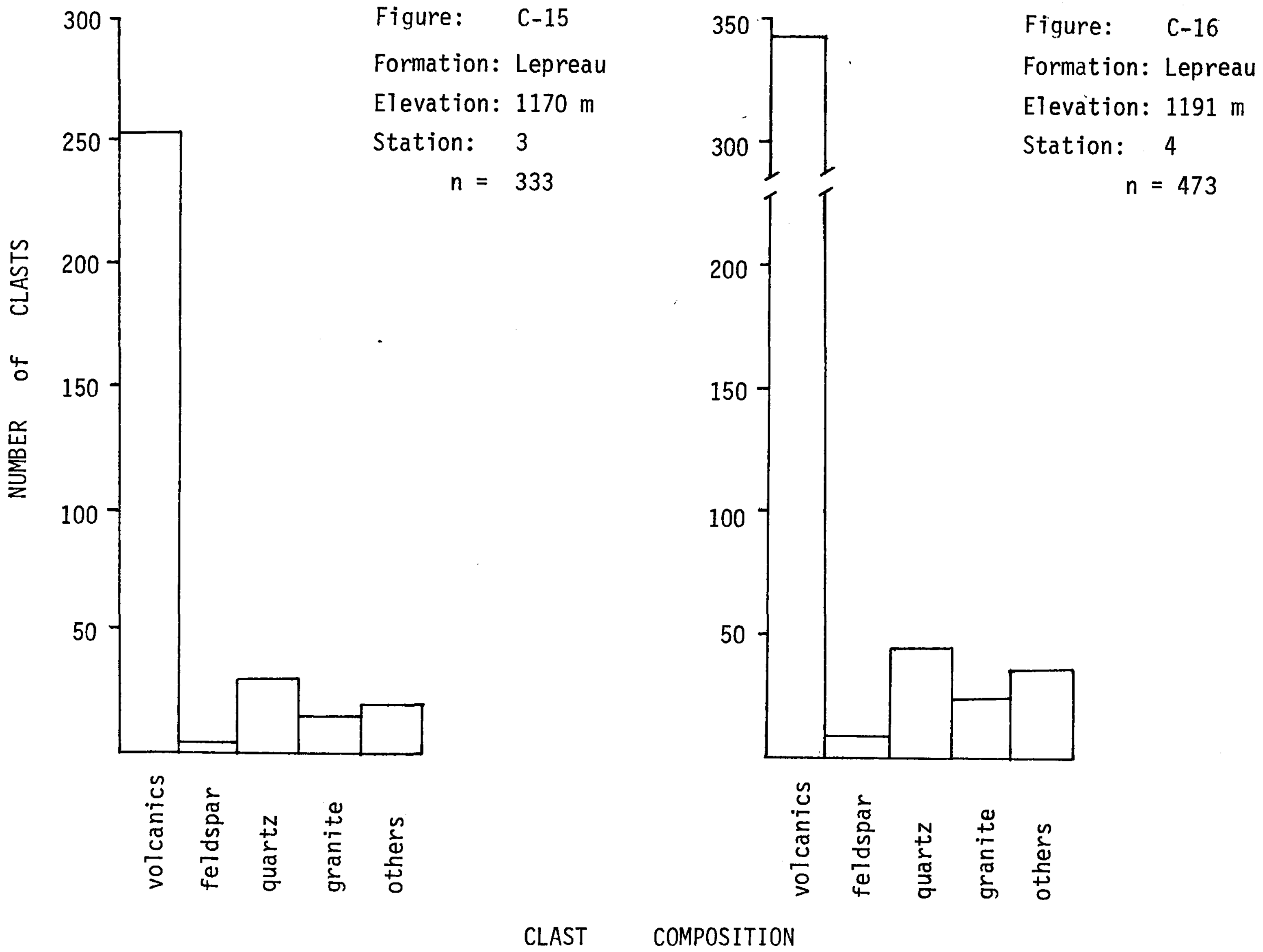
Figure: C-15
Formation: Lepreau
Elevation: 1170 m
Station: 3
n = 333
300
250
200
150
100
50
NUMBER of CLASTS
volcanics
feldspar
quartz
granite
others
Figure: C-16
Formation: Lepreau
Elevation: 1191 m
Station: 4
n = 473
350
300
200
150
100
50
volcanics
feldspar
quartz
granite
others
CLAST COMPOSITION

Table: D-1

Formation: Honeycomb Point (Browns Beach Member at Robinson Cove)

Sample No.: 08-12-01

Grain type / run number	1	2	3	4	5	6	Mean	S.D.
Quartz	26	20	34	29	20	29	52.3%	5.4%
Polyquartz	9	16	7	4	7	8	17.0	8.0
Chert	2	2	5	8	7	1	10.7	5.6
Feldspar	0	0	0	0	0	0	0.0	0.0
Void	12	11	2	6	9	11	17.0	7.7
Others	1	1	2	3	7	1	5.0	4.7
Rock fragments (Polyquartz + Chert)	11	18	12	12	14	9	21.7	11.4

Table: D-2

Formation: Honeycomb Point (Browns Beach Member at Robinson Cove)

Sample No.: 09-01-01

Grain type / run number	1	2	3	4	5	6	Mean	S.D.
Quartz	19	23	22	21	27	21	44.3%	5.4%
Polyquartz	8	8	11	12	13	12	21.3	4.3
Chert	7	5	4	5	3	8	10.7	3.7
Feldspar	0	0	0	0	0	0	0.0	0.0
Void	9	4	11	9	5	7	15.0	5.3
Others	7	10	2	3	3	2	9.0	6.5
Rock fragments (Polyquartz + Chert)	15	13	15	17	16	20	32.0	4.7

Table: D-3

Formation: Honeycomb Point (Browns Beach Member at Quaco Head)

Sample No.: 08-01-01

Grain type / run number	1	2	3	4	5	6	Mean	S.D.
Quartz	16	23	24	24	15	25	42.3%	8.9%
Polyquartz	13	8	13	8	13	9	21.3	5.2
Chert	4	5	8	9	11	4	13.7	5.9
Feldspar	1	2	0	0	1	0	1.3	1.6
Void	11	11	10	9	8	9	19.3	2.4
Others	4	1	0	0	2	3	3.3	3.3
Rock fragments (Polyquartz + Chert)	17	13	21	17	24	13	35.0	8.7

Table: D-4

Formation: Honeycomb Point (?) (Bains Corner)

Sample No.: 07-28-13

Grain type / run number	1	2	3	4	5	6	Mean	S.D.
Quartz	27	19	28	24	20	33	50.3%	10.5%
Polyquartz	7	11	9	6	7	1	13.7	6.7
Chert	1	0	0	4	0	2	2.3	3.2
Feldspar	0	0	0	0	0	0	0.0	0.0
Void	0	0	0	0	0	0	0.0	0.0
Others	17	18	13	16	23	14	33.7	7.1
Rock Fragments (Polyquartz + Chert)	8	11	9	10	7	3	16.0	5.7

Comments: 'Others' contains mostly carbonate cement with some hematite staining

Table: D-5

Formation: Lepreau (Maces Bay Member)

Sample No.: 08-05-01

Grain type / run number	1	2	3	4	5	6	Mean	S.D.
Quartz	18	25	20	16	15	23	39.0%	7.9%
Polyquartz	15	6	12	12	16	10	23.7	7.2
Chert	4	3	6	6	0	3	7.3	4.5
Feldspar	3	0	1	1	4	4	4.3	3.5
Void	6	9	9	13	15	19	20.3	6.5
Others	4	7	2	0	0	1	4.7	5.5
Rock fragments (Polyquartz + Chert)	19	9	18	18	16	13	31.0	7.7

Table: D-6

Formation: Lepreau (Fishing Point Member)

Sample No.: 01-01-01

Grain type / run number	1	2	3	4	5	6	Mean	S.D.
Quartz	25	22	16	27	20	29	46.3%	9.6%
Hematite	13	17	17	15	15	9	28.7	6.0
Feldspar	0	0	0	0	0	0	0.0	0.0
Calcite	7	6	15	6	15	10	19.7	8.5
Void	0	0	1	2	0	2	0.3	0.8
Others	3	5	1	2	0	2	4.3	3.4

Table: D-7

Formation: Lepreau (Fishing Point Member)

Sample No.: 01-01-02

Grain type / run number	1	2	3	4	5	6	Mean	S.D.
Quartz	24	18	16	15	19	18	36.7%	6.3%
Hematite	16	19	18	18	16	24	37.0	5.9
Feldspar	0	0	0	0	0	0	0.0	0.0
Calcite	10	12	5	15	14	8	21.3	7.6
Void	0	0	5	2	0	0	2.3	4.1
Others	0	1	6	0	1	1	2.7	4.7

Table: D-8

Formation: Lepreau Fishing Point Member)

Sample No.: 01-01-03

Grain type / run number	1	2	3	4	5	6	Mean	S.D.
Quartz	28	27	31	28	26	31	57.0%	4.1%
Hematite	15	14	13	9	15	12	26.0	4.6
Feldspar	0	0	0	0	0	1	0.3	0.8
Calcite	7	8	4	10	8	5	14.0	4.4
Void	0	0	0	2	0	0	0.7	1.6
Others	0	1	2	1	1	1	2.0	1.3

Table: D-9

Formation: Lepreau (Fishing Point Member)

Sample No.: 08-21-04

Grain type / run number	1	2	3	4	5	6	Mean	S.D.
Quartz	15	10	12	16	13	12	26.0%	4.4%
Hematite	5	5	3	6	5	1	8.3	3.7
Feldspar	0	1	0	0	0	1	0.7	1.0
Calcite	29	33	33	28	32	36	63.7	5.9
Void	0	0	0	0	0	0	0.0	0.0
Others	1	1	2	0	0	0	1.3	1.6

Comments: Slide cut from the base of a large trace fossil. Calcite much more abundant than normal and fills all pores.