SEDIMENTOLOGY AND STRATIGRAPHY OF THE CURLING GROUP (HUMBER ARM SUPERGROUP), CENTRAL WESTERN NEWFOUNDLAND

By

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SEDIMENTOLOGY AND STRATIGRAPHY OF CURLING GROUP, NEWFOUNDLAND

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ABSTRACT

Central western Newfoundland is mainly underlain by marine deposits ranging in age from Early Cambrian to Middle Ordovician. These deposits can be geographically separated into two parallel belts: on the east a platform sequence, and on the west a basin sequence. The latter constitutes the Curling Group.

The Curling Group comprises two distinct units: a shale unit below (Middle Cambrian-Lower Llanvirnian), consisting of shale, micritic limestone, limestone breccia, chert, and dolomitic siltstone; and a sandstone unit above (Upper Llanvirnian), consisting of medium- and coarse-grained sandstones plus scarce conglomerates.

In the shale unit shales predominate. Black, green, red, and gray shales are present, which may form units by themselves or appear interlaminated. Contrasted with modern deep-sea shales, the shales in the Curling Group are rich in silica and in magnesium; the black shales show a much higher content in organic carbon than the other varieties; many samples are calcareous or dolomitic.

Thinly-bedded micritic limestones are interbedded with shale. The limestone beds are massive or show

parallel lamination; bases and tops are flat and sharp. The limestone is rich in organic carbon. Limestone breccias are abundant locally but overall they are a minor lithologic component. Bedded and nodular chert forms two well developed units in the northern half of the region, but only a few beds in the southern half. Yellow-weathering dolomitic siltstones are restricted to the northern half of the region, where they are abundant; they form thin beds or cyclic, coarsening-upwards, units.

The sandstone unit consists of medium-grained to conglomeratic sandstones, interbedded with scarce shale; conglomerates are scarce and contain pebbles and cobbles of limestone and chert. According to bedding characteristics, grain-size, and sedimentary structures, the sandstones have been divided into several types. The main mechanism of deposition of the sandstones appears to have been turbidity currents, but with the concurrence of other mass flow mechanisms in the late stages of deposition, or immediately after deposition. The distribution of sandstone types and the geometry of the deposits, suggest the development of several small submarine fans. Nonetheless, it is not clear whether the fans developed wholly at the base of a slope, in the manner envisaged by the submarine fan model, or rather as prodelta fans on a platform and shallow basin.

The sandstones are quartzose wackes with less than 10% feldspar and about 40% rock fragments. Paleocurrent measurements show that provenance was from the east, with the possible exception of the sandstones on Woods Island which may have been derived from the west. Petrography and paleocurrents suggest derivation from the metamorphic Fleur de Lys Supergroup, presently exposed east of the Long Range Mountains, with the possible exception of the sandstones on Woods Island.

The Curling Group is currently interpreted as a nappe with roots to the east of the Long Range Mountains, and now lying on the platform sequence. New graptolite ages, petrography, and lithological correlations, presented in this thesis, suggest instead, that the Curling Group is approximately in place relative to the platform sequence, and that it passes laterally (eastwards) to the platform sequence.

An appendix is included giving details about the graptolite collections from the Curling Group secured during work for the present thesis. The collections were studied by Dr. D. Skevington, Memorial University of Newfoundland.

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The work and ideas of several persons are incorporated in this thesis. Some of those ideas were shared by them during discussions in the field or at home, and were distinct and separable at that point in time, but later they slowly merged into 'general knowledge' and cannot now be properly acknowledged.

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During the first field season, I was fortunate to meet Dr. R.K. Stevens, Memorial University of Newfoundland, and to assimilate a little of his vast knowledge of the geology of this region. I am grateful to Drs. Richard Hiscott and Noel James, Memorial University of Newfoundland, and Mr. Ota Mudroch, for their specific help, which is acknowledged in the text.

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TABLE OF CONTENTS

		Page
CHAPTER ONE	INTRODUCTION	1
	Regional setting	6
	Previous work	7
	Methods	13
CHAPTER TWO	CARBONATE SEQUENCE	21
	Grenville basement	23
	Carbonate sequence	23
	Long Point and Clam Bank Formations	44
	Discussion	45
CHAPTER THREE	CURLING GROUP - INTRODUCTION	50
	Fauna and age	51
	New formational names	54
	Structural geology	58
	Discussion	78
CHAPTER FOUR	CURLING GROUP - LITHOLOGY OF THE SHALE UNIT	80
	Rock types	80
	Distribution of rock types	104
	Conclusions	112
CHAPTER FIVE	CURLING GROUP - LITHOLOGY OF THE SANDSTONE UNIT	114
	Rock types	114
	Distribution of rock types	156
	Conclusions	165

		Page
CHAPTER SIX	CURLING GROUP - PROVENANCE	169
	Petrography	169
	Paleocurrents	186
	Provenance	193
CHAPTER SEVEN	THE NAPPE HYPOTHESIS	204
CHAPTER EIGHT	CURLING GROUP - CONDITIONS OF DEPOSITION	222
	The Curling Group basin	226
	Deposition of the shale unit	227
	Deposition of the sandstone unit	229
	Conclusions	235
CHAPTER NINE	SYNTHESIS AND CONCLUSIONS	238
	About the existence of Lower Cambrian in the region of the Bay of Islands	238
	Evolution of central western Newfoundland	244
	Conclusions	248
REFERENCES		253
APPENDIX I	Graptolites from Rocky Harbour, western Newfoundland	260
	Graptolites from Rocky Point, western Newfoundland	265
	Graptolites from the Piccadilly Area, Port au Port	266
	Graptolites from the Black Point Area	267

Page

APPENDIX II Glossary of Cambro-Ordovician stratigraphic names for central western Newfoundland 269

LIST OF FIGURES

		Page
1.	Location map	2
2.	General geologic map	3
3.	Geologic map of the area of Bonne Bay	36
4.	Structural cross-sections in the area of Bonne Bay	37
5.	Schematic structural cross-sections in the areas of Bonne Bay and of Port au Port	41
6.	Detailed map and cross-section north of Rocky Harbour Bay	56
7.	Detailed map and cross-sections in Rocky Harbour Bay and to the south	57
8.	Stratigraphic columnar sections for the Curling Group in the area of Bonne Bay	60
9.	Geologic map and schematic structural cross-sections for Woods Island.	66
10.	Geologic map and schematic structural cross-sections for the area of the Port au Port Peninsula	68
11.	Detailed map and cross-section at Black Point	69
12.	Detailed map and cross-sections at Rocky Point and at Piccadilly Beach	71
13.	Stratigraphic columnar sections for the Curling Group at Rocky Point	73
14.	Photographs of structural features	75
15.	Plots of fold axes	76
16.	Photographs of structural and lithologic features	77
17.	Idealized illustration of submarine sliding	79

Page

18.	Bed-thickness distribution in ribbon limestone	88
19.	Photographs of lithologic features	93
20.	Plot of content in inorganic versus organic carbon	100
21.	Field sketch of polymictic conglomerate	116
22.	Photographs of lithologic features	117
23.	Photographs of lithologic features	120
24.	Photographs of lithologic features	124
25.	Photographs of lithologic features	126
26.	Bed-by-bed sections for the Lobster Head Sandstone	128
27.	Bed-by-bed sections for the Blow-me-down Brook Formation and for the Rocky Point sandstones	129
28.	Channel and short sections in the Blow-me-down Brook Formation	130
29.	Two short bed-by-bed sections in the Lobster Head sandstone	131
30.	Grading patterns	134
31.	Sketches of beds illustrating grading patterns	136
32.	Graphs representing hydrodynamic behaviours	139
33.	Photographs of lithologic features	142
34.	Field sketches of two beds	146
35.	Photographs of lithologic features	148
36.	Bed-by-bed sections in thin dolomitic siltstone	150

Page

37. Photographs of textural features under the microscope 174

38. Sketches of grains as seen under the microscope 176

39. Mineralogical composition of Curling Group sandstones 182

40. Paleocurrents for the Lobster Head Sandstone 187

41. Paleocurrents for the Tourelle Formation 192

42. Possible dessication features 223

43. Schematic structural cross-section at Neddy Hill 232

44. Cross-sections illustrating the evolution of central western Newfoundland 245

LIST OF TABLES

		Page
I.	Analysis of variance of point-counting results	18
II.	Check of operator variance	20
III.	Stratigraphic correlation	22
IV.	Results of inorganic and organic carbon analyses	82
V.	Chemical analyses of shales	84

CHAPTER ONE

INTRODUCTION

Cambro-Ordovician strata in western Newfoundland can be conveniently grouped - as suggested by Rodgers and Neale (1963) - into a 'carbonate sequence' and a 'clastic sequence' (Figures 1 and 2). The carbonate sequence - so named because shallow water marine carbonates predominate in its middle part - ranges in age from Late Precambrian (?) to Middle Ordovician and is unconformably underlain by Grenville basement. The clastic sequence lies immediately to the west of the carbonate sequence; it ranges in age from Middle Cambrian to Middle Ordovician but its base is not exposed. Stevens (1970) gave the name Humber Arm Supergroup to the 'clastic sequence' of Rodgers and Neale (1963), and he subdivided it into the Cow Head Group (Kindle and Whittington, 1958) and the Curling Group.

The Curling Group is exposed between Rocky Harbour, immediately to the north of Bonne Bay, and the northern shore of the Port au Port Peninsula. This thesis deals exclusively with the sediments in the Curling Group, with

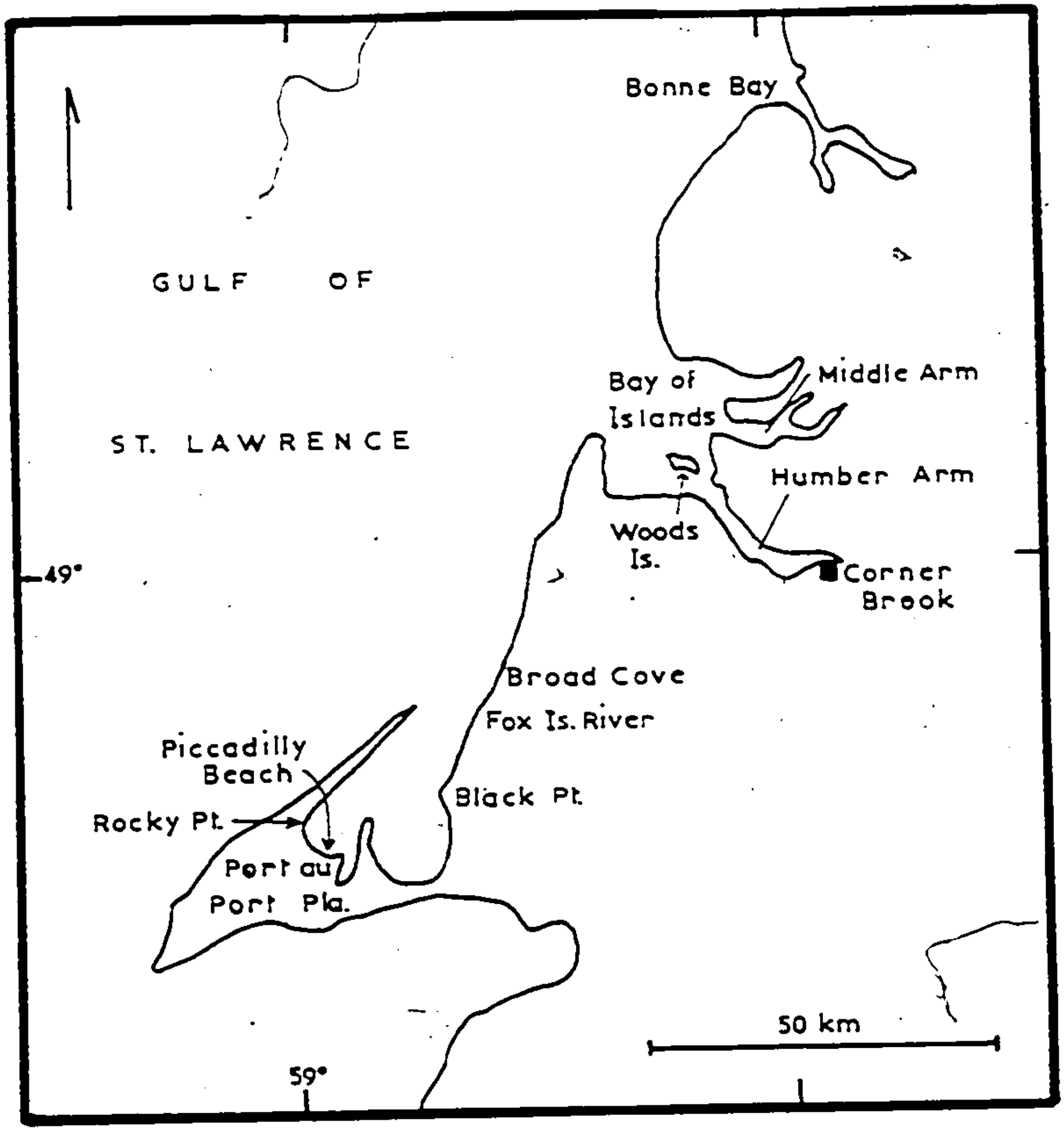


Figure 1. Orientation map with place names mentioned in text

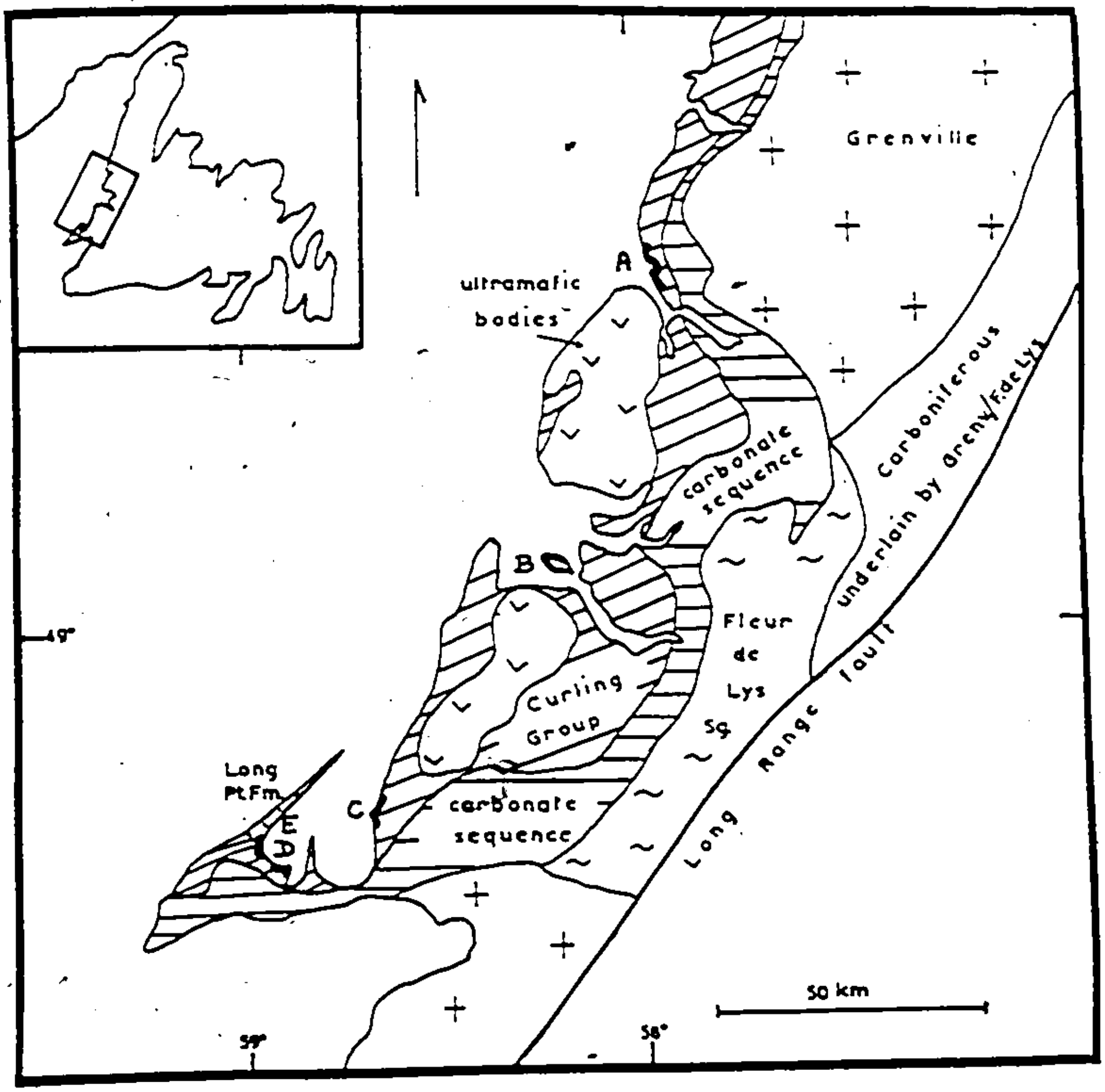


Figure 2. Simplified geologic map of the area studied. Coastal sections mapped in detail are indicated by thick segments: A. Rocky Harbour section; B. Woods Island section; C. Black Point section; D. Piccadilly Beach section; E. Rocky Point section.

special emphasis on those exposed around Bonne Bay and on the Port au Port Peninsula. The area studied forms part of the external zone of the northern Appalachians.

Interbedded with the Curling Group sediments are a few units of pillow lava and scarce dikes. These volcanic rocks are included in the Curling Group. On the other hand, there are several large bodies of ultramafic to mafic plutonic rocks and associated lavas, that are in contact with the Curling Group sediments. The contact is generally assumed to be tectonic (Williams, 1975). These igneous rocks are grouped under the name Bay of Islands Complex (Williams, 1973); they will not be discussed in this thesis.

The boundary between the carbonate sequence and the Curling Group is well exposed in the area studied. The carbonate sequence dips moderately to steeply westwards, against the Curling Group which - in turn - is strongly deformed along the contact. The relationship between the carbonate sequence and the Curling Group has not yet been definitely established. There are two prevalent hypotheses: one states that all the Curling Group was emplaced as a nappe on top of the carbonate sequence, and that the sediments in the Curling Group were originally deposited far to the east of their present position; the other hypothesis states that the Curling Group is in place with respect to the carbonate sequence and that the contact between the two sequences is stratigraphic. The conformable contacts between stratigraphic units within the Curling Group exclude any intermediate hypothesis, that is, either the whole of the Curling Group is a nappe or the whole is in place. These two hypotheses will be referred to as the nappe hypothesis and the autochthonous hypothesis. One of the aims of this thesis is to present new data that may help to solve this problem.

In the following chapters, the carbonate sequence will be described first but only briefly, because it was not studied in detail. Information gathered from the literature and some reconnaissance work, will serve to outline the evolution of the platform where the carbonate sequence accumulated so that it may be compared with the evolution of the Curling Group. Chapters Four, Five and Six are devoted to the Curling Group. Description of the Curling Group is straightforward but interpretation of the data is strongly dependent on the choice between the nappe or the autochthonous hypotheses. Wherever necessary, the alternative interpretations - according to which hypothesis is applied - will be pointed out. The nappe hypothesis will be critically reviewed in Chapter Seven, after all the available field and laboratory data pertinent to this revision has been presented.

REGIONAL SETTING

Twenhofel and McClintock (1940) divided western Newfoundland into three physiographic regions: the Long Range Plateau, the West Coast Lowland, and the Bay of Islands Serpentine Range. The Long Range Plateau is an uplifted peneplain with summits around 600 m, underlain by rocks of the Grenville basement and of the carbonate sequence. The Plateau descends rapidly to the West Coast Lowland, which is underlain by rocks of the Curling Group. At the foot of the Long Range Plateau lies the contact between the carbonate sequence and the Curling Group. From there, exposures of the Curling Group extend to the shores of the Gulf of St. Lawrence, forming irregularly disposed highs and lows, that range in elevation from sea level to over 300 m. Within the outcrop area of the Curling Group, stands out the Bay of Islands Serpentine Range, formed by two main flat-topped highlands surpassing 500 m in elevation, underlain by plutonic igneous rocks.

The shoreline generally shows a narrow sandy beach bordered by a cliff. Where igneous rocks or sandstones are being eroded, the cliff may be 50 m high, but it is very low where shales underlie it. A wide wave-cut platform exists around Rocky Harbour, to the north of Bonne Bay, but it is very narrow, or absent, elsewhere.

The best exposures of the Curling Group are along the shore, especially where the wave-cut platform adds a third dimension. Access by foot is possible for long stretches of the shoreline and access by boat is easy in the inner parts of Bonne Bay. In more open waters, the wind - while shifting constantly - never fails to blow from the wrong direction for landing the boat. The tide range is only about one metre but where the shoreline is rugged, high tide may block the way along the shore. Inland exposures are poor except for a few roadcuts.

PREVIOUS WORK

Geological exploration in western Newfoundland started very early thanks to the energetic administration of Sir William Logan as Director of the Geological Survey of Canada. In the years 1861 and 1862, James Richardson, explorer for the Geological Survey of Canada, travelled the coast of the British Newfoundland from the Strait of Belle Isle to Bonne Bay. In Bonne Bay he studied the carbonate and the clastic sequences and adequately subdivided the succession stratigraphically, using as a standard the stratigraphic scheme worked out by Logan for homologous rocks in Quebec. Richardson erred in assigning the whole of the clastic sequence, his Division Q, to the Middle Ordovician, younger than the top of the carbonate sequence, for it is now known that only part is younger. Considering the structural and sedimentological complexity of these sequences, this error cannot be harshly criticized. Graptolites, which are the only abundant fauna in the Curling Group had not yet been established as index fossils. Bulman (1958, p.159) remarked: "It was Lapsworth's 'Geological distribution of the Rhabdophora (1880)' that finally established the stratigraphic value of the graptolites, but any general discussion of the succession of graptolite faunas may take as its starting-point 'The Graptolite Faunas of the British Isles', published by Miss Elles in 1922". Richardson's observations were published long before this, in 1863 as part of 'The Geology of Canada', edited by Sir William Logan.

In 1864, Alexander Murray was detached by Logan to Newfoundland, and was paid by the Newfoundland government. He worked alone until 1867, when he injured his Achilles' tendon while doing field work. From then on James P. Howley was hired as his assistant. Murray worked for ten more years until his retirement, and Howley worked for forty years, in mapping the whole island of Newfoundland; a task that culminated with the publication of the first geological map of Newfoundland in 1907.

Exploration in western Newfoundland during the forty years following publication of Howley's map, was almost exclusively in the hands of geologists from the United States. First Charles Schuchert and his students studied outcrops along the shore from the Strait of Belle Isle to the Port au Port Peninsula. Their careful work resulted in a large collection of fossils, accompanied by detailed stratigraphic measurements and descriptions. For some outcrop areas, this work is - even today - the only source of published information. Their results were published by Schuchert and Dunbar in 1934. They found Tremadocian graptolites in two small outcrops of the clastic sequence, which they separated from the rest and explained by faulting. This discovery was made by the end of their field work and they lacked the time to pursue its implications; otherwise they might have established at this early date the partial equivalence of the carbonate and the clastic sequences.

The Peabody Museum of Yale University, had been involved in the study of the fossil collection of Schuchert. Later, Yale pursued this early involvement by sending several students to Newfoundland. The theses by Sullivan (1940) in the Port au Port region; by Troelsen (1947) in the Bonne Bay region, and by Weitz (1953) in the Bay of Islands region, are from this period.

To these contributions from the United States must be added the work of Walthier (1949) while employed by the Newfoundland Geological Survey, in the Bay of Islands region. Another major study was Lilly's (1963) thesis for Memorial University of Newfoundland, in the Bay of Islands region.

In 1958, Kindle and Whittington published their work on the Cow Head limestone breccia, exposed north of the study area for this thesis. Their study showed two important points; first, that the sequence was not all Middle Ordovician as Schuchert and Dunbar had thought but extended conformably from Middle Cambrian to Middle Ordovician. Second, that the clasts in each breccia bed were of the same age as the matrix. The first conclusion definitely established the partial contemporaneity of the carbonate and the clastic terrains; the second conclusion apparently provided a way of dating unfossiliferous shales with intercalated limestone breccias, a common association in western Newfoundland.

The scene was set for the appearance of the paper by John Rodgers and Ward Neale, the most influential of papers on western Newfoundland. Rodgers and Neale (1963) postulated that the clastic terrain was largely coeval with the carbonate terrain. This was a considerable extrapolation of the results of Kindle and Whittington and of

Schuchert and Dunbar, because in the whole region only two fossil localities older than Middle Ordovician had been found, one in the extreme north, the other in the extreme south. In support of this conclusion they relied heavily on lithologic correlation with the Taconic region, New York, which Rodgers knew so well. In order to explain the contrast of contemporaneous sedimentary facies, Rodgers and Neale (1963) put forward the nappe hypothesis, a hypothesis that has guided geological work until the present.

Many new fossil localities (Stevens, 1965; this thesis) have confirmed that the exposed Curling Group includes rocks at least as old as Middle Cambrian, thus supporting Rodgers and Neale's basic postulate. Faunas older than Middle Cambrian have been found only in clasts from conglomerates in the Curling Group.

The strata studied have been affected greatly by the Taconic orogeny, which caused folding, faulting, and some dynamic metamorphism. A later - pre-Carboniferous - deformation, that might be ascribed to the Acadian orogeny, resulted in minor faulting, tilting of strata, and local metamorphism associated with granitic intrusions (Williams, 1969; Rodgers, 1971). Emplacement of the nappes postulated by the nappe hypothesis would have constituted a major event during the Taconic orogeny.

Topographic maps cover the area studied in a scale 1:50,000. A geologic map (1:1,000,000) was compiled by Williams (1967) for the island of Newfoundland. Most of the area studied is covered by geologic maps in larger scales. Troelsen (1947) mapped the southern part of the region of Bonne Bay in a scale 1:100,000. The region of Bay of Islands is covered by the maps by Lilly (1963) and Stevens (1965), in a scale 1:50,000, and by Williams (1973) in a scale 1:125,000. The region of Port au Port is covered by the maps by Riley (1962) in a scale 1:250,000 and by Corkin (1965) in a scale 1:50,000. Walthier (1949) mapped the region between Bay of Islands and Port au Port in a scale 1:60,000. The northern part of the region of Bonne Bay had not been mapped before the present study.

Fragmentary but useful information about the Curling Group has been published in two field excursion guidebooks for the International Geological Congress in Montreal (Poole and Rodgers, 1972; Neale, 1972).

METHODS

Five months were spent in the field during the summers of 1976 and 1977. Work concentrated in three regions: Bonne Bay, Woods Island, and Port au Port Peninsula (Figures 1 and 2). Selected coastal sections, totalling 15 km in length, were mapped by plane table and alidade, at scales varying between 1:1500 and 1:3000. These are the Rocky Harbour section immediately north of Bonne Bay, and the Black Point, the Piccadilly Beach and the Rocky Point sections in the region of Port au Port.

In the region of Port au Port, the detailed maps comprise all outcrops of the Curling Group, with the exception of those on Shoal Point, which are very poorly exposed. The Rocky Harbour section accounts for one-fourth of the coastal outcrops of the Curling Group in Bonne Bay, but exhausts those to which access by foot is easy. North of the Rocky Harbour section there are no outcrops until Green Point, where rocks belonging to the Cow Head Group are exposed.

The western third of Woods Island was mapped on a 1:50,000 topographic sheet. Plane table was not used because of rugged relief along the shore and absence of a beach, compounded with strong winds. On the other hand, the jagged outline of the island facilitated the use of the topographic map.

Four months were spent in the study of these sections, of which close to two months were devoted to the Rocky Harbour section.

In addition to the detailed mapping, about one month was spent in reconnaissance mapping. All coastal exposures of the Curling Group, and many inland and coastal exposures of the carbonate sequence, were visited in Bonne Bay. In Bay of Islands, most of the exposures of the Curling Group along the shores of Humber Arm, a few outcrops along the southeastern shore of Middle Arm, and all coastal exposures in the eastern two-thirds of Woods Island, were visited. In the region of Port au Port, reconnaissance was carried out on the carbonate sequence from Black Cove to Cape Cormorant. In addition, exposures of the Curling Group were visited between Broad Cove and Fox Island River. Reconnaissance mapping was done on

1:50,000 topographic sheets. These results are presented in the form of schematic cross-sections or partial geologic maps. Since coverage of the region was incomplete and some stratigraphic correlations remain uncertain, it was decided not to present a general geological map.

All the geologic maps and cross-sections are presented as Figures 3 to 12. They are grouped to facilitate later reference and are arranged by areas, from north to south, that is, first the area of Bonne Bay, then that of Woods Island, and finally the area of Port au Port.

Ten bed-by-bed sections were measured in the sandstone unit of the Curling Group at several localities. The sections are short and do not cover the total exposed thickness. Correlation of individual beds from section to section is not possible but the sections illustrate typical bedding characteristics.

Paleocurrent measurements and orientations of fold axes were corrected for tilt of the strata by rotation about the local strike. The large scale folds show sub-horizontal axes so correction for plunge of folds was regarded as unnecessary.

The mineralogical composition of fine-grained sediments was studied qualitatively in thin-sections and by X-ray diffraction. The mineralogy of the sandstones was studied qualitatively in thin-section, making extensive use of the U-stage. A quantitative modal analysis was carried out on medium- and coarse-grained samples, by point-counting each section twice. A first count of 500 points in five traverses of 100 points each, with a spacing of 0.3 mm between points and 2 mm between traverses, served to estimate the proportions of quartz, plagioclase, potassium feldspar, rock fragments, matrix, and cement. In a second count, 100 rock fragments per thin-section were counted and classified into: high-grade metamorphic and plutonic (separating rock fragments composed solely by quartz from those composed by quartz and feldspar), sedimentary and low-grade metamorphic, and volcanic and hypabyssal.

No attempt was made to estimate the errors involved in the second count but for the first count they were calculated as follows. Four thin-sections were chosen to cover the textural range of the sandstones to be studied, and separated as standards. Each of these four thin-sections was point-counted in the manner described above, but the composition was computed for each traverse, that is to say, for each thin-section five subsamples were obtained. The set of standards was point-counted four times: one at the beginning of the modal analysis work, a second one week later, a third three weeks after the first, and a fourth time five months after the first, at the end of the modal analysis work.

The percentages of quartz, total feldspar, and rock fragments, were used to test the variation between replications. An analysis of variance was carried out for each of these constituents, in the manner shown in Table I for quartz over four replications. The results are given in Table I. Quartz means are significantly different over the four replications at the 95% confidence interval but they are not significantly different at the 99.5% confidence interval. If the first count at the beginning of the point-counting work is omitted, the quartz means are not significantly different at the 95% confidence interval. The means for total feldspar are not significantly different over the four replications at the 95% confidence interval; the relative error, however, is high. Rock fragment means are significantly different at the 95% confidence interval over the four replications and also over the later three replications; in the latter case, however, they are not significantly different at the 99.5% confidence interval.

The operator variance was checked with the help of Dr. Richard Hiscott, Memorial University of Newfoundland, who point-counted the set of standards once, following the operational conventions used in this thesis. His mean

Table I. Analysis of variance of point-counting results

Source of variation	SS	d.f.	MS
Between thin-section	7295	3	2432
Between replications	332	3	111
Interaction	209	9	23
Subtotal	7835	15	
Within traverses	1553	64	24
Total	9388		

$F_{.95(3,64)} = 2.8$; $F_{.995(3,64)} = 4.7$; $F_{.95(2,48)} = 3.2$; $F_{.995(2,48)} = 6.0$

	F		Possible error
	4 repl.	3 repl.	%
Quartz	4.6	0.7	±10
Feldspar	2		± 4
Rock fragments	21	5.9	±10

values for quartz, total feldspar and rock fragments are compared with the means over the four replications for each of these constituents (Table II). The results from each operator are fairly close.

The analysis of variance discussed above showed that at the beginning of the point-counting work - approximately over the first two counts - conventions were applied inhomogeneously. Consequently, it would have been convenient to devote more time for practice before commencing the definitive point-counting.

Table II. Check of operator variance

Sample	Q	F	Rx	R. Hiscott Q	F	Rx
1	33	5	13	36	7	12
2	20	4	16	25	3	10
3	45	6	17	54	7	9
4	41	2	19	47	3	16

CHAPTER TWO

CARBONATE SEQUENCE

The carbonate sequence is geographically interposed between the Grenville basement, on the east, and the Curling Group, on the west (Figure 2). It forms a monocline dipping steeply west, except in the Port au Port Peninsula where dips are low; it is moderately deformed but its older units show metamorphism in places. The term carbonate sequence was introduced by Rodgers and Neale (1963) to distinguish the rocks that are autochthonous in the nappe hypothesis.

In this chapter, the carbonate sequence will be described with information drawn largely from the literature. The purpose of this description is to allow a comparison with the Curling Group. Consequently, emphasis will be selectively lain on features that are relevant to this aim. In addition, the Grenville basement and the Long Point and Clam Bank Formations will also be described. The stratigraphic position of these units is shown in Table III.

Table III. Stratigraphic correlation

System	British series		Skev.	Berry	Carbonate Sequence: Bonne Bay	Carbonate Sequence: Bay of Islands	Carbonate Sequence: Port au Port	Curling Group: Bonne Bay	Curling Group: Bay of Islands	Curling Group: Port au Port
ORDOVICIAN	Caradoc.									
	Llandeil.		11	10			Long Point			
	Llanvirnian	Upper	10	9				Lobster Hd. South Arm	Blow me down Bk.	Black Pt. Rocky Pt.
				8	Gadd's Pt.	Piccadilly Beach	Crow Head		?	
		Lower	9	7	upper					
	Arenigian	Upper	8	6	middle	Table Head		Yellow Pt. MacKenzie Bk.	Middle Arm Pt.	shale unit
					lower					
		Middle	7	5						
		Lower	6 5 4 3	4 3		St. George				?
	Tremadoc.		2 1	2 1						
CAMBRIAN	Upper				East Arm	Reluctant Hd.	Petit Jardin		Cooks Bk.	
	Middle					Penguin Cove	March Point		?	
	Lower				Labrador	Mt. Musgrave	Kippens			
PRECAMBRIAN					Grenville basement			Grenville basement (?)		

GRENVILLE BASEMENT

The Grenville province of the Canadian Shield extends to western Newfoundland, where it crops out as inliers in the Long Range Plateau and in the Indian Head Range, east of the Port au Port Peninsula. Clifford and Baird (1962), Riley (1962), and Papezik (*in* Neale, 1972, p.74), have described these rocks well. Gneisses of granitic to tonalitic composition are the predominant lithology. Intruding the gneisses are discordant and concordant plutons of granitic to tonalitic composition. Minor rock types are hornblende gneiss, diorite, gabbro, diabase, and ultramafic rocks. Four radiometric ages have yielded values of 945 m.y. and 960 m.y. (Clifford and Baird, 1962), and 830 m.y. and 900 m.y. (Papezik, *in* Neale, 1972, p.74).

CARBONATE SEQUENCE

The order of description will be chronologic. The time divisions have been chosen to stress the main stratigraphic divisions but the equivalence is only approximate. Ordovician ages are given in terms of the British Series following the usage of Skevington (1968), which differs from usage in North America. The problem of correlation of graptolite zones and the British Series will be discussed in Chapter Three. The result of employing Skevington's correlation is that Ordovician stratigraphic units appear to be slightly older than is commonly reported; the relative ages, of course, remain unchanged.

Precambrian (?)-Lower Cambrian

Stratigraphic units of this age are the Labrador Group (Troelsen, 1947) in Bonne Bay; the Mount Musgrave Formation (in part ?) (Lilly, 1963), east of Corner Brook, and the Kippens Formation (Riley, 1962; Lilly, 1965) in Port au Port. The Labrador Group is generally unmetamorphosed, but it does reach low-grade metamorphism at some localities. The Mount Musgrave Formation is generally metamorphosed and reaches high-grade metamorphism in places. The Kippens Formation is generally unmetamorphosed but may reach low-grade metamorphism.

The Precambrian (?)-Lower Cambrian rests unconformably on the Grenville basement; the contact is exposed in the region of Bonne Bay and of Port au Port. Total thickness is about 1000 m each of Corner Brook and in Bonne Bay, but only 300 m in Port au Port. A basal clastic unit, with arkoses, feldspathic sandstones, quartzites, and minor pebble conglomerate, is present throughout. Above may follow the same rock types, with minor shale, limestone, and dolostone, as in the outcrops east of Bonne Bay and of Corner Brook, or - as in Port au Port - shale, limestone, and dolostone, may predominate. The limestone commonly shows stromatolites, and cross-bedding is abundant in the quartzite, so these rocks are interpreted as shallow-water deposits (Knight, 1977; Swett and Smit, 1972). Paleocurrents (Knight, 1977) indicate derivation from the west.

Mineralogical data on the Lower Cambrian sandstones is very scanty, which is unfortunate because such data would reflect the composition of the detritus shed by the Grenville basement. Lilly (1963, p.17), in his description of the Mount Musgrave Formation, wrote: "The coarse arkosic sandstones are generally similar in composition to the arkosic breccias but the proportion of feldspar is lower and seldom exceeds 15% of the rock. As in the coarser breccias, microcline is the dominant feldspar. Plagioclase in the albite-oligoclase range comprises about 30% of the total feldspar component.". And on his page 18, referring to "horizons containing subgreywacke-pebble-conglomerates", he wrote that "these rocks have a sericitic groundmass in which are quartz and perthite grains up to 8 mm in diameter as well as flakes of biotite and lesser amounts of chlorite. ...A higher proportion of plagioclase is present than in either the arkosic sandstones or breccias.". The Mount Musgrave Formation shows a degree of metamorphism varying between low- and high-grade.

In the region of Bonne Bay, south of the head of East Arm (Neale, 1972, Stop 8.6), the basal Lower Cambrian is exposed. The rocks are metamorphosed sandstones and carbonates. The carbonates are bioclastic and show - in thin-section - small nodules of chloritized biotite with a bright green to almost colourless pleochroism. The carbonates are conformably or disconformably underlain by about 40 m of olive green sandstones and two thin quartz pebble conglomerates. Descending stratigraphically in the sandstone unit, pink feldspar and granitic veins gradually become more abundant. The sandstone sequence appears to be conformable and unbroken; no evidence was found of the unconformity on top of the Grenville basement reported by Stevens (<u>in</u> Neale, 1972, p.69).

One thin-section of a meta-arkose from this exposure showed about 40% sand-sized grains of K-feldspar and muscovite, in a groundmass of fine-grained, equant-shaped, muscovite that strongly corrodes the feldspar. The K-feldspar was identified by its low index of refraction and, in addition, three grains showed - on the U-stage - negative optic angles of 76°, 77° (measured directly), and

80°. The K-feldspar is commonly surrounded by rims of albite. The rims are free of inclusions, show an index of refraction higher than the K-feldspar core, and in parts show twinning. Maximum extinction angles measured on these twinned parts exceed 15°. The contact between the rim and the core is irregular saw-toothed, and it follows the embayments formed by corrosion of the feldspars by the groundmass. The albite rims formed as a result of the metamorphism. Many grains of K-feldspar show, in their interior, irregular patches or well defined crystals of twinned albite. It appears, then, that as a result of the metamorphism, the K-feldspar was partly transformed to twinned albite.

The author had the opportunity to study three thin-sections (kindly lent by Dr. Noel James, Memorial University of Newfoundland) of coarse-grained arkoses from the Bradore Formation. The Bradore Formation is the basal unit of the Labrador Group (Schuchert and Dunbar, 1934), and it is exposed along the shore of Labrador, where it consists of red arkosic sandstones with abundant trough cross-bedding, and some conglomerates (Schuchert and Dunbar, 1934). The samples examined are subrounded arenites with about 10% cement and traces of matrix. The quartz content varies between 40% and 50%. The feldspar content varies between 20% and 50%. Rock fragments composed of quartz and feldspar are present but probably constitute less than 10%.

Opaque minerals and muscovite amount to less than 5%. The feldspar is perthite and microcline. The microcline is fresh, whereas the perthite is slightly altered, with a dusty appearance.

Two preliminary conclusions may be drawn from these observations: (a) that the detritus eroded from the Grenville basement was rich in K-feldspar, and (b) that part of the K-feldspar was transformed to twinned albite in areas subjected to regional metamorphism.

Middle and Late Cambrian

Stratigraphic units of this age are the East Arm Formation (Troelsen, 1947), in Bonne Bay; the Reluctant Head and Penguin Cove Formations (Lilly, 1963), east and northwest of Corner Brook; and the March Point and Petit Jardin Formations (Schuchert and Dunbar, 1934; Riley, 1962; Lilly, 1965), in Port au Port. The contact with the Lower Cambrian is a disconformity (?) east of Bonne Bay, and a conformity east of Corner Brook and in Port au Port. Total thickness is about 160 m in Bonne Bay, and about 300 m in the other two areas.

Limestone and dolostone predominate but cross-bedded sandstone and shale are abundant in the Lower part of the March Point Formation. Limestone breccia is abundant in the Reluctant Head and Penguin Cove Formations; very coarse, in parts. Stromatolites and oolites are common in parts. These rocks have been interpreted as shallow-water deposits (Swett and Smit, 1972; Knight, 1977).

Tremadocian and Early Arenigian

These epochs are represented by the St. George Group (Schuchert and Dunbar, 1934; Troelsen, 1947 ; Riley, 1962; Lilly, 1963, 1965). Total thickness is about 900 m at Bonne Bay, 1200 m east of Corner Brook, and 750 m in Port au Port. It conformably overlies the Upper Cambrian and it is now generally accepted that it extends into the Upper Cambrian.

The lithology of the St. George Group can be simplified into three divisions: a lower division (about one-third of the thickness) consisting of thick-bedded dolostones; a central division with gray or black, hackly-weathered limestones; and ~~an upper~~ division (about one-fourth of the thickness) where dolostones predominate. Nodular chert is common in the upper division. Stromatolites are present at several levels, including the uppermost beds. Reddish shades are common in the upper part of the St. George Group in Port au Port (Sullivan, 1940). (The stratigraphy of the St. George Group was the subject of a recent thesis by R. Levesque, Memorial University of Newfoundland, but this thesis was not available at the time of writing).

Middle Arenigian to Early Llanvirnian

These epochs are represented by the Table Head Formation (Riley, 1962; Lilly, 1963, 1965; Whittington and Kindle, 1963; Morris and Kay, 1966). Total thickness is about 100 m in Bonne Bay, 180 m east of Corner Brook, and 240 m in Port au Port. Contact with the St. George Group is generally conformable but may be disconformable in Port au Port Peninsula.

Schuchert and Dunbar (1934) divided the Table Head Formation into lower, middle, and upper members. The lower member consists of gray, massive bioclastic limestone, in thick poorly defined beds, commonly showing irregular and discontinuous dolomitic shaly partings. The middle member consists of interbedded thin-bedded, micritic limestone, and dark shale. The upper member consists of dark shale. Passages between the members are gradual. The shales of the upper member, in turn, pass gradually to sandstones that will be described below. The middle member is absent in Bonne Bay, where the lower Table Head is covered by 10 m of dark shales below the Gadd's Point

Formation described below.

The upper member and part of the middle member, contain graptolites that correspond to zone 9 of Berry (1960), or to the Lower Llanvirnian according to Skevington (1968). Graptolites and conodonts indicate that the Table Head Formation becomes slightly younger in a NNE-SSW direction, from Hare Bay, at the tip of the Great Northern Peninsula, to Port au Port (Whittington and Kindle, 1963; Fahraeus, in Stevens, 1970, p.170). This variation in age can be interpreted as progradation to the SSW, or - as Stevens (1970, p.170) suggested - as a recession of the bank to the SSW. The first interpretation implies provenance broadly from the east; the second, from the west.

One lithologic unit will now be described which is thought to be coeval with the upper member of the Table Head Formation but that is very poorly understood. It will be named, informally, the 'Table Head limestone breccia'.

The distinguishing characteristic of this breccia is that the limestone clasts show irregular but equant shapes, in contrast with the limestone breccias in the Curling Group, which show flat clasts. The breccia is massive and bedding is inconspicuous. The clasts are commonly in contact or separated by shaly partings; the proportion of matrix varies greatly but is generally low, in the order of 10%. Sorting is poor, with sizes generally ranging from 1 to 10 cm, but reaching 3 m. The large majority of the clasts are of gray, bioclastic limestone derived from the Table Head Formation (Corkin, 1965; DeLong, 1978, pers. comm.). A few other clasts, especially the larger ones, are of yellow-weathering dolomitic siltstone, or sandstone.

The Table Head limestone breccia is exposed near Bonne Bay (Figure 3), in Black Cove (Figure 5) and at Piccadilly Head (Figure 12b, eastern end of section). According to descriptions by other workers (Corkin, 1965; Stevens, 1970) the limestone breccia at Round Head, on the western shore of Port au Port Peninsula, can be included in the Table Head limestone breccia. The Table Head limestone breccia does not seem to constitute a single continuous stratigraphic unit, but rather four separate units; one in Bonne Bay, one in Black Cove, one around Piccadilly Head, and one at Round Head.

The upper and lower boundaries of the Table Head limestone breccia are very poorly exposed. In Bonne Bay it is overlain by the Gadd's Point Formation (described below), but also contains clasts from the Gadd's Point Formation suggesting that the breccia is, in fact, intercalated in the Gadd's Point Formation; the base of the breccia is not exposed. In the Black Cove exposure, the breccia is overlain by a bed of calcarenite which, in turn, is overlain by the Piccadilly Beach sandstones (described below); the breccia is underlain by rock types like those of the Piccadilly Beach sandstones at the north end of the exposure and by upper Table Head shales at the southern end of the exposure (Figure 5); clasts of Piccadilly Beach sandstones are present in the breccia. In this same exposure in Black Cove, at the northern end of the outcrop, the breccia passes gradually to a diamictite. The amount of green shale matrix increases until it is abundant in the diamictite. In addition, clasts from the Piccadilly Beach sandstones become numerous. Finally, in the quarry shown in the Piccadilly Beach section (Figure 12b) the breccia is underlain by upper Table Head dark shales; the top is not exposed.

These stratigraphic relationships indicate that the Table Head limestone breccia is approximately equivalent to the upper Table Head, as had been previously suggested by Sullivan (1940), Corkin (1965), and Stevens (1970). The breccia is intercalated in the upper Table Head and in the Piccadilly sandstones.

The thickness of the breccia could not be measured. The minimum thickness is 2 m in the Piccadilly Beach quarry and 5 m in the other exposures. Corkin (1965) estimated the thickness of the breccia in Black Cove to range between 15 and 80 m; the latter value appears to be much too high.

The conformable contacts and clast orientation roughly parallel to bedding, indicate that the Table Head breccia is a sedimentary deposit (Sullivan, 1940; Corkin, 1965; Stevens, 1970). Unfortunately the breccia lacks imbrication or other indicators of direction of sediment transport. Corkin (1965) and Stevens (1970) suggested that the breccia was derived from the west but their opinion was not supported by direct evidence.

One further rock type to be described in this section is a green nodular chert exposed on the western end of the Piccadilly Beach section (Figure 12b). The chert unit is developed in the upper Table Head and covered by the Piccadilly Beach sandstones. The unit forms a wedge that thins to the east from 10 m to nil, over a distance of 50 m.

It consists of olive green nodular chert interbedded with green argillite. The nodules are 10 to 15 cm thick and of variable length. The interbedded argillite has undergone shearing, perhaps due to relative movement of the nodules, but the unit as a whole is coherent. The argillite is slightly calcareous. Transition from chert nodules to argillite is gradual. Overlying the nodular chert is a thin unit of brownish cherty mudstone. Graptolites from these two chert units only serve to indicate a Llanvirnian age (Figure 12b, Loc. C).

Late Llanvirnian to Llandeilian

These epochs are represented by several fine-grained sandy units. Only one of these units has received a formational name: the Gadd's Point Formation (Troelsen, 1947) in Bonne Bay. For the units in the region of Port au Port, the informal names 'Piccadilly Beach sandstones' and 'Crow Head sandstones' will be employed.

The Gadd's Point Formation is exposed inland, between Rocky Harbour Pond and Neddy Hill, along the shore surrounding Neddy Hill, along the shore in the vicinity of Gadd's Point, and in roadcuts east of the head of South Arm (Figure 3). The type section is at Gadd's Point but the formation is better exposed and less deformed at Neddy Hill. The base is a conformity above the Table Head formation; the top appears to be a conformity under the Lobster Head Sandstone and the South Arm Formation, but this needs confirmation. The thickness at Neddy Hill is about 250 m. A strong cleavage oblique to the bedding is present in most outcrops.

Figure 3. Simplified geologic map for the region of Bonne Bay.

Formational boundaries in the southern half of the map are taken from Troelsen (1947) with little modification.

Paleocurrent diagrams are for the Lobster Head Sandstone; roses refer, respectively, to outcrops to the north and to the south of Rocky Harbour Bay. Roman numerals indicate position of cross-section presented in Figure 4.

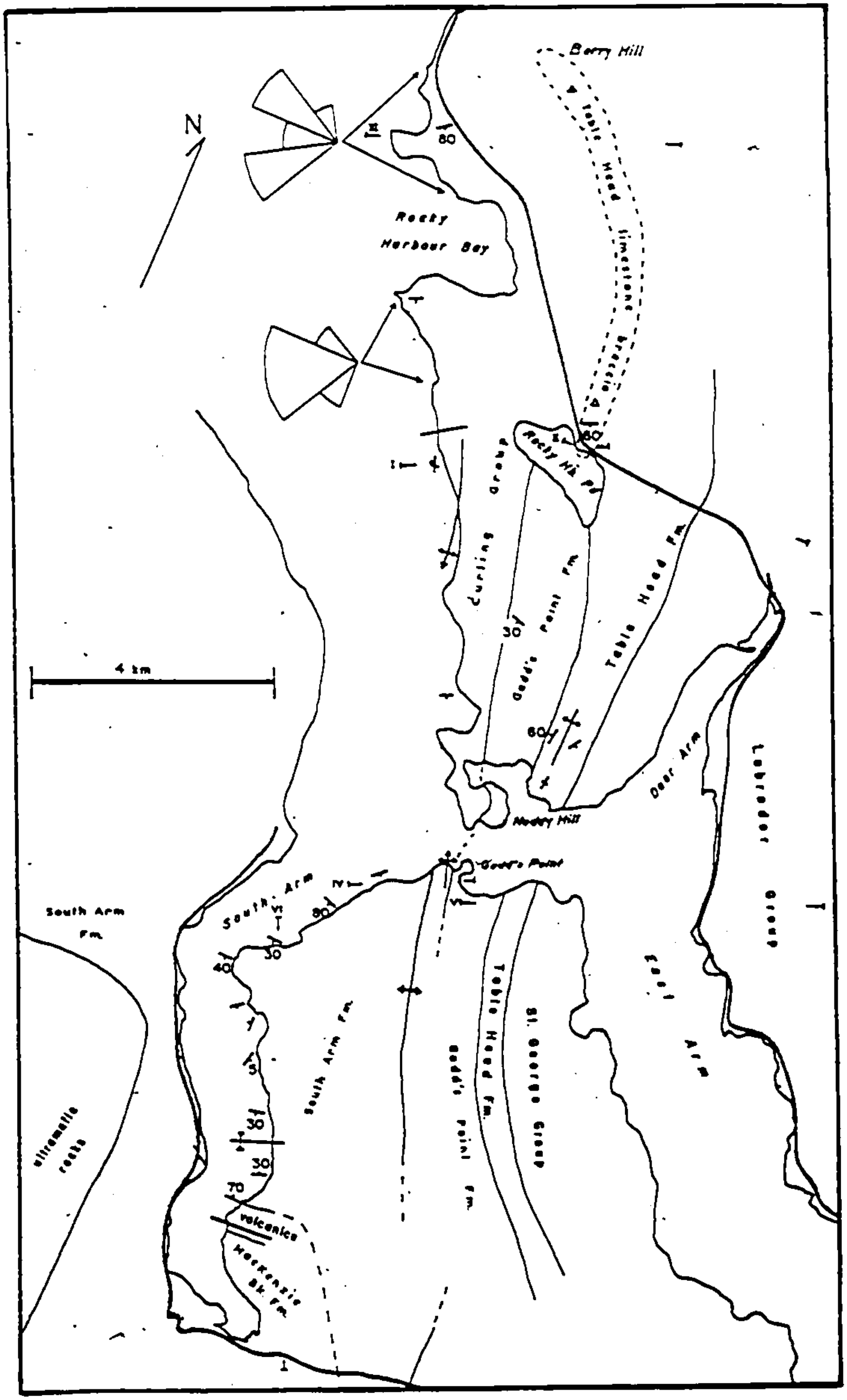
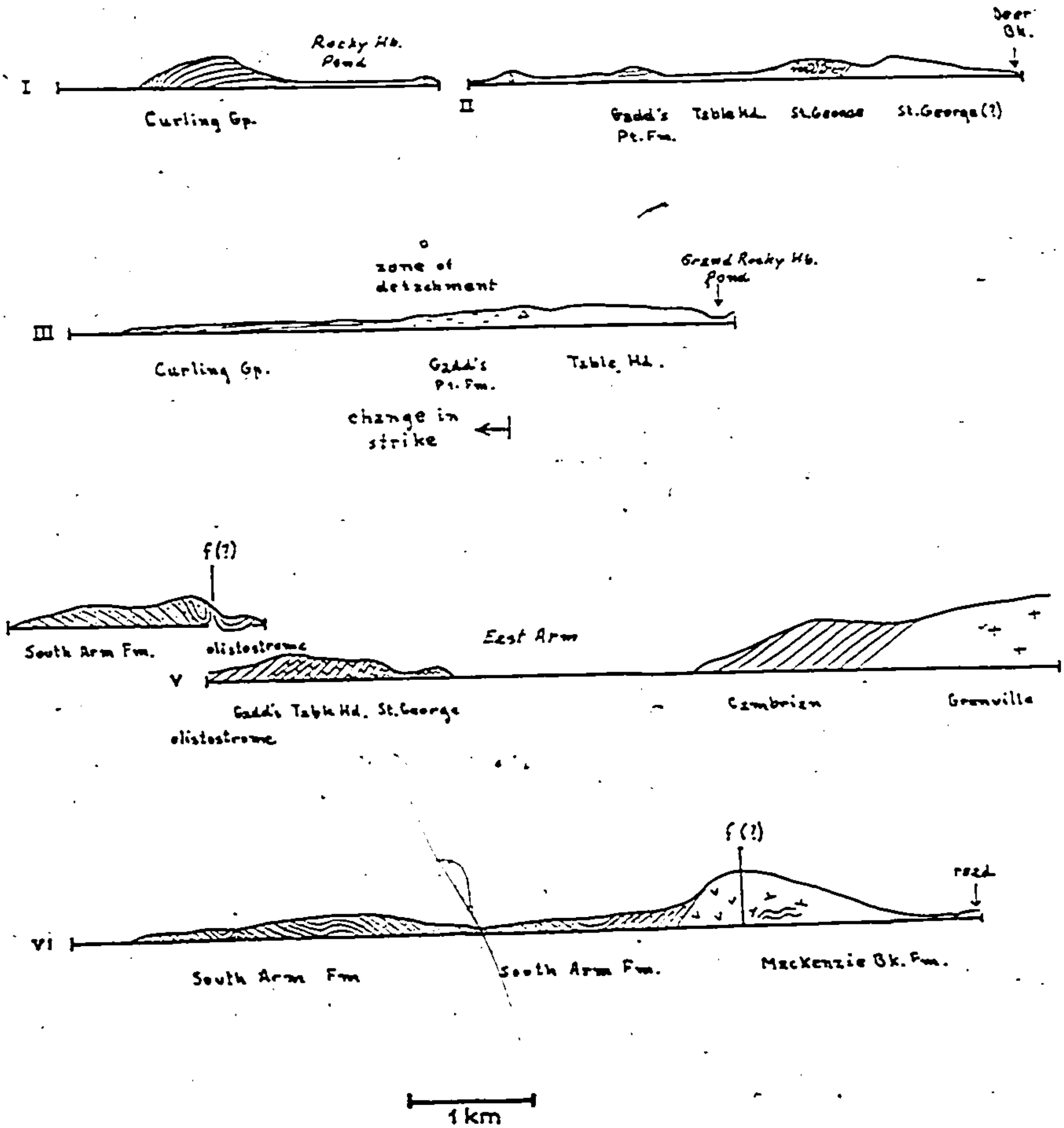

N
Berry Hill
Table Head limestone breccia
Rocky Harbour Bay
80
Rocky Hb. Pd.
Curling Group
Gadd's Point Fm.
Table Head Fm.
4 km
30
60
Deer Arm
Labrador Group
Gadd's Point
South Arm
South Arm Fm.
ultramafic rocks
East Arm
St. George Group
Table Head Fm.
Gadd's Point Fm.
volcanics
Mackenzie Bk. Fm.

Figure 4. Cross-sections in the Bonne Bay region.

Location of sections is given in Figure 3. Little vertical exaggeration.


Rocky Hb. Pond
Deer Bk.
I
II
Curling Gp.
Gadd's Pt. Fm.
Table Hd.
St.George
St.George (?)
zone of detachment
Grand Rocky Hb. Pond
III
Curling Gp.
Gadd's Pt. Fm.
Table Hd.
change in strike
f(?)
IV
South Arm Fm.
olistostrome
East Arm
V
Gadd's Table Hd. St. George
olistostrome
Cambrian
Grenville
f(?)
road
VI
South Arm Fm
South Arm Fm.
Mackenzie Bk. Fm.
1 km

The predominant rock type is a brown-weathering silty mudstone showing alternating dark green and black laminations. Intercalated in the mudstone are numerous thin siltstones and scarce medium-grained sandstones. The siltstones are commonly rippled or show parallel lamination; they have sharp bases and grade into the mudstone; beds are 5 to 10 cm thick. The siltstones are dolomitic and weather yellow. The medium-grained sandstones form beds 30 to 60 cm thick, massive, with sharp bases a few of which show flutes, and with normal grading in their upper parts; these features of the sandstone beds suggest that they were deposited as turbidites. Sandstone beds are found sparsely at all levels within the formation but on Neddy Hill, where a complete section of the formation can be studied, sandstones gradually become more abundant towards the top, as the sequence gives way to an olistostrome. The olistostrome shows blocks of limestone breccia and ribbon limestone, up to 6 m across, embedded in sheared and broken medium- and coarse-grained sandstone interbedded with abundant silty mudstone (cf. Stevens, in Neale, 1972, p.67).

On the west side of Gadd's Point, in the upper part of the Gadd's Point Formation, a limestone breccia 15 m thick appears intercalated in the mudstones. It shows equant limestone fragments, intraformational clasts of siltstone and dolomitic siltstone, and several boulders (up to 5 m across) of a brown-weathering, laminated, limestone or dolostone. This limestone breccia is tentatively correlated with the olistostrome on Neddy Hill and with the Table Head limestone breccia. A little farther west from the breccia, the coarse-grained sandstones of the South Arm Formation (Troelsen, 1947) are exposed. The contact has been obscured by deformation but at the base of the South Arm, the mudstone interbedded with the sandstones appears to be identical to that in the Gadd's Point Formation. It is quite possible that this contact between the South Arm and the Gadd's Point Formations, is conformable.

A medium-scale soft-sediment fold developed in laminated mudstone in the olistostrome on Neddy Hill, indicates movement to the S-SSW. The ripples in the siltstones consistently indicate southward flow. Six flutes have orientations between 200° and 210°.

No fossils were found in the Gadd's Point Formation. If the limestone breccia and olistostrome at the top of the formation are coeval with the Table Head limestone breccia, the Gadd's Point Formation would be more or less equivalent to the upper and middle members of the Table

Head Formation. The relatively large thickness of the Gadd's Point can be accommodated because the middle Table Head is not developed here.

The name 'Piccadilly Beach sandstones' is given to fine-grained sandstones exposed in the Piccadilly Beach section (Figure 12b) above the nodular chert, and at Black Cove (Figures 5 and 11, southern end of section) above and partly also below, the Table Head limestone breccia.

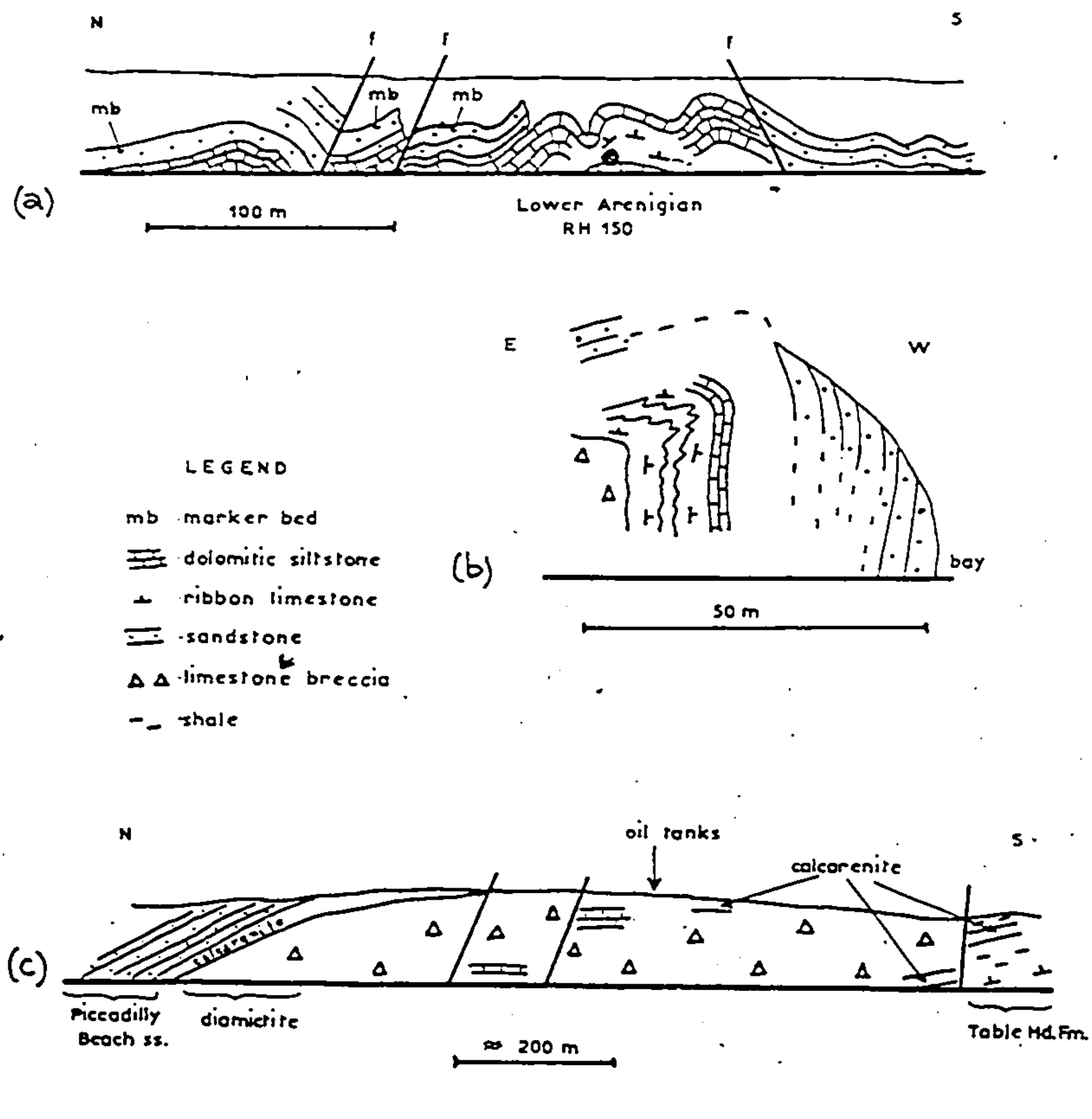
In the Piccadilly Beach sandstones the predominant rock type is gray and green mudstone. Interbedded are sparse beds of siltstone or medium- to fine-grained sandstones; bedding is medium (20 to 50 cm) and the beds show well developed parallel parting, smooth and flat bases, and normal grading in their upper portions; some show convolute lamination near the top. Several medium-grained sandstones show the Bouma sequence T_{CD}; a few beds have convolute lamination developed in both divisions. The fine-grained sandstones show lamination and parting in the lower 15 cm, and then a sharp transition to silty shale which, in turn, imperceptibly grades into the background mudstone; in these, divisions C and D of the Bouma sequence may be recognized below the sharp transition, and perhaps division E immediately above it but without lamination. In parts, the predominant Bouma

Figure 5. Schematic cross-sections resulting from reconnaissance work.

(a) section along Little Green Point, continuation of Figure 7.

(b) section on the south side of Little Green Point.

(c) section at Black Cove, continuation of Figure 11.


N
S
f
f
f
mb
mb
mb
(a)
100 m
Lower Arenigian
RH 150
E
W
(b)
bay
50 m
LEGEND
mb marker bed
dolomitic siltstone
ribbon limestone
sandstone
limestone breccia
shale
N
oil tanks
S
calcarenite
(c)
Piccadilly
Beach ss.
diamictite
≈ 200 m
Table Hd. Fm.

sequence is T_{BE} with convolutions instead of ripples. On parting planes, oriented graptolites may be found. Bases are flat and generally smooth but several beds show well formed flutes. Seven paleocurrent measurements coherently indicate flow to the south. The siltstones and sandstones can be interpreted as turbidites.

The Piccadilly Beach sandstones above the Table Head limestone breccia at Black Cove, yielded graptolites suspected of being Lower Llanvirnian (Figure 11, Loc. C). The presence of Piccadilly Beach sandstones underlying the Table Head limestone breccia indicates that the former are partly equivalent to the upper Table Head.

The Crow Head sandstones are exposed along the western shore of the Port au Port Peninsula, around Crow Head and in a small syncline to the southwest (Figure 10). According to the description by Corkin (1965), green, in parts brown, sandstone predominates greatly over shale; limestone is a minor component. The sandstone is mainly fine- and medium-grained but coarse sandstone is common. Cross-bedding is very common; fine-grained beds are micaceous; glauconite is present in trace amounts. The shale is gray to black, micaceous. The limestone is thin bedded, gray and fine-grained. Conglomeratic beds are present, with clasts of quartz and chert.

Exposures visited by the author show mainly olive green fine-grained, micaceous sandstones. Bases are sharp, beds show normal grading and well developed parallel parting. The sandstones are interbedded with abundant green-gray shale. Less common are olive green, thick, coarse-grained sandstones. These beds have sharp bases, a few with flutes or grooves, and normal grading; beds may be massive or show parallel parting, depending on the content of mica. A few beds show calcareous concretions, fluid escape structures, or large cross-sets. Float reveals the presence of shale breccia with coarse sandstone matrix. The sandstones can be interpreted as turbidites.

Nine paleocurrent measurements coherently indicate flow to the southwest. Flutes and ripples measured by DeLong (1978, pers. comm.) in the Crow Head sandstones, show a strong component to the west.

The Crow Head sandstones are about 400 m thick (Corkin, 1965). The formation lies conformably above the Cape Cormorant breccias and lies conformably below the Long Point Formation (Stevens, 1970). Graptolites from the Crow Head belong to zone 10 of Berry (Stevens, 1970), or to the Upper Llanvirnian. The base of the Long Point Formation (described below) lies close to the Llanvirnian-Llandeilian boundary, so the Crow Head sandstones appear to be restricted to the Upper Llanvirnian.

LONG POINT AND CLAM BANK FORMATIONS

The Long Point Formation (Rodgers, 1965) is exposed on Long Point, in the Port au Port Peninsula (Figure 10). The formation is about 800 m thick. The lowest part shows cross-bedded sandstones and green shale; above follow nodular shaly limestones and green shale, with reef-building organisms. The upper part - most of the thickness - consists of dark greenish shale with intercalated beds of brown-weathering limey sandstone. The base is an unconformity above the Curling Group, but it is a conformity above the Crow Head sandstones (Stevens, 1970). The top is probably a disconformity below the Clam Bank Formation. The age of the Long Point is mainly Llandeilian, but reaches into the Late Llanvirnian (Poole and Rodgers, 1972, p.96).

The Clam Bank Formation (Rodgers, 1965) is exposed on Long Point, in the Port au Port Peninsula (Figure 10). The formation is about 450 m thick. It consists of red sandstones and mudstones; the sandstones are cross-bedded and coarse-grained to pebbly. In addition there are brown and green, fine-grained sandstones and siltstones. The base is probably a disconformity above the Long Point Formation. The top is uncovered by erosion.

DISCUSSION

The lithostratigraphy of the carbonate sequence can be simplified to three units: (1) a Precambrian (?)-Lower Cambrian clastic unit, varying in thickness from 300 to 1000 m; (2) a Middle Cambrian to Arenigian carbonate unit, with a thickness of 1200 to 1700 m, and (3) a Lower Llanvirnian clastic unit, approximately 100 to 250 m thick.

Mineralogy and paleocurrents indicate that the older clastic unit was derived from the Grenville craton to the west. The younger clastic unit shows paleocurrents mainly indicating flow to the south or southwest, that is parallel to the tectonic strike and possibly parallel to the axis of the basis of deposition, but there are also paleocurrents indicating flow to the west. It appears safe to conclude that the younger clastic unit was derived from the east.

Consequently, a reversal in provenance direction occurred during the time of deposition of the carbonate -

central - unit. As contacts between the formations that constitute the carbonate unit are conformable, the reversal must have taken place either at the beginning or at the end of the period of carbonate deposition.

Stevens (1970) suggested that the reversal in provenance occurred during upper Table Head time. The shales of the upper Table Head would, in his opinion, be a hemipelagic deposit accumulated during a time when neither the carbonate bank nor the rising source area to the east had a dominant influence on the basin.

There are two observations that cast doubts on this idea. One is that the lower Table Head is dolomitic and the younger clastic unit is also dolomitic. The dolomite in the siltstones and sandstones of the younger clastic unit is concentrated in discrete bands commonly showing ripple cross-lamination; the dolomite here must be detrital. In the lower Table Head limestones the dolomite is concentrated in the shaly partings; it might be detrital. If the dolomite in the Table Head is detrital and if the dolomite in both units have the same provenance, then it is likely that the Table Head and the younger clastic unit have the same provenance direction: from the east.

The other observation is that in the Black Cove exposures it can be shown - using the Table Head limestone breccia as a time horizon - that at the time of deposition of the upper Table Head shale, the Piccadilly Beach sandstones (mainly siltstones and shale) were also being deposited. As there is no obvious field difference between the shale in the Piccadilly Beach sandstones and in the upper Table Head, it is reasonable to assume that both units have the same source area: to the east.

These two observations taken together suggest that the lower Table Head, the upper Table Head, and the younger clastic unit, all have the same provenance direction: from the east.

If the reversal in provenance direction did not take place by the end of the period of carbonate deposition, then it could have taken place at the beginning. Such a change may be recorded by the disconformity at the base of the carbonate unit. Clearly, to talk about provenance direction for a carbonate bank may not carry the same significance as when referring to terrigenous siliciclastic sediments. Detritus on a carbonate bank may have been derived locally from the biological activity on the bank itself. What is necessary is to define the position of the edge of the bank.

The nappe hypothesis states that until Table Head

Formation times, western Newfoundland was underlain by a carbonate platform. This platform faced to the east, that is to say, the edge of the platform lay to the east of the present outcrops of the carbonate sequence. The Table Head Formation, with the passage from bioclastic limestones (lower Table Head) to shales (upper Table Head), would record the subsidence of this platform. There is evidence, however, suggesting the existence of a carbonate bank edge in western Newfoundland much before Table Head time, during the Middle and Late Cambrian.

For instance, at the top of the Mount Musgrave Formation, at the base of the Reluctant Head Formation, and in the Penguin Cove Formation, Lilly (1963, p.20, 23, 24, 27) found coarse limestone breccias and slumped horizons. These deposits may well be taken as indicators of the proximity of the edge of the carbonate bank. Now these three formations are overlain by the stromatolitic St. George Group, which extends, in outcrop, several km to the east of the localities with breccias and slumping. If the breccias had been derived from the west, deeper waters would have existed to the east of the breccias and the stromatolitic St. George would not have developed in such a setting. If, instead, the breccias had been derived from the east, the St. George would occupy the platform area.

In this case, the western edge of the St. George outcrops would roughly coincide with the edge of the carbonate bank, a bank that would have bordered a basin immediately to the west.

The arguments presented above are not meant to prove a point of view, but to show that many uncertainties remain concerning the polarity of the carbonate bank and the time of reversal in provenance direction. These problems will be re-evaluated after the Curling Group is described.

CHAPTER THREE

CURLING GROUP - INTRODUCTION

The name Curling Group was proposed by Stevens (1970) for the sediments, and scarce volcanics, of the clastic sequence exposed between Bonne Bay and the Port au Port Peninsula. Curling is a town on the south shore of Humber Arm.

Regionally the Curling Group can be divided into an upper sandstone unit, of Late Llanvirnian age, and a lower shale unit, of Middle Cambrian to early Late Llanvirnian age. In the region of Bay of Islands, an even older sandstone unit, of Early to Middle Cambrian age, has been postulated (Stevens, 1970), but needs corroboration. This older sandstone unit will be discussed in Chapter Nine.

In the region of Bay of Islands, the Curling Group has been subdivided into the following formations: the Cooks Brook and the Middle Arm Point Formations for the shale unit, and the Blow-me-down Brook Formation, for the sandstone unit. All names were proposed formally by

Brückner (1966) on the basis of the work by Lilly (1963, 1965) and Stevens (1965). In the southern part of the region of Bonne Bay, Troelsen (1947) distinguished the MacKenzie Brook Formation, for the shale unit, and the South Arm Formation, for the sandstone unit. For the northern part of the region of Bonne Bay, the present author proposes the names Yellow Point Formation, for the shale unit, and Lobster Head Sandstone, for the sandstone unit. In the region of Port au Port, no formational names have been proposed but the informal names 'Black Point sandstones' and 'Rocky Point sandstones' will be used in this thesis for the sandstone unit. The shale unit will be left unnamed because more work is needed to establish whether the different outcrops should be grouped into one formation or more than one.

FAUNA AND AGE

Graptolites were collected from the shale and the sandstone units in the regions of Bonne Bay and of Port au Port. In Bonne Bay the fossiliferous localities are fairly numerous and well distributed, but in Port au Port they are very few. Fossiliferous localities are shown in the detailed maps by solid circles identified by letters; the letters refer to Appendix I, where the graptolites identified at each locality are listed.

All graptolite collections were studied and classified by Dr. David Skevington, Memorial University of Newfoundland. He dated the faunas in terms of the following units:

Upper Llanvirnian
Lower Llanvirnian
Upper Arenigian
Middle Arenigian
Lower Arenigian
Upper Tremadocian

Those samples that could be dated more precisely fall into only three of these units, namely, Upper Tremadocian, Lower Arenigian, and Upper Llanvirnian.

Graptolites are the main autochthonous fauna in the Curling Group and in the upper member of the Table Head Formation. Most of the graptolite ages for the external Appalachians have been established using as a standard the graptolite succession worked out by Berry (1960) for the Marathon region, Texas. He divided the Ordovician into 15 graptolite zones and correlated these zones with the British series (Berry, 1967). Skevington

(1968) did not accept Berry's correlation, instead he proposed a correlation that is substantially different. Both are compared in Table III. In this thesis, Skevington's opinion will be followed but the author realizes that the debate has not been settled. In any case, the relative ages of the faunas in the Curling Group can be clearly established.

It is possible to work out a correlation of the faunas in the Curling Group with the Table Head Formation and use it as a reference. The upper, and part of the middle, members of the Table Head Formation contain graptolites that belong to zone 9 of Berry, or to the Lower Llanvirnian (Skevington, 1968), while the lower member corresponds to zone 7 (Berry, 1968). Two localities in Bonne Bay that yielded Lower Arenigian fauna had been sampled by Kindle and Whittington (1965, p.687), who classified their collections as 'probably belonging to zone 6 of Berry (1960)'. Also, Dr. Skevington identified 11 different species in the Lower Arenigian faunas. A comparison with the lower Deepkill faunas (Berry, 1963) showed that 9 of the 11 species are present there, mainly in zones 5 and 6. It appears then that the Lower Arenigian of this thesis includes zone 6 of Berry, which is slightly younger than the base of the Table Head Formation.

Consequently, the rocks dated in this thesis are mainly older (Upper Tremadocian, Lower Arenigian) or mainly younger (Upper Llanvirnian), than the Table Head. As the Curling Group forms a continuous and conformable sequence, the gap in ages is probably due to imperfect sampling, or lack of preservation of graptolites.

NEW FORMATIONAL NAMES

Two new formational names are proposed for the Curling Group in Bonne Bay: the Yellow Point Formation and the Lobster Head Sandstone.

The name Yellow Point Formation is proposed for the fine-grained calcareous and dolomitic sediments, plus some chert and limestone breccias, exposed along the shore and inland, in the region of Bonne Bay, between Lobster Cove and Wild Cove. The type section is at Yellow Point, on the prominent peninsula immediately to the north of Rocky Harbour Bay (Figure 6a). The formation is structurally segmented.

The base of the formation is not exposed. The top is a conformity below the Lobster Head Sandstone. Maximum exposed thickness is 150 m. Its age ranges from Late

Tremadocian to early Late Llanvirnian, based on graptolites; in terms of the carbonate sequence it is largely equivalent to the St. George Group, the Table Head Formation, and the Gadd's Point Formation.

The name Lobster Head Sandstone is proposed for the marine sandstones and interbedded shales, with minor conglomerates, exposed along the shore and inland in the region of Bonne Bay, between Lobster Cove and Wild Cove. The type section is at Lobster Head on the prominent peninsula immediately north of Rocky Harbour Bay (Figure 6a). The formation is structurally segmented.

The base is a conformity above the Yellow Point Formation along the shore, but to the east it is thought to be a conformity above the Gadd's Point Formation. The base is located where the first sandstones appear. The top has been removed by erosion or faulting. The maximum exposed thickness is 150 m. The age of the formation is Late Llanvirnian, based on graptolites; in terms of the carbonate sequence it is largely equivalent to the Crow Head sandstones.

Figure 6. Detailed sections north of Rocky Harbour Bay.

Scale is the same for both sections but orientation of the North differs. Heavy lines are faults (F) or folds (f). F_1 faults separate structural units. Prime symbols designate structures whose time of formation is in doubt. Fossil localities are shown by solid dot on map; the age is followed by a letter that refers to Appendix I.

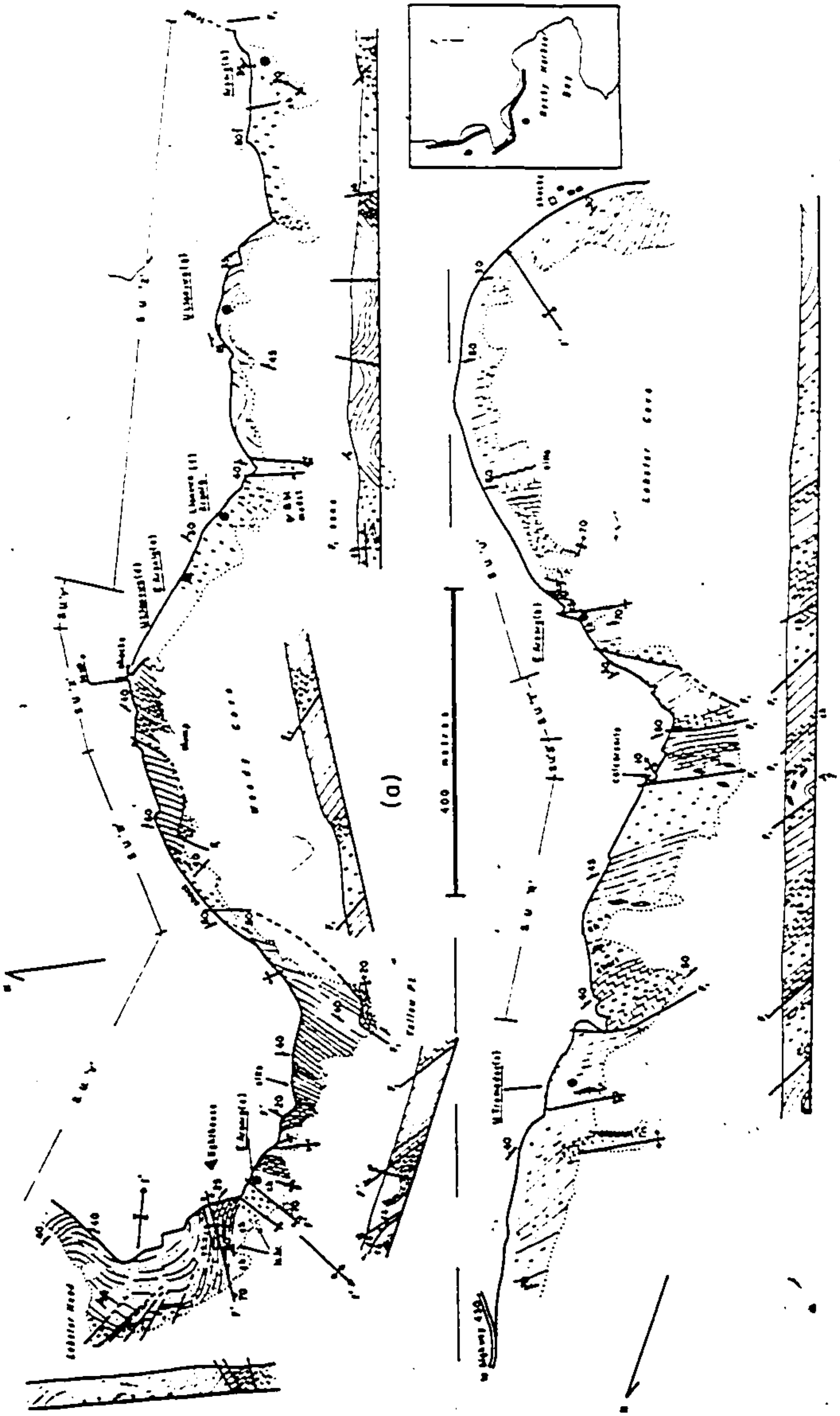
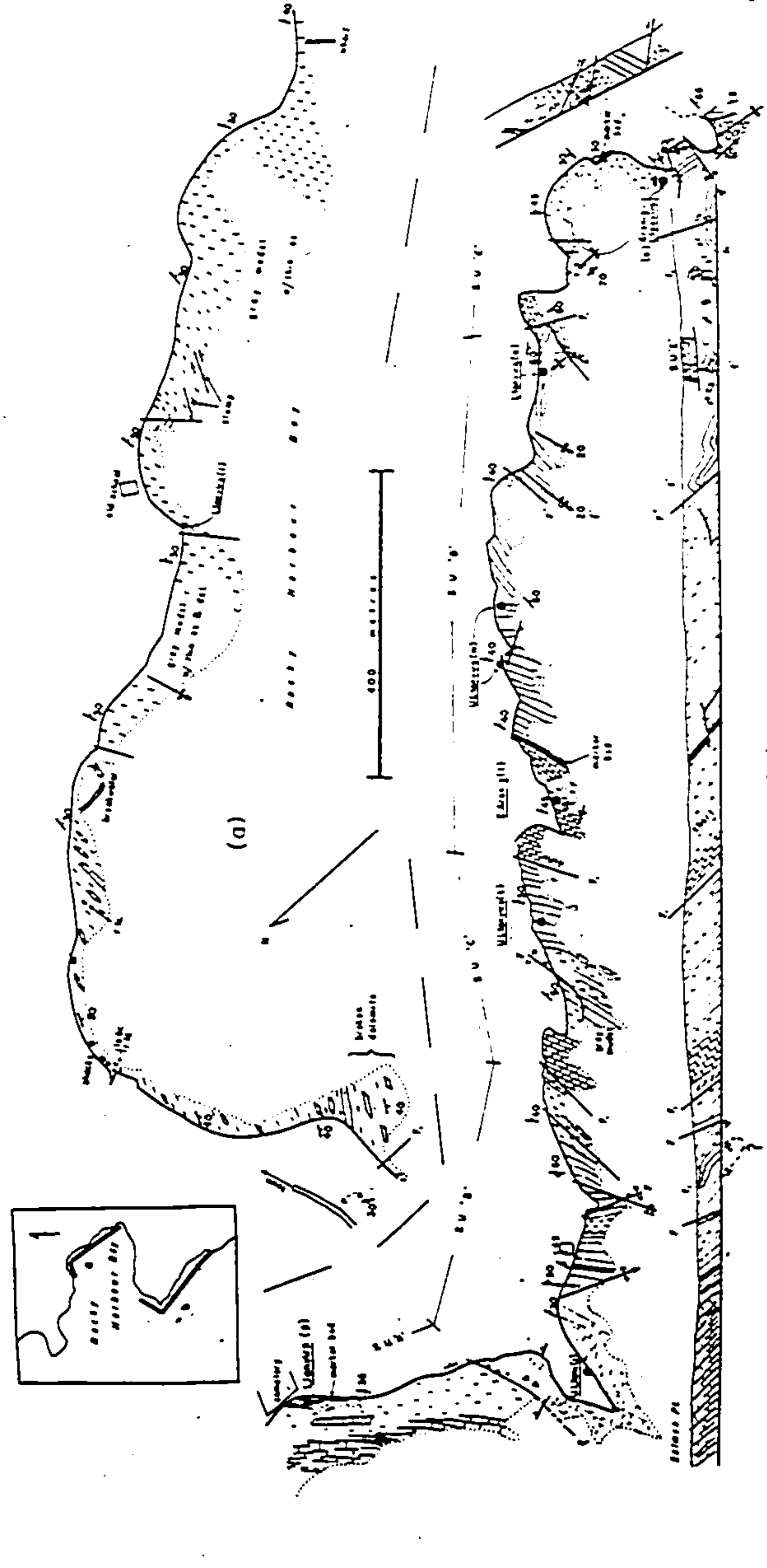

(a)
(b)
400 metres

Figure 7. Detailed sections in Rocky Harbour Bay and to the south.

Scale and orientation of the North are the same for both sections. Other characteristics as in Figure 6.


(a)
(b)

STRUCTURAL GEOLOGY

Most sections of the Curling Group are segmented by faults, and folded tightly in parts. The rocks are unmetamorphosed so rock types can be studied well, but correlation of lithofacies is obscured by the strong deformation.

The structural geology in each of the sections mapped in detail will be described separately commencing with the Rocky Harbour section, which is the better understood thanks to the numerous fossiliferous localities and the better exposures. A general characteristic of the structural style is the repetition of stratigraphy through faulting, giving rise to several 'structural units' that are bounded by faults. Each of these structural units comprises part of the shale unit and part of the sandstone unit, and within each structural unit the sequence is conformable and unbroken. In the detailed maps, the structural units are designated by letters preceded by the abbreviation SU (for example: SU'V'). The faults that limit structural units are designated by the subscript 1, that is: F_1, to distinguish them from other, less important faults.

Rocky Harbour section

Going westward across the steeply dipping but otherwise little deformed monocline of the carbonate sequence, deformation increases greatly in the Curling Group. The regional strike of the strata also changes markedly from a NS trend in the Table Head - and older - formations to a ENE trend in the Curling Group. Dips vary between 30 and 60 S (Figure 3).

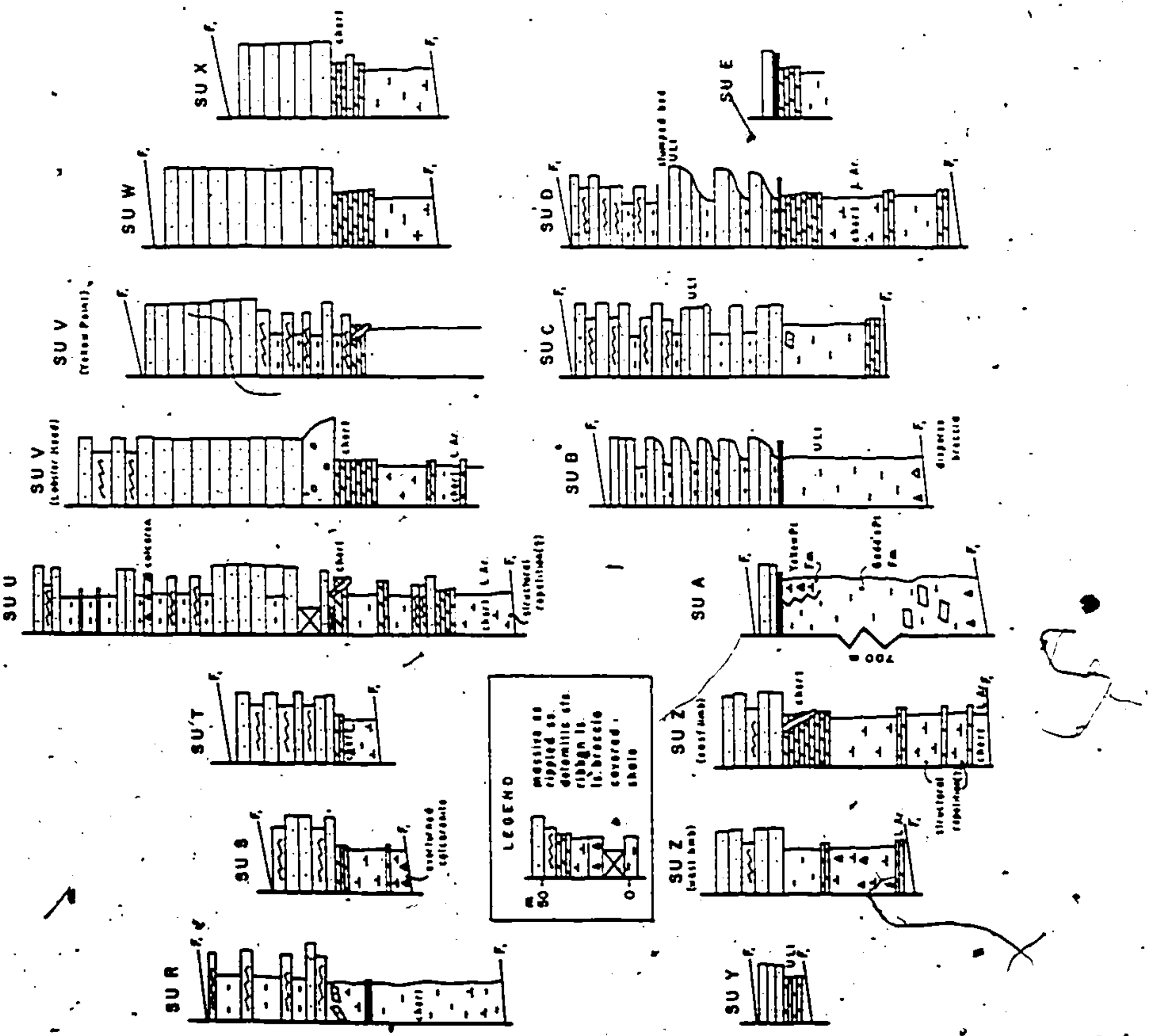
The Yellow Point-Lobster Head sequence is segmented into at least 14 structural units separated by F_1 faults. The northern end of the section has been left undivided because the structure is poorly understood. Likewise, SU 'E' is probably a composite of two structural units. In general, the structural units offlap to the south. The stratigraphic thicknesses of the structural units vary between about 50 m and 250 m. Repetition of the stratigraphy in each structural unit is indicated by lithologic correlation and by fauna (Figure 8).

The F_1 are mainly bedding-plane faults but in some places they change in attitude seaward, from bedding-plane to normal faults, for example in structural units V and W (Figure 6a). The F_1 are, in fact, zones of deformation, but thanks to the lithologic contrast between the Yellow Point and the Lobster Head, they can be mapped

Figure 8. Stratigraphic sections for all structural units.

Total thicknesses were measured on the map. In the Yellow Point Formation the order and thickness of different rock types represent the outcrops closely. In the Lobster Head Sandstone representation is schematic but the position of specific features such as cycles or distinctive beds, is accurate within the scale of representation. The cycles themselves are idealized and are far from being so nicely developed in outcrop.

Notice that SU A corresponds wholly to the Lobster Head Sandstone, whereas SU B,C,D, and D, the Yellow Point Formation, follows below the sandstones. This representation stresses the partial correlation between the Gadd's Point Formation and the Yellow Point Formation.


SU X
SU W
SU V
SU V
SU U
SU T
SU S
SU R
SU E
SU D
SU C
SU B
SU A
SU Z
SU Z
SU Y
LEGEND
massive ss
rippled ss
dolomitic stn
ribbon ls
ls breccia
covered
shale
chert
ULI
700 m

accurately. The zones of deformation are more extensively developed in the Yellow Point Formation and this will be described first.

The Yellow Point shows three main rock types: (a) dolomitic siltstone, which shows a brittle mode of deformation; (b) thin-bedded limestone alternating with shale, which shows a ductile mode of deformation; and (c) shale or sandstone, which is ductile where it is enclosed by the other rock types but brittle where it forms thick units.

The thicker units of dolomitic siltstone are generally undeformed: The thinner may be disrupted into fragments (boudins) 20 to 100 cm long and 10 to 50 cm thick (original thickness of the bed). Smaller fragments are biconvex, larger ones may show lozenge shapes. The fragments have been displaced parallel to the bedding and also rotated; it is seldom possible to reconstruct a fragmented bed for more than a couple of metres. Some beds show internal brecciation, or faults of very short displacement, that do not extend across the bed.

The thick units of shale or mudstone commonly show shearing subparallel to bedding; calcite veins may follow the planes of shear. In SU 'B' and 'C', shear has produced a rock with a fluidal, ignimbrite-like, texture, that forms units 1 to 2 m thick (Figure 14a). The fluidal aspect is given by stretched fragments of yellow dolomitic mudstone against the dark shale background. Shale units may also develop numerous small chevron folds with steep axial planes and amplitudes of very few cm. A few cases of shale injected into fractures in dolomitic siltstone were observed. In SU 'E', a brown-weathering mudstone with silty intercalations shows numerous medium-scale isoclinal recumbent folds.

The thin-bedded limestones are commonly deformed into harmonic, isoclinal, recumbent or gently inclined, folds with sharp hinges. Limb lengths range between 20 cm to 1 m (Figure 14b). The orientation of the fold axes and the vergence of the folds indicate the sense of movement if plotted as Hansen (1971) suggested. This was done for several structural units and the results are presented in Figure 15. Rotation of field measurements to account for bedding dip was done for each folded unit using the dip in an adjoining, less deformed exposure. In general, displacement of the structural units was westwards.

The Lobster Head Sandstone commonly shows boudinage near the F_1 faults or at the contact with the Yellow Point Formation. Boudins are roughly biconvex or elongated lozenges, with long dimensions in the order of 1 to 3 m (Figure 14c), both translation and rotation occurred. The boudins are generally isolated in shale and the original beds cannot be reconstructed.

In SU 'B' there is a large overturned syncline; the overturned limb can be found again on top of the cliff. It may be the result of local overthrusting towards the west or northwest.

Sandstone dikes and sills intrude the uppermost beds of the Yellow Point Formation. The thickest are about 30 cm thick and intersect the bedding at very low angles. Thinner dikes are variously oriented and may be folded. Some appear to have been emplaced along secondary faults. Dikes and sills can be recognized by their sharp tops and bases and lack of graded bedding.

An interesting structural feature is the presence of sandstone beds located along fault planes of normal faults (Figure 14d). These can be seen in different stages of development, the one shown in Figure 14d is an extreme case which could be confused with a sandstone dike.

The F_1 faults and the associated zones of deformation, as well as the boudinage in the Lobster Head Sandstone at the contact with the Yellow Point Formation, are regarded as the result of one and the same episode of deformation. The overturned syncline in SU 'B' may be a slump fold because it is very tight and parallel to bedding. The sandstone intrusions may have originated from pressure developed during that episode of deformation, as well.

Large folds, especially those with upright axial planes and associated with thrust faulting, may correspond to a different episode of deformation, at a later time.

As the sequence Yellow Point-Lobster Head is unbroken within each structural unit, deformation must have taken place after deposition of the Lobster Head Sandstone, approximately in the late Late Llanvirnian, or later. In the Rocky Harbour section, unfortunately there are no younger deposits covering the Lobster Head Sandstone, so it is not possible to put an upper limit to the time of deformation.

The results of reconnaissance mapping of the Curling Group south of the Rocky Harbour section, are shown in Figures 3, 4 and 5. The Lobster Head Sandstone is steeply dipping to slightly overturned along the shore from Little Green Point to Wild Cove, and is interpreted to form the western limb of a large anticline with axis approximately N-S.

Further south, in South Arm, is exposed the South Arm Formation of Troelsen (1947). Near the contact with the Gadd's Point Formation, the thick sandstone beds of the South Arm are thrown into several tight isoclinal folds with vertical axial planes oriented N-S (Figure 4, section IV). Along the eastern shore of South Arm, the formation is folded into a shallow syncline whose southern limb is underlain by lavas.

The structural style of the Rocky Harbour section, with structural units separated by F_1 faults, was not recognized to the south.

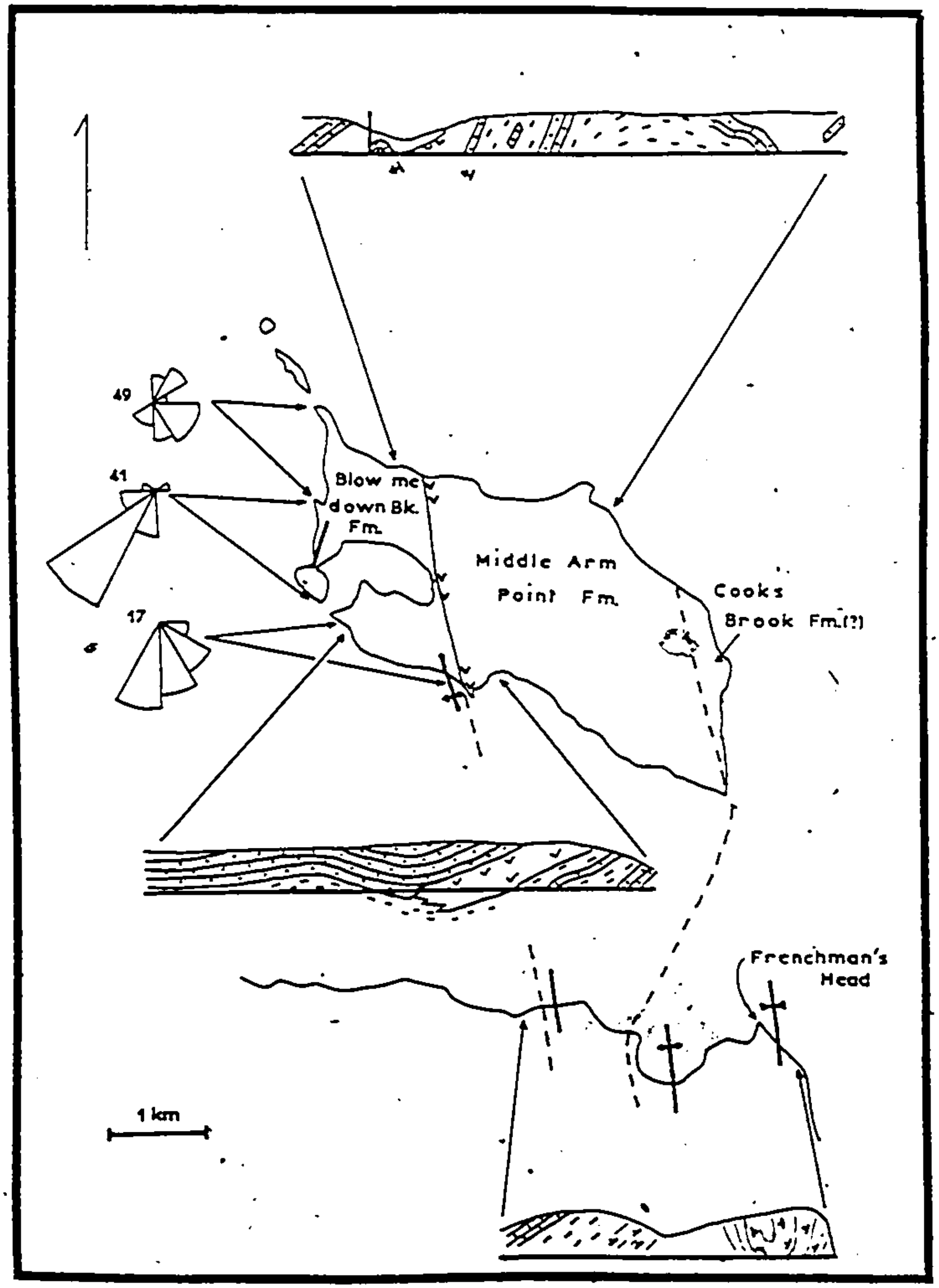
Woods Island section

The eastern two-thirds of the island are occupied by the Middle Arm Point and the Cooks Brook (?) Formations, but this area was only briefly studied. East of the schematic cross-section shown at the top of Figure 9, deformation is greater and zones of mélange alternate with well-bedded intervals. In this part may lie one or several F_1 faults.

The Blow-me-down Brook Formation occupies the western third of the island, above the pillow lava unit. Along the northwestern point of the island, these beds form a steeply dipping monocline with locally overturned strata. Along the southeastern shore of the island and in the area of the deep embayment, the strata are gently folded and low-lying. Numerous vertical faults cut the strata, and although displacements are small, they sufficed to impede correlation of beds while measuring the bed-by-bed section.

Figure 9. Geologic map of Woods Island and schematic cross-sections.

Paleocurrents from the Blow-me-down Brook Formation are plotted; number of measurements indicated. Thin solid lines indicate the stretch of shoreline represented by each of the insets.



49
41
17
Blow me down Bk. Fm.
Middle Arm Point Fm.
Cooks Brook Fm.(?)
Frenchman's Head
1 km

Woods Island differs in setting from the other sections in that is far away from the edge of the carbonate bank. This position may reflect an originally large separation, between the edge of the carbonate bank and the site of deposition of the Blow-me-down Brook Formation.

Black Point section

The carbonate sequence dips moderately towards the Curling Group, with a strike oblique to the shore, which it intersects at the south end of the section mapped in detail (Figures 10 and 11). The Curling Group here consists of a lower shale unit, with shales and thin-bedded marls, overlain by the Black Point sandstones. The shales are strongly sheared; small chevron folds are common. The thin-bedded marls show two styles of folding, one, in the southern part of the marl unit, consists of upright folds with straight limbs and sharp hinges; the other, in the northernmost part of the marl unit, consists of open and shallow folds with poorly defined axes (Figure 16a) (these folds could not be drawn in the cross-section).

Immediately to the north of the open folds is exposed the nose of a large recumbent anticline, with a horizontal axis trending EW. Most of the section to the south of this point is on the overturned limb of this

Figure 10. Geologic map for the Port au Port Peninsula compiled from Riley (1962) and Corkin (1965).

Paleocurrents from the Black Point and the Rocky Point sandstones are plotted; number indicates number of measurements. Inset shows structure for the Rocky Point section.

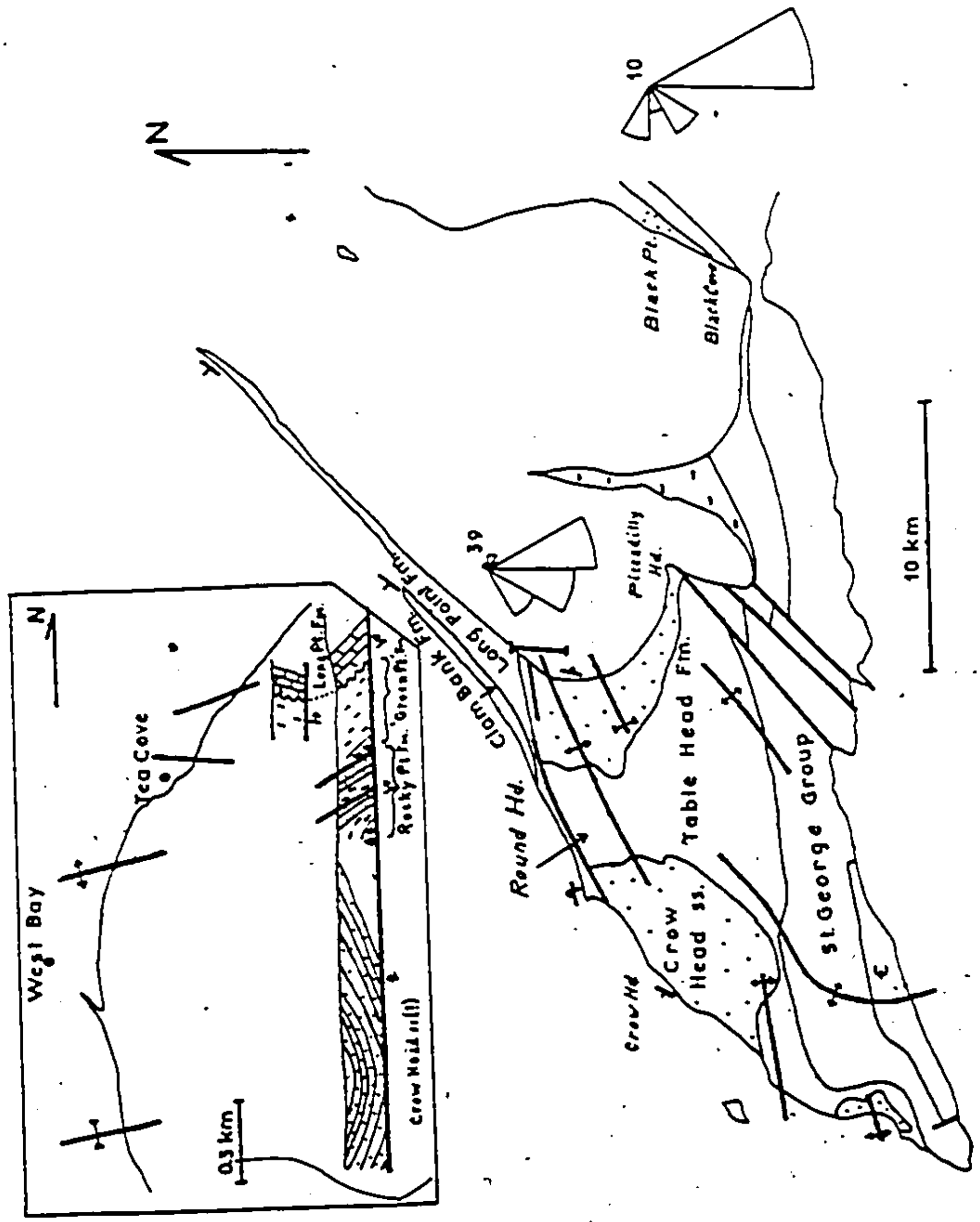
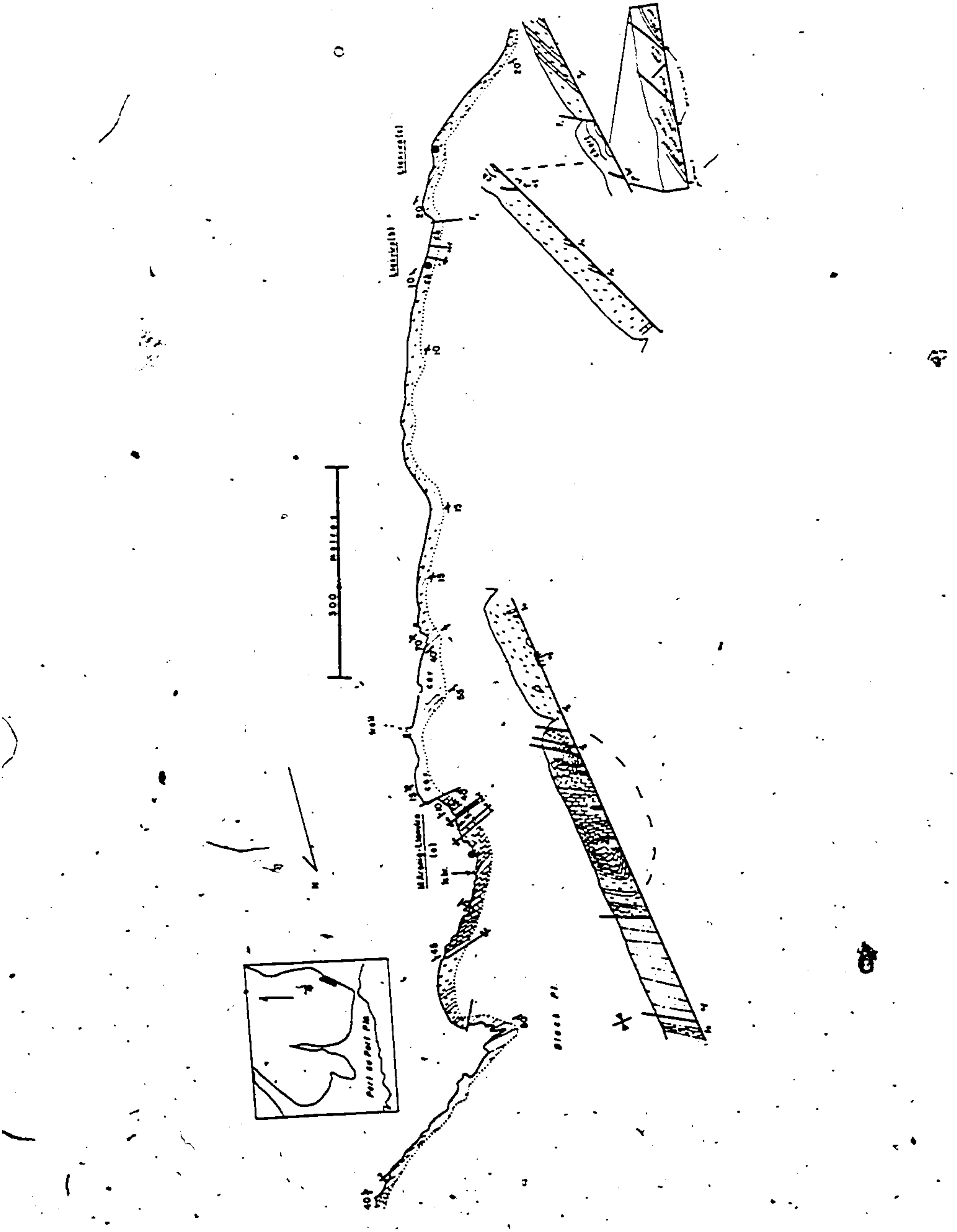

N
10
39
Black Pt.
Black Cove
Piccadilly Hd.
Long Point Fm.
Clam Bank Fm.
Round Hd.
Table Head Fm.
St. George Group
Crow Head ss.
Crow Hd
10 km
West Bay
Tea Cove
0.5 km
Long Pt. Fm.
Rocky Pt. Fm.
Crow Head ss (?)

Figure 11. Detailed section at Black Point.



anticline, for instance the sharp folds are in overturned strata while the open folds are in steep but normal strata. This overturned anticline had already been described by Stevens (<u>in</u> Neale, 1972, p.79). The attitude of the sheared shales between the nodular chert and the marl unit could not be determined.

The Black Point sandstones, for the most part, form an undeformed, steeply dipping monocline, but at the northern end of the section, a sandstone interval a few metres thick, underlain by marls, is definitely overturned. The contact of this unit with the main part of the Black Point sandstones appears to be a fault.

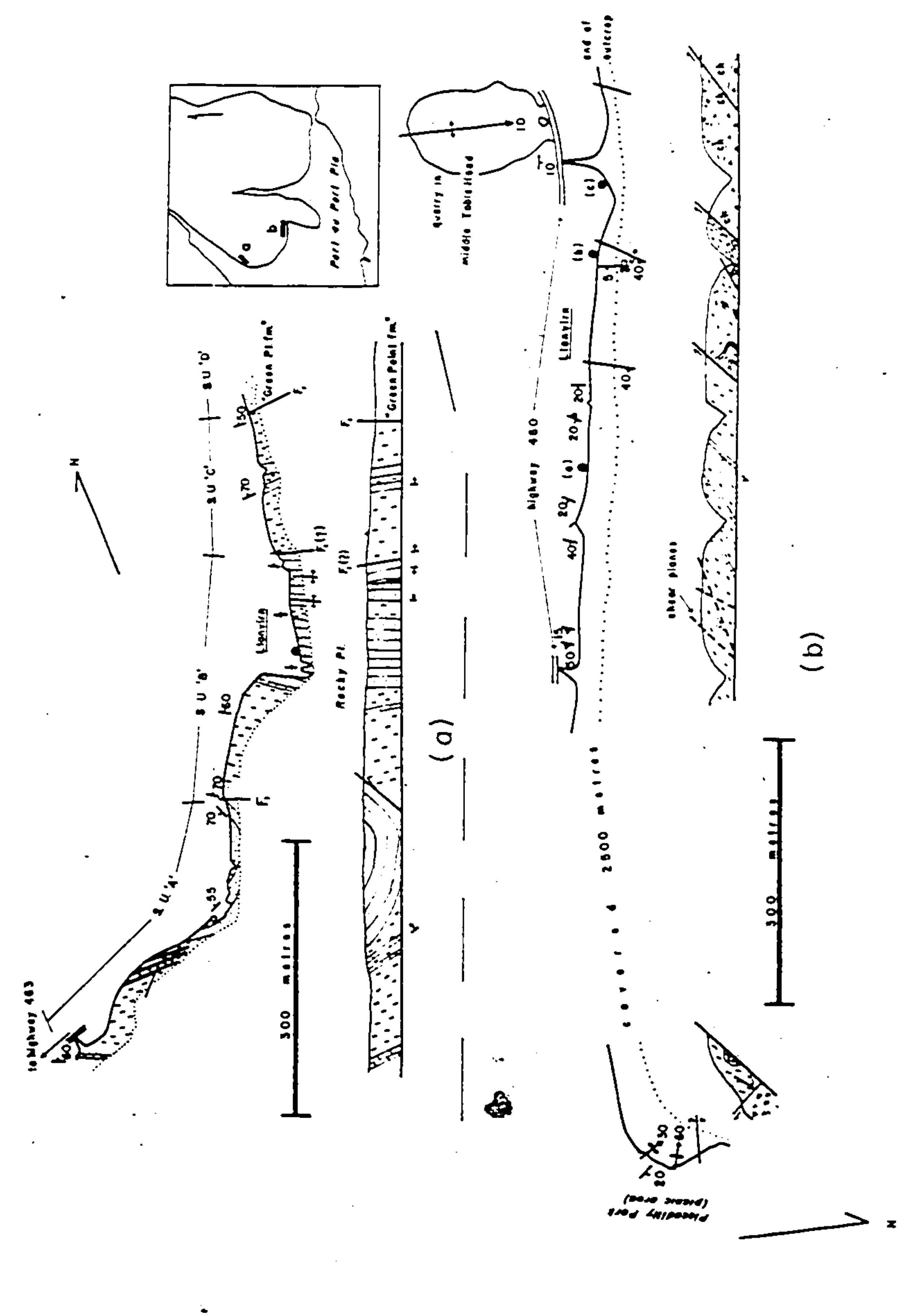
That part of the section where shales predominate, between the marls and the chert (Figure 11), is strongly deformed and shows numerous small-scale folds. Orientations of these fold axes are plotted in Figure 15. They indicate a northeastward sense of displacement.

The structural style of the Black Point section is similar to that in Bonne Bay, south of the Rocky Harbour section, that is, folding is more important than faulting.

<u>Rocky Point section</u>

The carbonate sequence is not exposed in the immediate surroundings of this section, the nearest exposures are 5 km

Figure 12. Detailed sections at (a) Rocky Point, and (b) Piccadilly Beach.



to Highway 463
S U 'A'
S U 'B'
S U 'C'
S U 'D'
Llanvirn
"Green Pt fm"
"Green Point fm"
Rocky Pt.
300 metres
(a)
Port au Port Pta
Quarry in Middle Table Head
Highway 460
end of outcrop
covered 2500 metres
shear planes
300 metres
(b)
Piccadilly Park (picnic area)
N

to the south in Piccadilly Beach and 4 km to the west, near Crow Head (Figure 10). The Curling Group is segmented into at least 4 structural units, separated by F_1 faults, and offlapping to the north (Figure 12a). The two southern structural units can be correlated well thanks to the presence of the well developed shale and sandstone units (Figure 13). In the other two structural units this division is not apparent and correlation is doubtful.

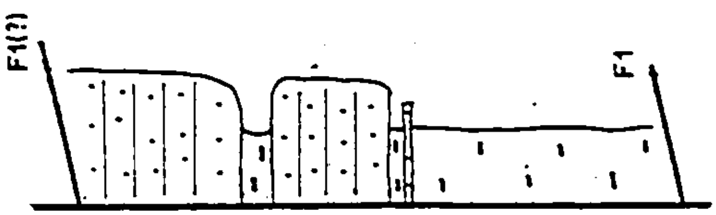
Graptolites found in the sandstones in SU 'B' and regional correlations suggest that the Rocky Point sandstones are Upper Llanvirnian and the shale unit is mainly Arenigian and Lower Llanvirnian. In SU 'D', however, is exposed the 'Green Point Formation' of Schuchert and Dunbar (1934) which contains Lower Tremadocian graptolites in its upper part (the formation is 400 m thick), and whose lithology is somewhat different from that in the shale unit of the other structural units. At the base of SU 'D', apparently conformably below typical green shales of the Green Point Formation but with the contact covered, are calcarenites and limestone breccias. Similar rock types form the lowermost beds in SU 'A'. Since rock types as these are absent anywhere else in the Rocky Point section, it is quite possible that the two lithologies are correlative.

North of the base of SU 'D', the shoreline cuts the

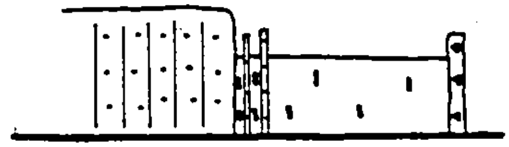
Figure 13. Stratigraphic sections for two structural units in the Rocky Point section.

Total thicknesses were measured on the map. Limestone breccias cropping out at the base of SU 'A' may be correlative with limestone breccias below (?) the 'Green Point' formation shown in Figure 10, inset.

SU B



SU A



Green Point Formation obliquely upsection. At the top of the formation, some sandstones occur (Riley, 1962). Rodgers (1965) mentioned the presence of 'Humber Arm sandstones' unconformably underlying the Long Point Formation. If these sandstones are conformably above the Green Point Formation the whole sequence might range from Lower Tremadocian to Llanvirnian. In conclusion, there exists the possibility that - as in Rocky Harbour - all the structural units are the same age.

The overall structure of this section is a syncline-anticline pair, with the northern limb of the anticline gradually passing from normal to overturned towards the west (Figure 10, inset).

There is no indication of the direction of movement of the structural units during sliding. Judging from the orientation of the folds in Piccadilly Beach (Figure 12b), movement could have been westwards.

The Rocky Point sandstones are unconformably overlain by the Long Point Formation, which does not show the same style of deformation as the Curling Group. This led Rodgers (1965) to conclude that the Curling Group had been deformed before Long Point time, that is, before the latest Llanvirnian (cf. Chapter Two).

Figure 14.

(a) Fluidal texture in mudstone. Upper part of the Yellow Point Formation in SU 'C'. Light gray areas are fragments of yellow-weathering dolomitic mudstone; dark areas are gray mudstone; white veins are of calcite. Hammer handle for scale. Note larger boudins. Small folds indicate movement to the right (west).

(b) Slump folds in ribbon limestone; Yellow Point Formation. Bedding dips steeply to the left. Folds such as these were plotted in Figure 15. Note difference in bed thickness among limestone beds.

(c) Boudins in sandstone near base of the Lobster Head Sandstone. It is possible to correlate coarser bottoms in the two fragments. Boudins appear to result from the intersection of two faults at low angles to bedding: one fault runs along the point of the hammer and cuts the thin bed below; the other fault would follow the upper boundary of the bed, crossing the handle of the hammer. The upper part of the sandstone bed must have been faulted away.

(d) Oblique sandstone; medium-bedded massive sandstones; thickening upwards cycle; in SU 'B'. The oblique sandstone can be followed across the platform to the right. The sandstones show cementation bands; one is shown by the arrow. A thickening-upwards cycle can be seen on the right, forming the cliff. Cliff is about 12 m high.


a
b
c
d

Figure 15. Plots of folds axes orientation taken mainly from units of ribbon limestone.

Vectors indicate sense of movement of the submarine slide at the end of its trajectory. Vectors located as explained in Hansen (1971).

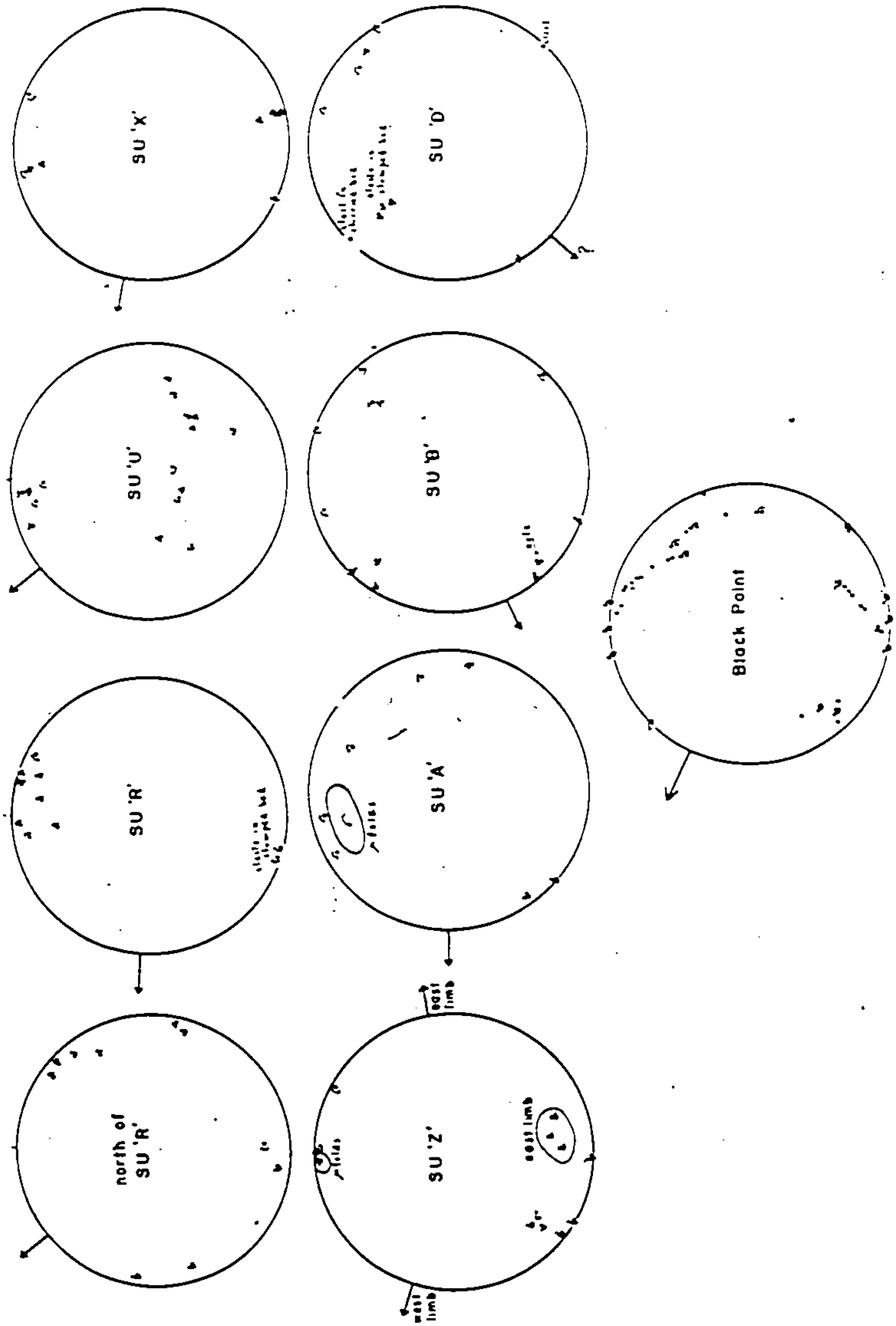

SU 'X'
SU 'D'
SU 'U'
SU 'B'
Black Point
SU 'R'
SU 'A'
north of SU 'R'
SU 'Z'
east limb
west limb

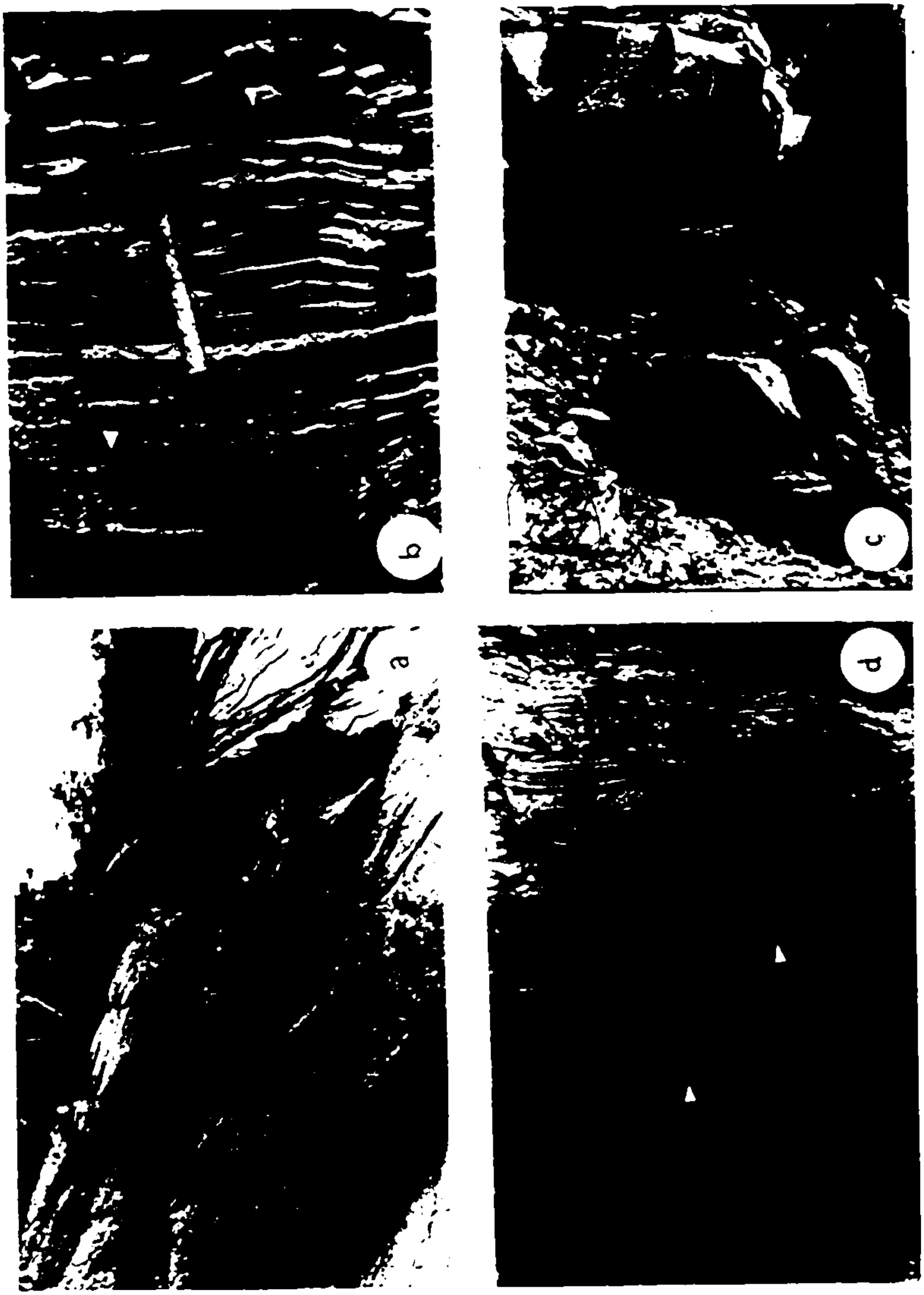
Figure 16.

(a) Open folds in green and red marls at Black Point. The folds could be slump folds. The marls are evenly bedded and brittle.

(b) Ribbon limestone in the Yellow Point Formation. Black shale interbeds relatively thin. Note parallel lamination in several limestone beds. Arrows show beds of nodular limestone. Base to the right.

(c) Cyclic dolomite in the Yellow Point Formation. Three cycles are shown. Light gray areas are yellow dolomitic siltstone. The uppermost cycle has little green and black shale at the base. Note that black (or gray) laminations disappear upwards in each cycle. A thin unit of ribbon limestone, in parts nodular, occurs near the base of the central cycle, below the hammer; isolated beds of limestone also occur near the base of the lower cycle. Base to the left.

(d) Detail of lower cycle. Note disappearance of gray laminations at the top. Arrows point to bands where horizontal and oblique burrows can be seen; they are light coloured in the dark bands and dark in the light bands. Burrows are very thin and short streaks, in photo. Do not confuse with weathering marks as in the lower right edge of photo. Green and black shale below hammer. Base to the left.



DISCUSSION

Lithological correlation and fauna indicate that the shale and the sandstone units are, respectively, time equivalent throughout western Newfoundland. It appears reasonable, then, to extrapolate to the other areas the upper time limit for the deformation of the Curling Group established by Rodgers (1965) for the Rocky Point area. The Curling Group would have been deformed during the latest Llanvirnian.

The vergence of the folds in the Rocky Harbour and Black Point sections definitely shows that the movement of the structural units was broadly westwards. The structural geology gives no indication of the displacement along the F_1 faults; this problem will be discussed in a later chapter.

Figure 17 illustrates a manner of sliding that explains the aberrant strike of the strata in many exposures of the Curling Group. The figure can be interpreted as illustrating a short-distance movement from the edge of a basin, or the last stage in the emplacement of a far travelled nappe.

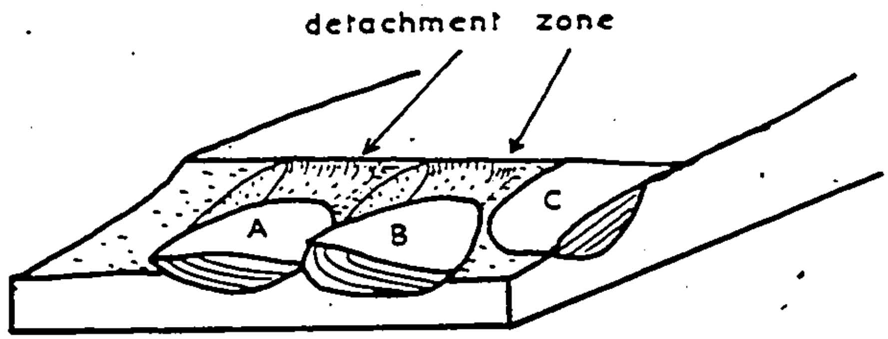


Figure 17. Hypothetical geometric representation of submarine sliding in the Curling Group.

Blocks A and B have slid and are at rest. They have left a slump scar here called detachment zone, characterized in the field by strong deformation. Block A shows sub-horizontal bedding. Block B slid in the same fashion as A, but one of its sides onlapped on block A, causing the beds in block B to tilt and acquire a transverse strike direction with respect to the original depositional strike. Block C has not yet slid, but the F_1 fault that will accommodate its movement is shown.

CHAPTER FOUR

CURLING GROUP - LITHOLOGY OF THE SHALE UNIT

The lithologies of the shale will be described in order. The results of reconnaissance work outside the areas mapped in detail will be included but clearly separated in the text. Rock types will first be described as independent entities for the area as a whole. In a second section, the vertical and lateral variations in rock types will be given for each of the sections. Finally, facies changes in the area as a whole will be described.

The shale unit was studied in the Rocky Harbour, Black Point, and Rocky Point sections, but not in the Woods Island section.

ROCK TYPES

Shale and mudstone are the predominant rock types in the shale unit. Black, red, and green shale, and green and gray mudstone, are present. The fissility of the of the shale may be locally obliterated by deformation or bioturbation, so the term 'shale' as used here includes argillites. A cursory mineralogical and chemical examination of the shales and mudstones was carried out to check for significant differences in composition, which would suggest different source areas.

The clay mineral composition is similar in all varieties: 13 samples were studied, of which 11 contained illite (muscovite type) and chlorite; the other two samples are from two laminae in the same hand sample, and showed only illite peaks. (Several samples treated with glycerol did not show the presence of expandable clays. Kaolinite appears to be absent because the peak around 7 Å is very broad and disappears when chlorite is absent, but no special test for kaolinite was carried out.).

The black shale is relatively rich in finely crystalline opaque minerals, which in thin-section appear as stringers or small clusters. Their composition was not determined but they may be pyrite because nodules of pyrite 1 to 4 cm in diameter are common in the black shale and heavy mineral separates from crushed shale show abundant pyrite. As shown in Table IV, black shale is rich in inorganic and organic carbon, that is, it is calcareous and relatively rich in organic matter. Very thin

Table IV. Results of inorganic and organic carbon analyses

Sample	Lithology	Total	Carbon Inorg.	Org.
RH48	limestone in ribbon ls.	5.13	4.35	0.78
RH58	limestone in ribbon ls.	7.88	6.96	0.92
RH10	gray shale in sandstone	4.02	3.64	0.38
RH179	gray mudstone	1.22	0.66	0.56
RH221	green shale	0.05	0.03	0.02
RH240	black cherty shale	1.84	1.80	0.04
RH243	black shale in ribbon ls.	4.97	4.37	0.60
RH257	gray mudstone	0.64	0.33	0.31
B27	green shale	0.84	0.27	0.57
B21	green chert	1.46	1.02	0.44
B50	green shale in ribbon ls.	0.59	0.41	0.18
R13	red shale	0.13	0.07	0.06
R13	green shale	0.08	0.01	0.07
R23	green shale in sandstone	0.40	0.32	0.08
R28	gray shale	1.07	0.49	0.59
R29	red shale	0.03	0.02	0.01
R29	green shale	0.03	0.02	0.01

O. Mudroch, analyst

(less than 3 mm) lenses and laminae of limestone were seen in the field, in black shale units. The black colour is probably due to the organic matter and the opaque minerals. Graptolites are commonly found in black shale.

Red shale is poor in organic and inorganic carbon (Table IV). Hematite (?) was identified in the diffractograms and may give the red colour. Green shale is poor in organic carbon (Table IV). The samples of green shale analyzed for carbon were from finer-grained, more shaly, varieties, and show a low content of inorganic carbon. Slightly coarser-grained, mudstone, varieties show dolomite in diffractograms and thin-sections. The dolomite is finely crystalline and euhedral, and may be abundant. These dolomitic varieties of green shale are transitional to <u>dolomitic siltstone</u> (described below). Nodules of pyrite may be present in green shale.

Gray shale generally lacks fissility and should be called a mudstone. The yellowish-weathering colour, in places, and diffractograms, show that it is commonly dolomitic. No carbon analyses were made of gray mudstone.

Table V presents chemical analyses for 7 samples of shale from the Curling Group. The analyses were done, by Mr. O. Mudroch, McMaster University, by X-ray fluorescence. RH240 is from a cherty black shale; the other samples (RH221, R13, and R29) are from green and red, and

Table V. Chemical analyses of shales

	R13		R29		RH221		RH240	Av.
	green	red	green	red	green	black		shale[1]
SiO_2	65.45	64.26	68.15	62.55	63.56	67.10	73.16	58.10
Al_2O_3	15.12	14.63	13.86	13.54	13.29	13.04	9.25	15.40
Fe tot.	4.55	6.45	4.28	10.22	7.74	6.07	6.47	6.47
MgO	6.89	6.73	6.54	6.27	8.78	7.71	7.69	2.44
CaO	1.09	1.22	1.02	1.10	0.51	0.34	0.30	3.11
Na_2O	0.64	0.59	0.63	0.60	1.52	1.14	0.80	1.30
K_2O	5.26	5.13	4.40	4.62	3.64	3.81	1.72	3.24
TiO_2	0.83	0.82	0.70	0.75	0.74	0.69	0.54	0.65
MnO	0.10	0.11	0.39	0.24	0.04	0.04	0.05	-
P_2O_5	0.06	0.06	0.05	0.10	0.17	0.08	0.03	0.17

1 Average shale taken from Pettijohn (1957, Table 61).

Analyst: O. Mudroch

green and black, laminated shales. From each of the latter three hand samples, the different colours of shale were separated by hand and analyzed separately; this gave the total of 6 samples. The last three columns are for comparison purposes; the first two give average compositions for red and for blue and green, deep-sea clays, the third is a general average of shale composition.

The samples from the shale unit show more silica and less alumina than the averages on the right of the table. The greater amount of silica may be due to a greater proportion of quartz, either in the form of detrital quartz grains or of recrystallized radiolarian tests; the proportion of alumina would be inversely tied to the silica. Magnesium is markedly higher than in the averages, showing that the Curling Group shales are dolomitic.

The samples from Rocky Point (designated R) show a ratio Na_2O/K_2O much lower than the samples from Rocky Harbour (designated RH); the latter show more typical values. On the other hand, the content of calcium is higher in the Rocky Point samples than in the Rocky Harbour samples. The causes for these differences are not known. One possibility is that each area had a different source lithology. But as the samples from Rocky Point are oxidized, it is also possible that an original uniform composition was modified within the basin of deposition.

Considering the green/red couples from Rocky Point (designated R), the red shale is richer in iron than the green shale. The same relationship, although less marked, is shown by the averages of deep-sea clays. The data is too scarce to allow a generalization; the difference may reflect an original difference in the source material, or it may be due to changes occurring within the basin of deposition.

Each of these varieties of shale may form units by itself but more commonly they are intimately associated. The most common association is green and black shale, which shows alternating black and green laminae 1 to 4 mm thick, with sharp contacts, to form units that may be several metres thick. The proportion of each variety of shale varies greatly and anyone may predominate. Green and black shale units are characterized by intense burrowing that destroyed much of the lamination. The burrows are horizontal or gently oblique to bedding (chondrites) (Figure 16c).

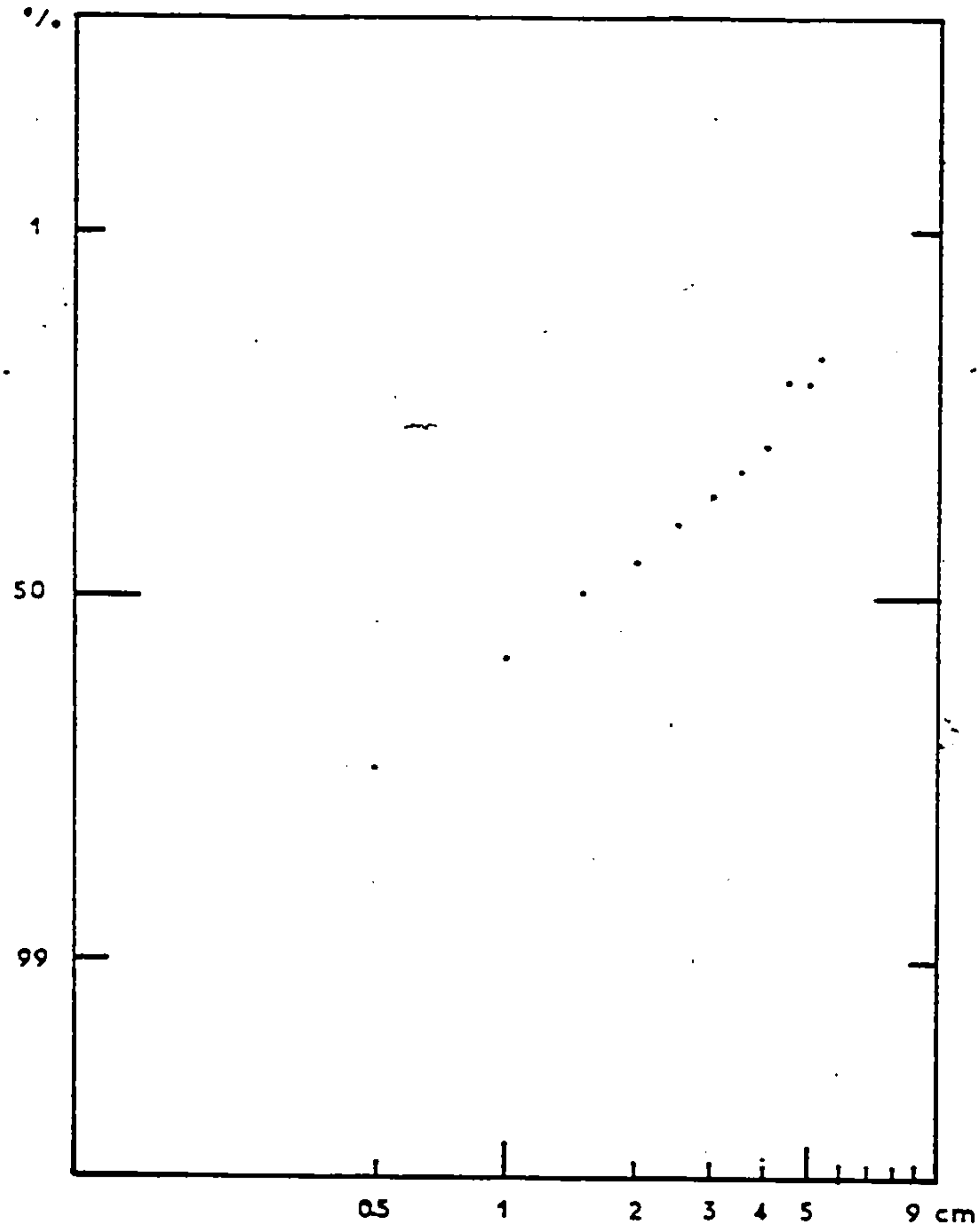
An infrequent but significant association is of green and red shale. It is like green and black shale in structure but, in the exposures seen, bioturbation is practically absent. The significance of this association lies in that it suggests that the red and the black shale are homologous, differing only in the state of oxidation of the iron minerals and the content of organic matter. Nonetheless, it should be noted that the available analyses of black and red shale (Table V) show that the iron content, with respect to the associated green shale, is markedly different.

Ribbon limestone is a convenient descriptive name for the units of thin-bedded, gray limestone, interbedded with dark shale in such a way that the limestone beds stand out as ribbons (Figures 14b, 16b). The origin of the name is unknown to the author.

Where best developed, ribbon limestone consists of light gray limestone (dark gray on fresh fracture) alternating with black shale. The limestone is micritic, with flat and commonly sharp top and bottom. Faint parallel lamination is common but many beds are massive; ripple lamination was noticed only in a couple of cases, forming sets less than 1 cm thick. The thickness of the limestone beds is constant laterally within the extent of the outcrops. The thickness of different beds may range from 0.5 to 10 cm, over a 1 m thick interval. The thicknesses of 50 consecutive beds were measured over a 1.5 m interval; they showed lognormal distribution like any other bed thickness distribution (Figure 18). Units of ribbon

Figure 18. Cumulative distribution of thicknesses of 50 consecutive limestone beds in a ribbon limestone unit in the Yellow Point Formation.

Logarithmic-probability plot. Distribution is closely lognormal.


%
1
50
99
0.5
1
2
3
4
5
9 cm

limestone range from a few beds to units 20 m thick. The limestone is rich in organic carbon (Table IV). Bioturbation is weak in general but some limestone beds show numerous vertical burrows (including U-tubes).

A departure from typical ribbon limestone is formation of nodular limestone. In this case, nodules of micritic limestone, mostly not more than 3 cm thick and 20 cm long, are interbedded with shale. Nodular limestone is very scarce. Many nodules can be seen to be bounded above and below by very thin laminae of black shale; to the sides, these laminae follow the contour of the nodule, approaching each other to define a lamina only a few mm thick (Figure 16b). If this lateral variation in thickness is mainly the result of differential compaction between the shale and the early-lithified nodule, compaction must have amounted to 50 or 60%.

The shale interbedded in the ribbon limestone is black shale, green and black shale, or yellow-weathering, gray, dolomitic mudstone. The first two varieties are more common. The thickness of the interbeds varies from a parting to several decimetres thick. Typically the interbeds account for 40 to 70% of the thickness of the ribbon limestone units.

A few ribbon limestone units show intercalations of calcarenite. Also, medium- to coarse-grained calcarenites, in beds 10 to 15 cm thick separated by shale partings, may form units a few metres thick. The calcarenites commonly show only parallel lamination but ripple lamination may be present. Two thin-sections showed 70 to 80% of micrite intraclasts, subrounded to well rounded, plus traces of quartz and bioclastic limestone, in 15% sparry cement; fragments of crinoids are abundant in some beds. Heavy mineral separates from ribbon limestone and from calcarenites contain almost exclusively pyrite.

Units of calcarenite and of ribbon limestone show an overall similarity that suggests the same mode of deposition for both. Supporting this idea is that the middle member of the Table Head Formation, which typically consists of micritic ribbon limestone, may show (for example, in outcrops near Western Brook Pond) medium-grained calcarenites, some with ripple trough lamination. It is quite possible that the relation between micritic limestone and calcarenite is a distal-proximal relationship. Nevertheless, the mechanism of deposition is in doubt. A likely choice is turbidity currents but the scarcity of graded bedding and the absence of sole marks, pose a problem.

Marl. Thin (less than 10 cm thick) beds of green, occasionally red, marl, occur interbedded with green or red shale (Figure 16a). The marl beds show gradational tops and bottoms, in general, but some show sharp bases. Parallel lamination is common but many beds are massive; a few show ripple trough cross-lamination. Bioturbation is moderately strong, with vertical and horizontal burrows (including U-tubes). Marl may form thick, evenly-bedded units or isolated beds.

It is possible that marl is only a variety of ribbon limestone, more silty, but gradual transitions between ribbon limestones and marls were not observed.

Dolomitic siltstones. This rock type is conspicuous for its bright yellow colour on weathered surfaces. It consists (Figure 16c, 16d) of dark gray laminations or bands, mostly less than 1 cm thick, alternating with yellow dolomitic siltstone or mudstone bands, mostly less than 2 cm thick. The yellow bands are gray on fresh fracture. Thin sections show the yellow bands to be finely crystalline dolomite, in parts with ripple lamination, whereas the dark laminae are micritic or dismicritic, with a dusty aspect possibly due to clay plus iron oxides, and streaks or small clusters of iron oxides and opaque minerals, they are slightly dolomitic (dolomite rhombs can be seen), but most of the carbonate is micritic calcite. The proportion of siliciclastic material, always silt-size, may vary from traces to about 30%.

Dolomitic siltstones appear associated with green and black mudstone to form cycles. Typically the cycles show green and black mudstone in the lower part that pass rapidly but gradually to yellow dolomitic siltstones (Figures 16c, 16d). The thickness of the laminations and the grain size increase upwards, the top is sharp and is followed by a black lamina that marks the beginning of the next cycle. In most cases, though, the top is not so sharp but passes gradually again into green and black mudstone of the next cycle. The thickness of cycles varies from less than 1 m to 2 or 3 m. Usually only a few cycles occur together. This variety of dolomite will be called 'cyclic dolomite'.

Cyclic dolomite is a more silty and more dolomitic variety of green and black shale, in which the bands of green shale are replaced by yellow dolomitic siltstone. The transition between green shale and dolomitic siltstone suggests a common source area.

Another variety of dolomitic siltstone, here called 'thinly-bedded dolomite', is commonly found immediately below the sandstones of the Lobster Head Sandstone, although

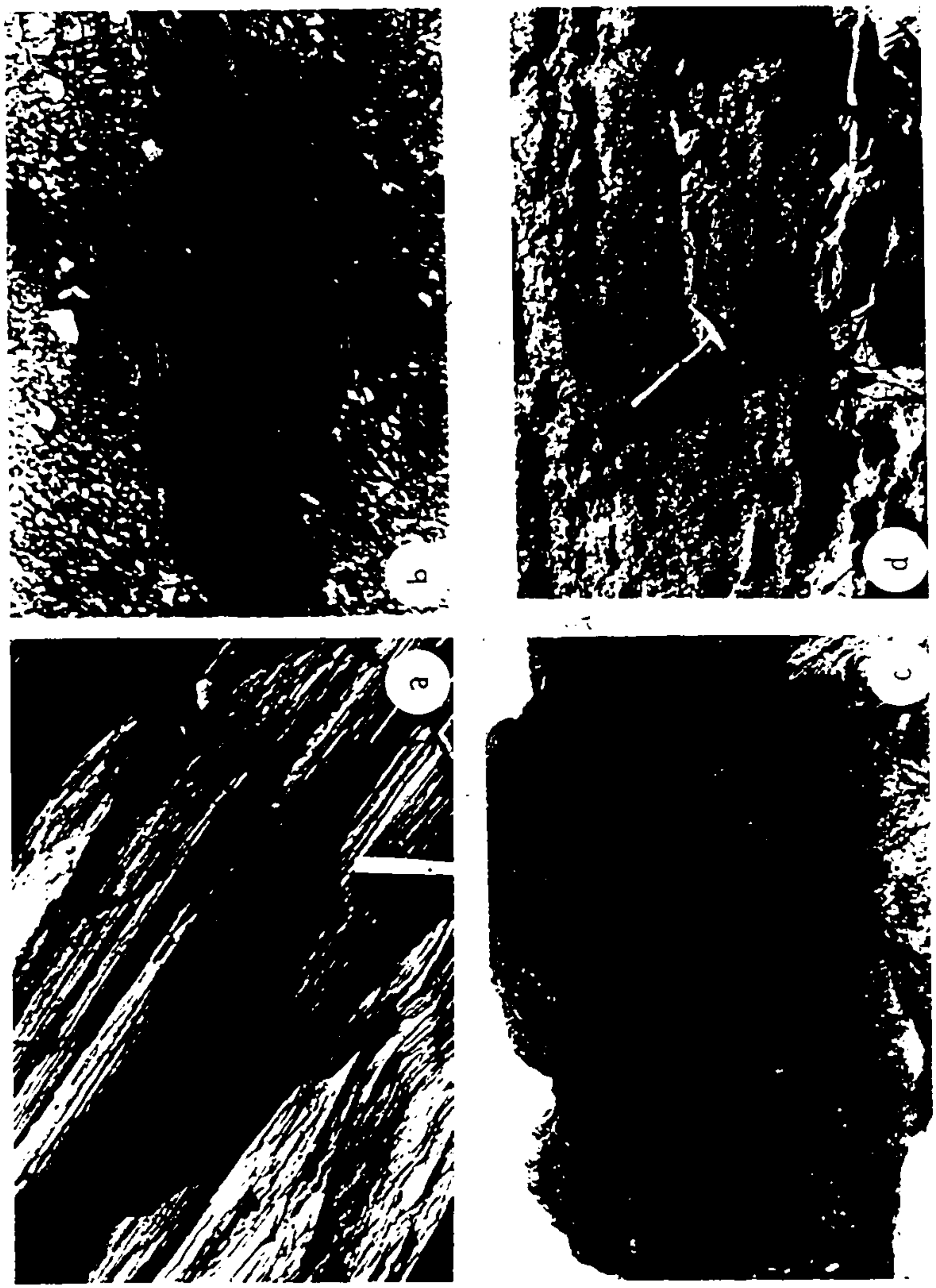
Figure 19.

(a) Thinly-bedded dolomitic siltstone in the Yellow Point Formation. Yellow siltstone beds stand out relative to the gray mudstone. Beds show parallel lamination or parallel parting.

(b) Fine-grained sandstone intercalated in abundant green shale; upper member of the shale unit at Black Point. Note massive (shows parallel lamination in the field) lower half, and sharp transition to upper half with sinusoidal lamination. Other beds show ripple cross-lamination and convolute lamination in the upper half. These beds are very similar to those in the Piccadilly Beach sandstones.

(c) Polymictic conglomerate in the Lobster Head Sandstone; SU 'V'. Green-gray shale at base underlain by massive thick sandstone.

(d) Polymictic conglomerate, same locality as (c). Illustrates part of the southern half of the conglomerate unit, where it is underlain by massive thick sandstone. Shows granule and pebble conglomerate with layers of sandstone.


a
b
c
d

not exclusively there. It consists of yellow bands 2 to 5 cm thick; with parallel lamination (rarely with ripple cross-lamination), alternating with gray mudstone that appears massive or faintly laminated (Figure 19c). The yellow bands show thin and discontinuous laminae of black, or gray, shale. The gray mudstone appears to be a dolomitic variety of black shale.

Bioturbation is very strong in dolomitic siltstones and of the same type (chondrites) as in the green and black shales (Figure 16c).

Chert is a rock type that resulted from the addition of silica to any of the rock types described previously. It is better developed in green and black shale and in thinly-bedded dolomitic siltstone. In thin-section, scattered spherical amygdules infilled with microcrystalline quartz are seen and may be radiolarian molds. Where developed in green and black shale, chertification is thorough, in other cases it is incomplete, forming nodules with gradational boundaries. One calcarenite unit shows a black nodular chert developed between the calcarenite beds.

The assertion that the chert resulted from simple addition of silica, is based on field evidence and thin-sections. For instance, chert from green and black shale shows the laminations and burrowing that characterizes the non-chertified green and black shale. Nodular chert in green mudstone shows nodules that are well chertified in the centre and gradually pass outwards to non-chertified green mudstone. The colours change slightly to become duller where the rock is chertified.

The question of whether cherts result from the simple addition of silica or a more complex combination of factors, does not seem to have received much attention. Mpodozis (1977) carried out a thorough chemical study - including trace elements - of cherts from Greece, and showed that simple addition of silica was involved. Presumably the silica was deposited as radiolarians. The ultimate origin of the silica, however, remains in doubt. At present, the prevalent opinion is that silica was derived directly from the continent by erosion (Calvert, 1966; Garrison, 1974; Mpodozis, 1977; Steinberg et al., 1977).

Limestone breccia. Two types of limestone breccia can be distinguished. In the more common type, larger clasts are flat pebbles or cobbles of micritic limestone, derived from ribbon limestone, plus clasts from black cherty mudstone, calcarenite, or limestone breccia, granite pebbles may be present. Clasts are well packed in a calcarenite matrix. Beds are less than 1 m thick, with flat bases; normal grading is rarely present.

The other type of breccia shows equant limestone clasts, plus some chert, scattered in a gray or green mudstone matrix. This breccia does not appear to form well defined beds. This second type will be called 'disperse breccia'. Although very poorly represented, disperse breccia has a special significance because it appears to be equivalent to the Table Head Limestone breccia. Disperse breccia resembles the diamictite at Black Cove (c.f. Chapter Two).

The well defined beds of limestone breccia could have been deposited by turbidity currents judging by the sharp bases and the - scarce - normal grading. The beds of disperse breccia could represent deposits from debris flows or slumps. In addition, there are beds of limestone breccia that appear to have undergone very little transport before deposition and that seem to have originated from the breakage of ribbon limestone during slumping: the clasts are very tightly packed but disorganized. Such beds are found in SU 'Z' (west limb) (Figure 8).

Discussion

The origin of the colour in shales and, in particular, the origin of red shale, has been extensively discussed (Grim, 1951; Berner, 1971; McKerrow and Ziegler, 1971; Ziegler and McKerrow, 1978). The essential conditions for red shale are: (a) that the material be oxidized before burial, and (b) that organic matter be absent when burial takes place. The first condition is probably satisfied by most detritus derived from land, even if it is not derived from laterites, because during weathering and the prolonged transport to the sea, it would become oxidized. The second condition is crucial because if organic matter is present, even detritus originally red can be changed to green by reduction (Hinze and Meischner, 1968).

Destruction of the organic matter can be accomplished by oxidation at the bottom or as it settles through the water column. Under special conditions, an 'oxygen-minimum layer' may form and can create reducing conditions at the bottom (Sverdrup et al., 1942; Stefansson et al., 1971). The same result may be obtained if bottom circulation is restricted by topography and the bottom water is stagnant. In both cases, any organic matter that reaches the bottom will be buried. In the end, whether organic matter is buried or not - or, symplifying, whether black or red shale is formed - depends on the balance between supply and destruction of organic matter.

The associations of green and black and of green and red shales, suggest that black and red shales were identical in composition at some point in time, and that the difference in colour is the result of processes taking place within the basin before burial. If so, the origin of the clay fraction would have been the same for both. Green shale, on the other hand, could have a different origin. As will be shown below, green shale may be interpreted as derived from erosion of the Burlingtonian Orogen; if so the green shale would be hemipelagic.

Deposition of the shale could have taken place by slow settling of clay particles through the water column or it could have been deposited by turbid-layer transport (Moore, 1969), which is a turbidity current of very low density and very low velocity.

It may be envisaged, for example, that the black (or red) shale was the 'normal' deposit and that the green shale was emplaced sporadically (for example, during floods or storms). Alternatively the change in colour could have been caused solely by changes in chemical conditions within the basin (for example, fluctuations of the oxygen minimum layer).

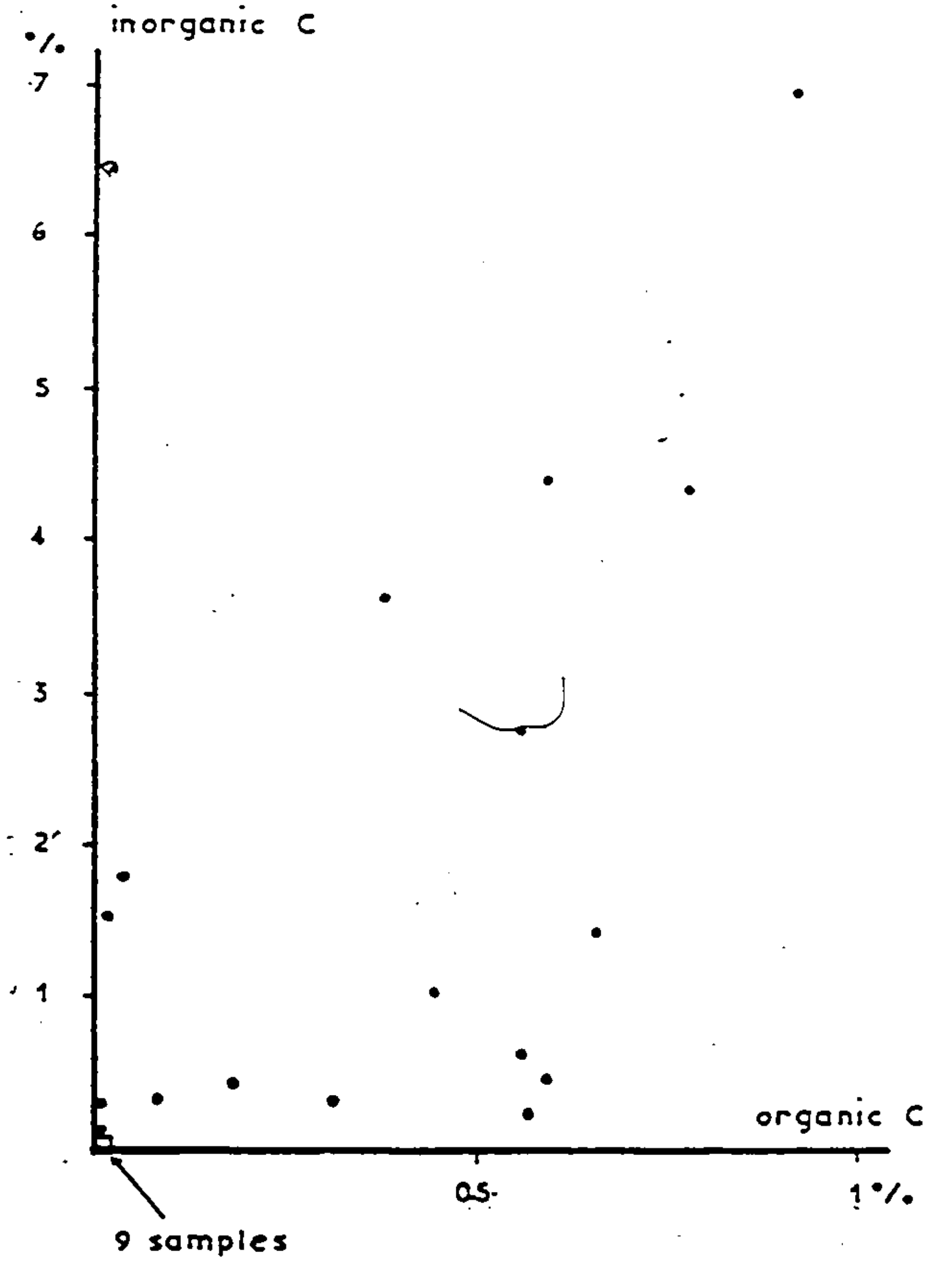
The micritic limestone in the ribbon limestone could be pelagic or, alternatively, it could have been derived directly from a carbonate bank and deposited by turbidity currents or by bottom currents. If the suggested analogy between ribbon limestones and calcarenite units is correct, the second alternative would be more plausible. In support of a detrital origin for the micritic limestone is the fact that the Table Head Formation shows a gradual passage from massive calcarenites to micritic ribbon limestones, again suggesting that the latter are fine-grained equivalents of the calcarenites.

Figure 20 is a plot of inorganic versus organic carbon in samples of shale and ribbon limestone from the Curling Group. The content of organic carbon is directly proportional to the content of inorganic carbon, suggesting that both were derived from the same source area.

An active carbonate bank - such as that represented by the St. George Group - is a zone of high organic productivity. The carbonate bank could have provided not only the calcite but also the organic matter represented in the micritic limestones by the relatively high content in organic carbon. The micritic limestones are commonly interbedded with black shale which is also relatively rich

Figure 20. Plot of content in inorganic versus organic carbon in rocks from the Curling Group.

Data is presented in Table IV. Plot shows a positive correlation.


inorganic C
%
7
6
5
4
3
2
1
organic C
0.5
1%
9 samples

in organic carbon. This association suggests that the clay in the black shale originated on, or at least crossed, the carbonate bank, where it incorporated organic matter. If the black and the red shales are, in fact, homologous, it would be necessary to postulate that the clay in the red shale did not cross the carbonate bank or, more likely, that it did but that the incorporated organic matter was destroyed later, before burial.

Formation of chert is controlled mainly by the relative proportion of silica in the buried sediment, but there may well exist chemical components that act as catalysts, or as inhibitors, to silicification. Concentration of biogenous silica is favoured by accumulation below the carbonate compensation depth or in areas of low terrigenous input. These observations have led to the generalization that chert is indicative of abyssal depths, a generalization that found support in results of the JOIDES program.

Nonetheless, it must be kept in mind that chert is known to have formed in very shallow waters, for instance the chert associated with stromatolites in the St. George Group or the occurrence described by Banerjee and Narain (1976). A selective blooming of silica secreting organisms could lead to formation of, for example, cherty mudstone, in any depth of water.

None of the rock types in the shale unit of the Curling Group are depth indicators. Dr. G. Pemberton, McMaster University, briefly studied hand samples and photographs of trace fossils from the Yellow Point Formation. He favoured an upper bathyal depth of deposition but stressed that the evidence was inconclusive.

Jansa (1974) studied the Cow Head Group exposed on the Cow Head Peninsula. From the presence of U-tubes (Arenicolites) and other supporting evidence, he concluded that the ribbon limestones and limestone breccias of the Cow Head Group were deposited in about 200 m of water depth. As U-tubes are also found in the ribbon limestones of the Yellow Point Formation, a similar conclusion may apply.

According to Jones (1969) a high proportion of vesicles in a submarine lava indicates relatively shallow water depth, say less than 800 m. Pillow lavas in the Curling Group are extremely vesicular in exposures near Fox Island River (Figure 1), and are moderately vesicular in exposures on Woods Island (Figure 9). Such qualitative data point to bathyal depths of deposition.

The volume on 'Deep-water carbonate environments', edited by Cook and Enos (1977), contains several papers describing rock types similar to those found in the shale unit of the Curling Group. In some of these papers the authors estimate the depth of deposition. Invariably the estimates fall within the bathyal range and, commonly within very shallow bathyal depths.

Bezrukov et al. (1977) showed that the content of organic carbon in the upper layer of sediment in the present oceans, decreases with distance from the shore and is low in the abyssal plains. In a very general and qualitative way, then, the black graptolitic shales in the Yellow Point Formation - relatively rich in organic carbon - could be interpreted as deposited relatively close to the shore and not in the abyssal plain.

In conclusion, the available information coherently suggests that the shale unit of the Curling Group was deposited in bathyal depths, probably in shallow bathyal depths. After the nappe hypothesis is discussed, the problem of depth of deposition will be re-examined.

DISTRIBUTION OF ROCK TYPES

The vertical and lateral variation of the rock types will now be described, separately for each section.

Rocky Harbour section

Most of the information from this section has been summarized in Figure 8. In this Figure, bed thicknesses are exaggerated but the stratigraphic position of the rock types and the thicknesses of the units, are moderately accurate. The sections were measured along cliff exposures. In most cases, units exposed on the cliff can be followed across the platform but lateral variations in thickness are common, and some units disappear altogether. It is not known whether these changes are mainly structural or mainly sedimentary.

The Yellow Point Formation can be partly divided into three members: a lower 'chert member', a middle 'ribbon limestone-dolomitic siltstone member', and an upper 'dolomitic siltstone and mudstone member'. In SU 'D' are exposed green and black shales below the chert member; from these shales Whittington and Kindle (1963) collected graptolites possibly belonging to zone 4 of Berry. Likewise, north of SU 'S', Upper Tremadocian fauna was collected from black shales that are below the chert member (Figure 5, Loc. A). Consequently, the three members do not comprise all the Yellow Point Formation. Boundaries between members are poorly defined.

The chert member is well developed in SU 'U', 'V', and 'Z' (east limb), whereas in SU 'S', 'D', and 'E', it is poorly developed. This suggests that the chert disappears laterally both to the north and to the south. Where better developed it formed from green and black shale and shows malachite-green seams and coating. In the other localities it is developed in black shale, associated with ribbon limestone. Graptolites from the chert member indicate Early Arenigian age, possibly in zone 6 of Berry.

The middle ribbon limestone-dolomitic siltstone member, comprises the majority of the occurrences of ribbon limestone, calcarenite, green and black shale, and cyclic dolomite. This member is not exposed in SU 'Y', 'B', and 'C'. Dolomitic siltstone is absent in SU 'S' (Figure 6), and south of SU 'E' (Figure 5a, schematic cross-sections), suggesting its disappearance to north and south. No fossils were found in this member.

The upper dolomitic siltstone and mudstone member, has its upper boundary defined by the base of the Lobster

Head Sandstone, but its lower boundary is difficult to locate because it is transitional. In most structural units it consists of thinly-bedded dolomitic siltstone, that is cherty in parts, but in SU 'B', 'C', and in part, 'E' (the latter not shown in Figure 8), it consists of massive or laminated gray dolomitic mudstone, and in SU 'Z' (west limb), it consists of green shale. Its stratigraphic position and graptolites from SU 'Y' and 'B' (Figure 8), indicate a Late Llanvirian age for this member.

A rough correlation of the Yellow Point Formation with the carbonate sequence will now be attempted. The lower chert member, with possible zone 6 graptolites, would correspond to the upper part of the St. George Group. Black nodular chert is present in the upper division of the St. George Group. The upper member in SU 'B', 'C', and 'E', shows - interbedded with the dolomitic mudstone - units of brown-weathering mudstone with thin siltstone intercalations, identical to the predominant rock type in the Gadd's Point Formation. In addition, the lower part of the upper member in SU 'B' and, in part, 'E' (the latter not shown in Figure 8), there are disperse breccias. These two features suggest correlation with the Gadd's Point Formation and with the upper member of the Table Head Formation, in part. The middle ribbon limestone-dolomitic siltstone member of the Yellow Point Formation would, then, be coeval with most of the Table Head Formation and, perhaps, the uppermost St. George Group. The abundance of ribbon limestone, calcarenite, and limestone breccia, in this member, would reflect the nearby presence of the active carbonate bank.

Reconnaissance work south of Little Green Point, showed that the Yellow Point Formation is very poorly exposed and consists mainly of green and black shale, ribbon limestone and limestone breccia. About 500 m south of the schematic section in Figure 5, is exposed a limestone breccia that appears to be interbedded with ribbon limestone. This breccia is similar in texture and clast composition to the Table Head limestone breccia. From clasts in this breccia, Whittington and Kindle (1963, p.687) collected fossils that are mainly Whiterock in age, that is to say, probably derived from the Table Head Formation. Along South Arm and farther south, ribbon limestone, dolomitic siltstone, and black shale, are common in the MacKenzie Brook Formation of Troelsen (1947).

Woods Island section

The shale unit on Woods Island was only briefly studied. It represents the Middle Arm Point and possibly the Cooks Brook Formations.

Green and black shale, ribbon limestone, and black shale, are common; red shale, and green and red shale are present. In addition, gray micaceous silty shales, and numerous beds of siltstone and sandstone, commonly rusty-weathering, are common. These latter rock types resemble some seen in the Irishtown Formation, which will be discussed in Chapter Nine.

A general idea of the vertical distribution of rock types in this area can be obtained from descriptions by Brückner (1966), Lilly (1965), and Stevens (1965). The Cooks Brook Formation (Middle Cambrian-Tremadocian) consists of black shale, ribbon limestone, and limestone breccia. The Middle Arm Point Formation (Arenigian, mainly) consists of green and black shale, and dolomitic siltstone.

Black Point section

The shale unit as exposed south of Black Point (Figure 11) can be divided into a lower and an upper member. In the lower member, well bedded green marls with red mudstone interbeds are the predominant rock type; the marls are cherty in parts. Also present are green and black, and green and red shales, one unit of ribbon limestone about 1 m thick, and one bed of limestone breccia 40 cm thick. This breccia is interesting because it contains about 5% granitic pebbles (cf. Stevens, in Neale, 1972). Granitic pebbles were also found at the base of a chert layer in the marl unit. A few blocks are present of limestone breccia and of ribbon limestone.

In the upper part of the marl unit, the red mudstone interbeds are replaced by green mudstone. Gradually, the thin marl beds also disappear and green shale becomes predominant: this is the upper member.

In the upper member olive green shales predominate, with intercalations of very thin (less than 3 cm) beds of marl, and sparse beds of siltstone or fine sandstone in thin beds (less than 10 cm thick). The siltstones and sandstones show flat bases with occasional sole marks such as burrows or prod casts, normal grading, parallel lamination or parallel parting in the lower parts of the beds and sinusoidal lamination or ripple cross-lamination, in the upper parts. Transition between the lower and upper parts of the beds is commonly sharp (Figure 19b). Their field aspect resembles that of the Piccadilly Beach sandstones.

The extensive zone of deformation that extends between the nodular chert and the marl unit (Figure 11), shows red, green, and minor black, shale; also present are broken sandstone beds and a disperse breccia. Intercalations of thin siltstones are frequent. The stratigraphic position of these outcrops is uncertain. The red shale suggests correlation with the lower member; the broken sandstone beds and the disperse breccia (assuming it is correlative with the Table Head limestone breccia), suggest correlation with the upper member.

Reconnaissance showed that exposures of the shale unit continue for about 400 m farther than the northeast end of the section in Figure 11. At the top (?) of the sequence are red and green cherty marls that appear to be in sharp but confomable contact with the Black Point sandstones. Farther to the northeast, are variegated shales, with sparse intercalations of ribbon limestone and thin siltstones. Lower Arenigian graptolites were found in these rocks (Appendix I, Loc. d). If the red and green cherty marls are equivalent to the lower member defined south of Black Point, it would mean that the upper member was eroded away and that the Black Point sandstones are filling a channel.

Much farther north, near Fox Island River, are exposed red, black, and green and black, shales, interbedded with pillow lavas.

The lower member probably spans the Arenigian: two samples from northeast of Black Point yielded Lower Arenigian fauna, the ribbon limestone in the marl unit yielded graptolites that could be Middle Arenigian to Llanvirnian; the bed of limestone breccia contains Arenigian brachiopods in clasts and matrix (Stevens, in Neale, 1972; pers. comm.). The upper member yielded no fossils but comparison with the Rocky Harbour section suggest an Early (?) Llanvirnian age. Lithologically, the upper member resembles the Piccadilly Beach sandstones, which are probably Lower Llanvirnian.

Rocky Point section

The stratigraphy of the shale unit in this section is poorly known due to uncertainties in the structural geology and lack of fossils. Considering only SU 'A' and 'B', it is possible to recognize an upper and a lower member. The upper member has shales and thin fine-grained sandstones, and passes rapidly but gradually to the Rocky Point sandstones through thickening and coarsening of the sandstones (Figure 13). The lower member in SU 'B', consists mainly of red shale, plus minor green shale, siltstone, marl, and chert, but in SU 'A' red shale is very scarce while green shale predominates, with intercalated thin siltstones. At the base of SU 'A' are calcarenites and nodular limestones, in parts brecciated.

In SU 'C', shales are green with silty beds in many parts. It is possible that they are mainly equivalent to the upper member but they could be part of the Rocky Point sandstones, as well.

The age of these members is uncertain. The Rocky Point sandstones appear to be Upper Llanvirnian, as elsewhere, so correlation with other sections would indicate a mainly Arenigian age for the lower member and an Early Llanvirnian age for the upper member.

CONCLUSIONS

Regionally, green and black shale predominates in Bonne Bay (Yellow Point Formation), while red shale is abundant only on the Port au Port Peninsula. Ribbon limestone, calcarenite, and limestone breccia, are abundant in Bonne Bay and Bay of Islands (Yellow Point and Cooks Brook Formations). Dolomitic siltstone is abundant in Bonne Bay (Yellow Point Formation) and common in the southern part of Bonne Bay and in Bay of Islands (MacKenzie Brook and Middle Arm Point Formation), but virtually absent in the Port au Port area. Cyclic dolomite, however, was seen only in the Yellow Point Formation. Chert is present throughout the area but it is abundant only in Bonne Bay and Bay of Islands (Yellow Point and Middle Arm Point Formations).

Regarding the vertical distribution of rock types, the little data available suggests that black shale and ribbon limestone are the earliest rock types (Yellow Point Formation, Upper Tremadocian beds; Cooks Brook Formation). Green shale appears in the Arenigian, jointly with dolomitic siltstone (Yellow Point and Middle Arm Point Formations) and both continue into the Upper Llanvirnian. The vertical distribution suggests that influx of green shale and dolomitic siltstone is related to the initiation of uplift of the source area that - in the Late Llanvirnian - shed detritus for the sandstone unit. Ribbon limestone is absent from the upper members of the shale unit.

CHAPTER FIVE

CURLING GROUP - LITHOLOGY OF THE SANDSTONE UNIT

As with the shale unit, rock types will be described first, followed by their distribution. The order of presentation is from coarser to finer and does not reflect their relative abundance. The Tourelle Formation (Hiscott, 1977) and the Cloridorme Formation (Enos, 1969), which crop out in eastern Quebec, show rock types similar to those in the sandstone unit of the Curling Group, and will be used for comparison.

ROCK TYPES

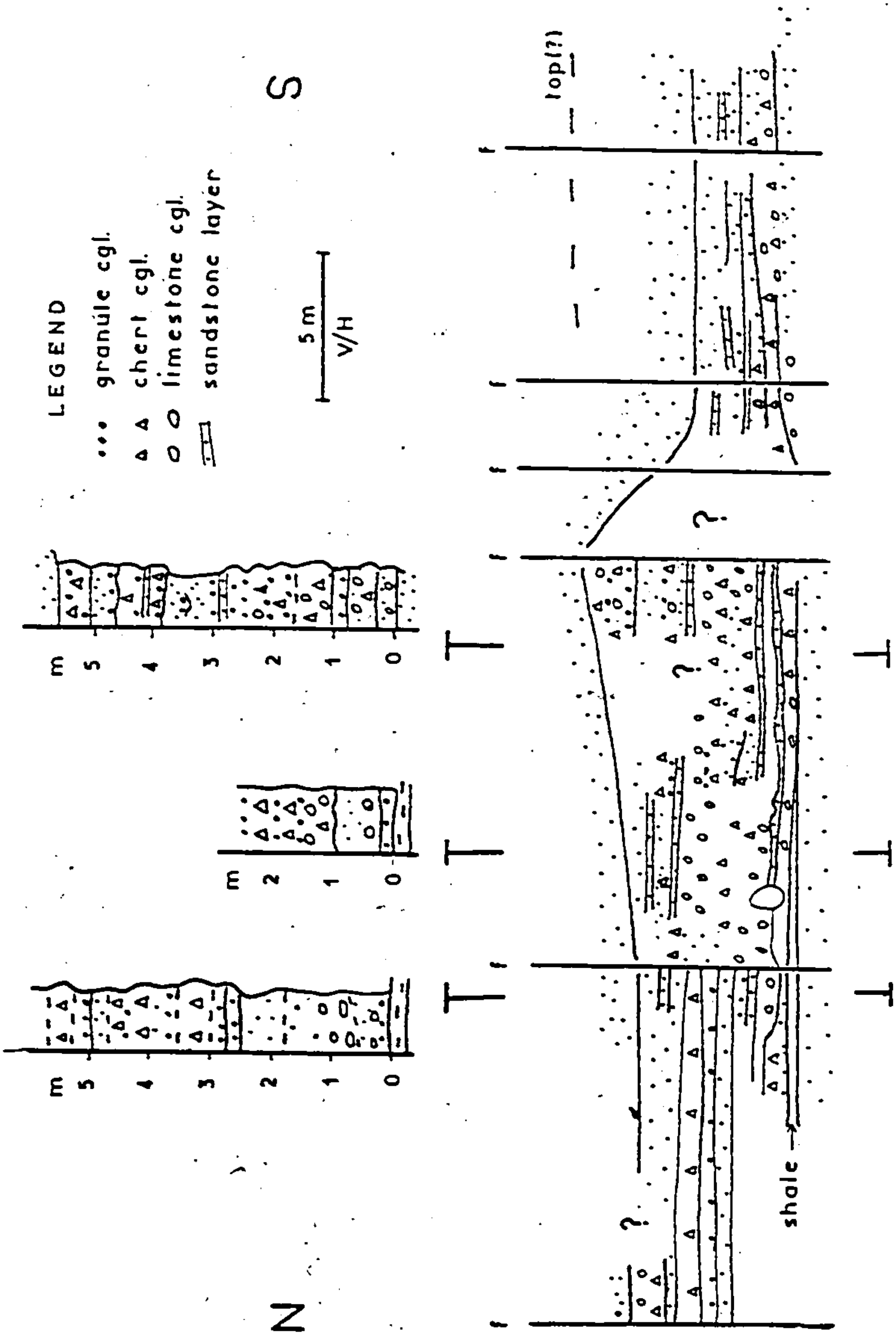
Conglomerate constitutes less than 1% of the sandstone unit. There are two contrasting types of conglomerates: one is polymictic, the other is oligomictic.

Polymictic conglomerate is almost restricted to SU 'V' in the Rocky Harbour section (Figure 6a), and the following description is taken from that locality. There, polymictic conglomerate forms a unit 15 m thick and 40 m in outcrop width. In the coarser, possibly axial, part, the conglomerate is irregularly bedded, but laterally and upwards it becomes finer and more regularly bedded, as it passes gradually to thick sandstone (described below). The base is sharp and the conglomerate erodes into a green silty shale 30 cm thick, totally eliminating it along its axis and reaching into an underlying sandstone (Figures 19c, 19d, 21). Medium-grained sandstone forms discontinuous intercalations (Figure 19d).

Framework clasts consist mainly of limestone, chert, and sandstone. Clasts segregate by lithology, forming irregular layers of limestone conglomerate (Figure 22a), alternating with irregular layers of chert conglomerate; sandstone clasts become common only in the upper part of the unit. The largest clasts of limestone reach 1.3 m across, with an average of 80 cm for the ten largest and are subspherical. The largest clasts of chert are about 40 cm long with an average of 30 cm for the ten largest, and are subrounded but flat. The largest clasts of sandstone are about 40 cm in diameter, subrounded and subspherical. Nonetheless, field measurements showed that 90% of the framework clasts measure less than 6 cm. The

Figure 21. Field sketch of polymictic conglomerate unit at Lobster Head (SU 'V').

Distances were measured with tape. Boundaries within the conglomerate are invariable diffuse and gradational. Position of sections shown at base of drawing.



LEGEND
granule cgl.
chert cgl.
limestone cgl.
sandstone layer
5 m
V/H
S
N
top(?)
shale
?
m
5
4
3
2
1
0

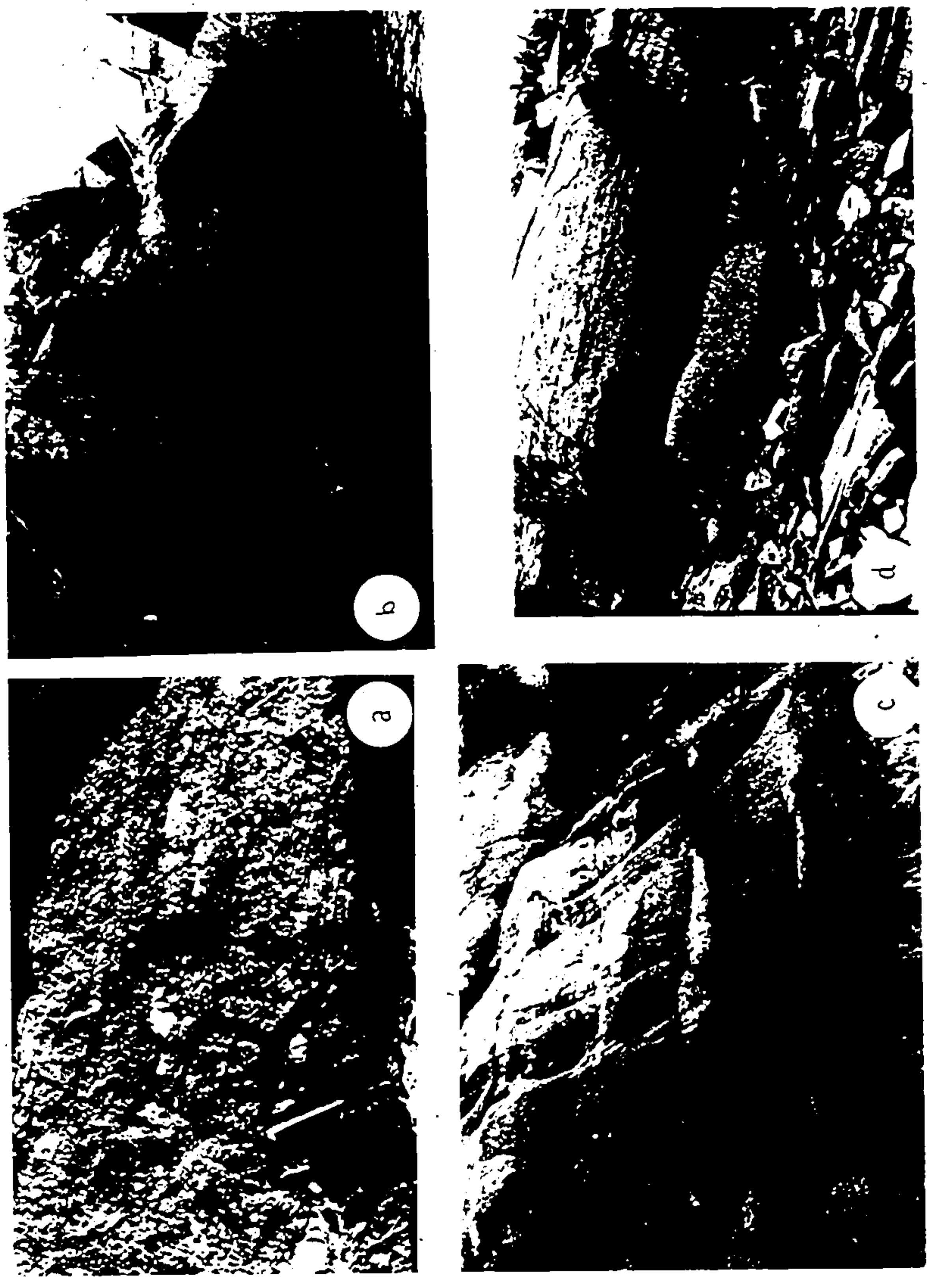
Figure 22.

(a) Polymictic conglomerate in the Lobster Head Sandstone (SU 'V'). Upper part of the southern half of the conglomerate unit illustrated. Shows moderately well bedded limestone conglomerate. Note possible very low-angle imbrication.

(b) Oligomictic conglomerate; north shore of Woods Island. Base to left. Three beds of quartz pebble conglomerate alternate with coarsely laminated, or massive, thick sandstone. Oldest bed shows a relatively large scour (boulder in water is about 1.5 m across); in this same bed note banding oblique to bedding. Normal grading can be seen in the three conglomerate beds but inverse grading appears to be present at several levels.

(c) Lenses of oligomictic conglomerate; north shore of Woods Island. The conglomerate grades up to massive thick sandstones with regular normal grading. The conglomerates are lag deposits from the same flow that deposited the massive sandstones. In the lowest conglomerate bed the interval b is conspicuous.

(d) Isolated lens of oligomictic conglomerate, below coarsely laminated thick sandstone; Woods Island. Conglomerate lens is completely detached from bed above.


a
b
c
d

matrix is abundant and consists of granule sandstone with subrounded granules of quartz, plus limestone and chert, embedded in a calcareous siltstone.

Among the framework clasts, limestone predominates slightly over chert, by number, while sandstone clasts are the less numerous. The limestone is mostly gray massive biomicrite, or micrite from ribbon limestone, but there are calcarenites and other types. The lithology of the limestone clasts matches well that of the Table Head Formation. A calceola coral - common in the Table Head - was found in one clast.

Chert clasts are black or green. The larger clasts are flat and slightly rounded; this roundness could have been acquired but it might really reflect an original nodular shape. The chert in the upper member of the Yellow Point is developed in dolomitic siltstone and does not match the clasts of chert. It is possible that the chert was eroded from the carbonate sequence. The sandstone clasts are intraformational. Notable is the absence of clasts of dolomitic siltstone, which suggests that it developed only in the deeper parts of the basin.

This polymictic conglomerate corresponds to 'facies A2. Disorganized conglomerates' of Walker and Mutti (1973). No conglomerate as coarse or as thick as this one has been described from the Tourelle or the Cloridorme Formations.

The oligomictic conglomerate is restricted to the Woods Island section, where it forms whitish beds or lenses generally less than 30 cm thick and - in the case of the lenses - 0.5 to 2 m wide (Figures 22b, 22c, 22d). It is a quartz pebble conglomerate with clasts up to 2 cm in diameter (Figure 23a). The conglomerate is structureless or may show normal grading from pebble to granule. The lenses show sharp, erosive bases, and generally sharp tops; in the conglomerate beds contacts are not so sharp. In addition to quartz there is pink feldspar, shale, and scarce volcanic pebbles. The matrix is scanty so the pebbles are well packed.

On Woods Island the sandstones show large elongate scours (Figure 23b). The scours measure about 1 m across, 2 to 3 m in length and are 20 to 60 cm deep. Some of these scours can be seen to be partly infilled by coarse sandstone but most are empty. Perhaps some were formerly infilled by oligomictic conglomerate.

An origin for the oligomictic conglomerates will be postulated after the <u>thick sandstones</u> are discussed. The mechanism of deposition of the polymictic conglomerates must explain the following features: (a) the erosional bottom, (b) the discontinuous internal layers

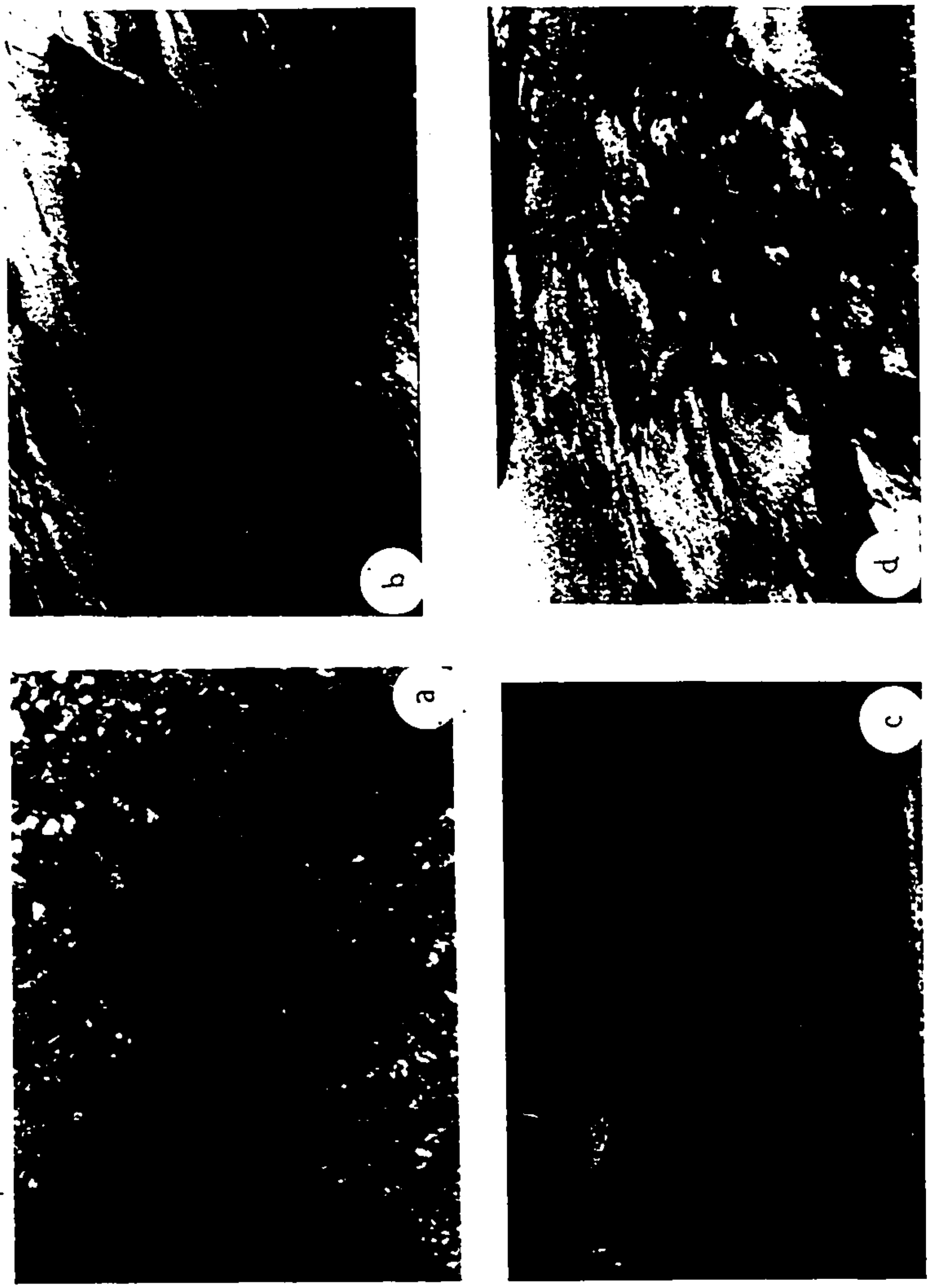
Figure 23.

(a) Texture of conglomerate lens in Figure (d). Note angularity of clasts.

(b) Large scours, once infilled by oligomictic conglomerate (?); Woods Island. Scour to the right appears to have been formed slightly later than the other.

(c) Asymmetric scour by massive thick sandstone; Black Point sandstones. Note concentration of larger clasts in scour (interval a), sharp transition to coarse sandstone (a very thin interval b), and massive to granule sandstone above.

(d) Massive thick sandstone with spherical calcareous concretions; Lobster Head Sandstone. Bed dips at low angle to the left.


a
b
c
d

of sand, (c) the segregation of clasts by lithology, (d) the overall normal grading and the lateral passage to granule sandstones, and (e) the presence of the largest clasts at some distance above the bottom. No single mechanism can explain all these features but a combination of debris flow and turbidity current, in the sense of turbulent debris flow or a very high density turbidity current, could account for all except (b) and (c). The segregation of clasts might be due to erosion of different lithologies at different times, as the flow advanced. If turbulence was not well developed, complete mixing could have been prevented. The discontinuous sandstone layers, however, cannot be explained. Faced with a somewhat similar problem, Hendry (1973) suggested deposition by a turbidity current, with the condition that the slump that originated the turbidity current did not occur as one single event, but rather as series of successive events in the manner of progressive liquefaction of a sand bed.

Thick sandstone beds are whitish to green-gray, and are characterized by thicknesses ranging from 1 to 10 m and by grain-size in the range coarse sand to granule, or even small pebble. Interbeds are commonly absent and where present they are of silty shale or fine sandstone.

Thick sandstone constitutes about 60% of the sandstone unit.

On the basis of internal sedimentary structures, four different types of thick sandstone can be distinguished: (1) massive, (2) banded, (3) coarsely laminated, and (4) nodular. These types will now be described in order.

Massive thick sandstone ranges in thickness between 1 and 5 m, and maximum grain-size for quartz seldom exceeds granule size, except for scattered flat shale pebbles. Normal grading can be detected in most beds; it is regular and continuous, or delayed, with a rapid grading in the uppermost part of the bed. Inverse grading over the basal few cm (up to 20 cm) was noticed in several beds. Bases are sharp and many beds show semicircular to asymmetric scours about 20 cm deep and up to 50 cm wide (Figure 23c). Bottoms are seldom exposed but one bed - at the base of the Black Point sandstone - shows flutes about 1 m long, 40 cm wide, and 20 cm deep. The scours, then, could be cross-sections of flutes.

A few beds show numerous subspherical concretions 5 to 15 cm in diameter (Figure 23d), or calcareous cementation bands. Imbrication is very well developed in some beds but is not present in most beds. Fluid escape structures are common. Polymictic conglomeratic layers are present in many beds, commonly in their lower parts (Figure 24a).

Massive thick sandstones are similar to the massive beds of Hiscott's (1977) 'thick sandstone', and to the 'facies A4. Organized pebbly sandstones' of Walker and Mutti (1973).

Banded thick sandstone is characterized by the development of granulometric banding, which may occupy the whole bed or only part of it. The bands are 5 to 15 cm thick, with alternating medium- to coarse-grained and granule bands (Figure 24b). Contacts between the bands are generally gradational but in several beds the bands show sharp bases and inverse grading from medium to coarse sandstone to granule sandstone (Figure 24c). Within the medium- to coarse-grained sandstone bands, scattered granules or coarse sand grains, are commonly present. These larger grains stand out and give the aspect of a 'disperse texture'. The granule bands may occasionally show imbrication of the larger flat clasts; imbrication is better developed, though, in bands with disperse texture.

Banded thick sandstones have sharp bases; a few show semicircular scours. They reach thicknesses of up to 10 m and commonly are over 2 m thick. The banding may occupy the whole thickness of the bed, but in most cases

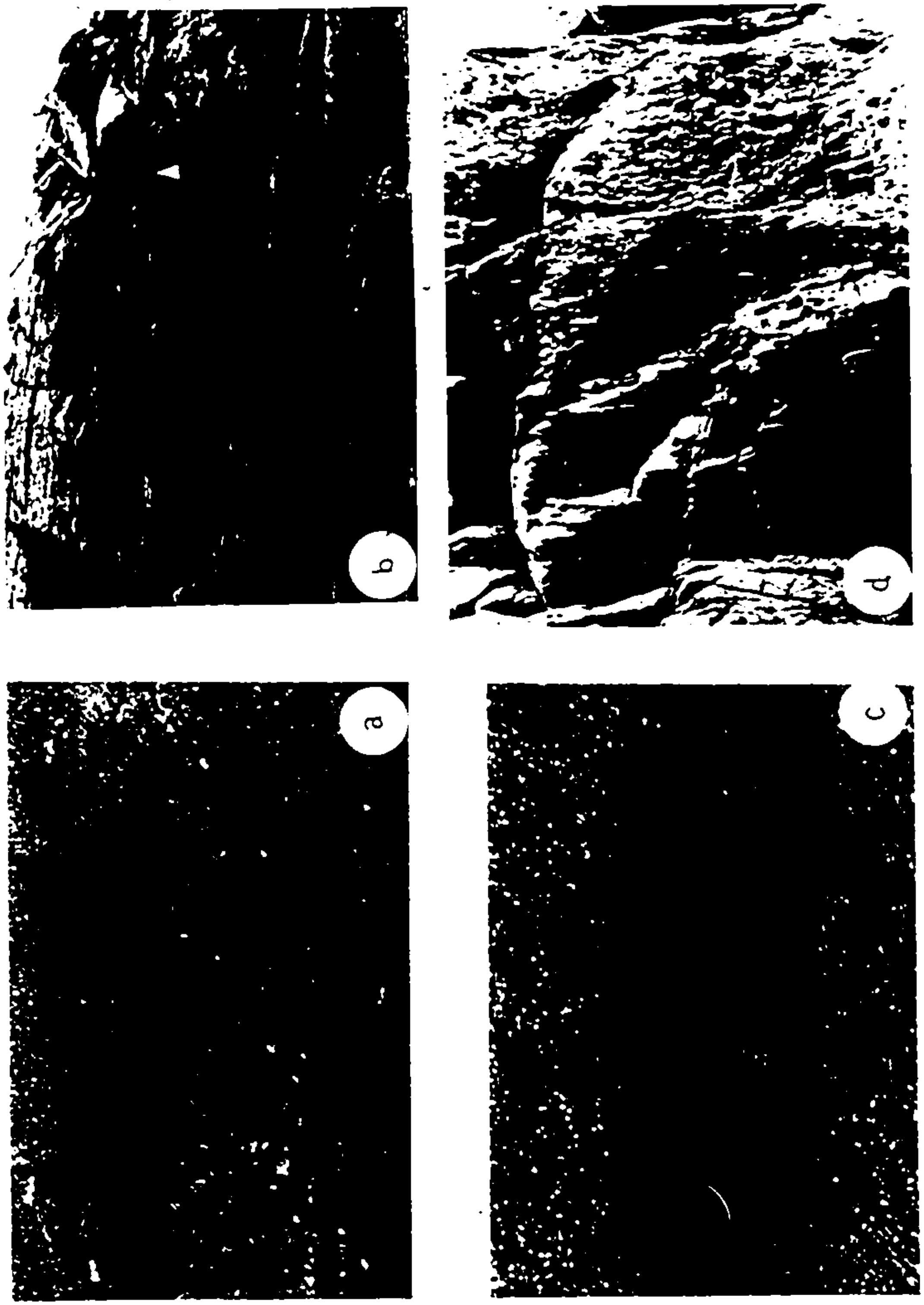
Figure 24.

(a) Conglomeratic massive sandstone; Rocky Point sandstones. More than one bed may be illustrated by photo.

(b) Banded thick sandstone; Woods Island. Hammer in lower left quadrant. Note that upper part of bed is less well banded. Arrow points to fluid escape structures. It is possible that the banding was partly destroyed during compaction and dewatering.

(c) Banded thick sandstone; Rocky Point sandstones. Detail of bands to show inverse grading and disperse texture.

(d) Thick sandstone with cementation bands and nodules; Woods Island. Fluid escape structures are present in nodular part of bed. Base is to the left.


b
d
a
c

only part of the bed shows banding. It may develop only in the lower part of the bed, with the upper part massive or nodular and cut by numerous fluid escape structures (Figure 24d), or, more rarely, the banding is present only in the upper part, with the lower part being massive. The bands may be disrupted by fluid escape structures.

Beds with poorly developed and inconspicuous banding resemble massive thick sandstones (Figure 25a), so it is probable that these two types of thick sandstone are parts of a continuous spectrum of rock types.

Hiscott's (1977) 'thick sandstones with coarse near-horizontal stratification' are identical to the banded thick sandstone. Hiscott interpreted the bands to be the result of shearing during deposition, with the bands being formed regularly one after the other, upwards. This interpretation is applicable to the banded thick sandstones.

Coarsely_laminated_thick_sandstone is characterized by alternating laminae of fine sandstone or siltstone, less than 0.5 cm thick, and laminae of medium-grained sandstone, about 1 to 3 cm thick; the latter are seen to be finely laminated in some beach exposures (Figures 22d, 25b). Parallel parting is commonly developed, especially in the more micaceous beds. Delayed normal grading is present in most beds. Flutes are common sole marks but in most beds

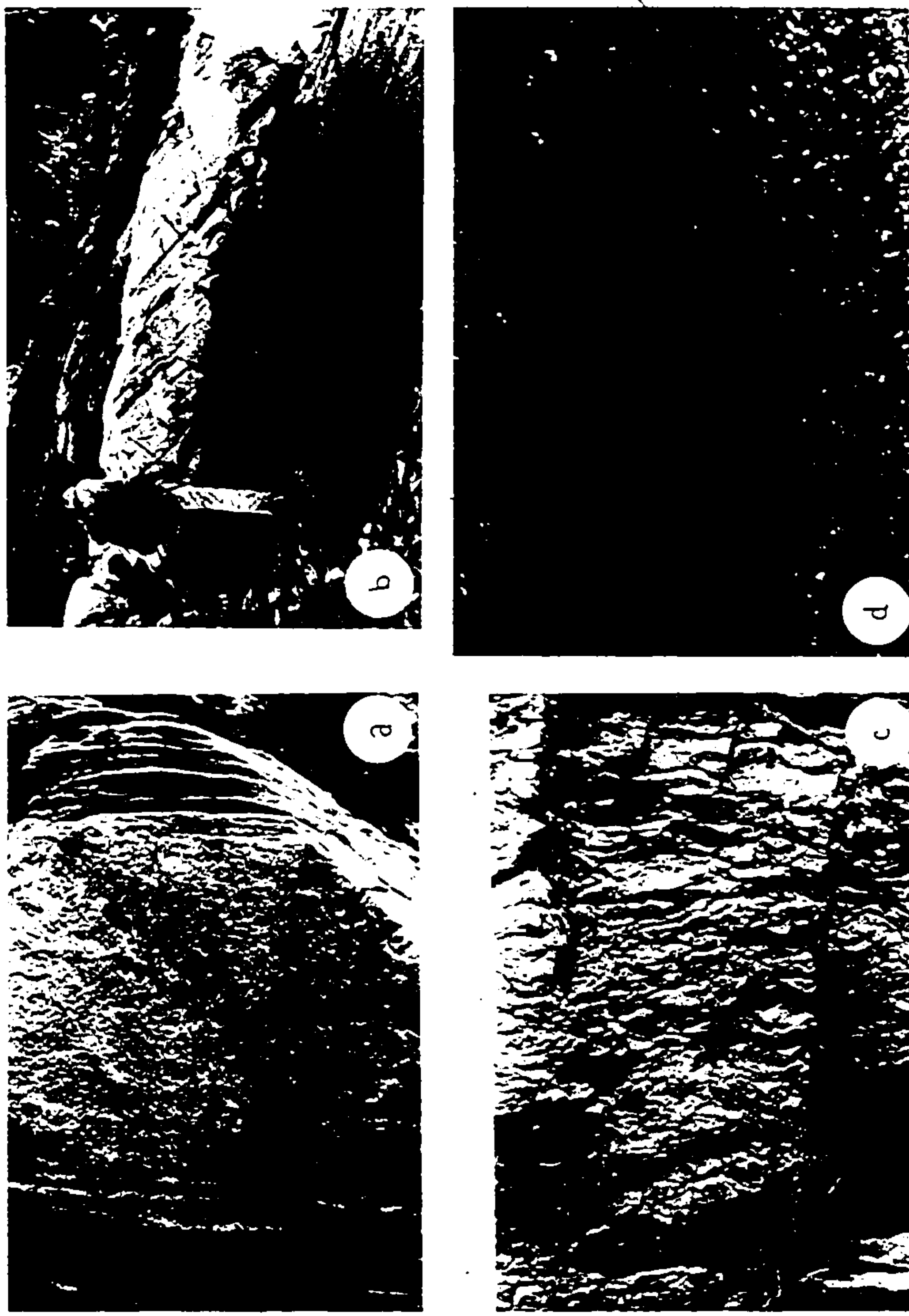
Figure 25.

(a) Complete massive thick sandstone, Woods Island. Slightly scouring bottom. Intervals a, b, and c, well developed. Concentration of clasts in interval a is not as large as in other beds; imbrication well developed. Interval b shown by camera cap. Interval c shows disperse texture, and poorly developed banding. Base to left.

(b) Quartzite with tabular cross-stratification, Woods Island. Quartzite overlies with sharp contact a coarsely laminated thick sandstone (same bed as in Figure d). At the top of the quartzite bed, are small cross-sets (not visible in photo) indicating flow

(c) Nodular thick sandstone, Woods Island. Close-up to show nodules surrounded by sheared sandstone and fluid escape structures (white vertical lines).

(d) Detail of massive sandstone to show interval a, below, and interval c, above. Note relatively high angle of imbrication in interval c.


b
d
a
c

bottoms are not exposed. Convolute lamination and cementation bands may be present. Bed thicknesses are 1 to 2 m; some of the thicker beds are suspected to being amalgamated, but in the absence of interbeds and due to the poorly developed grading, it is difficult to be sure.

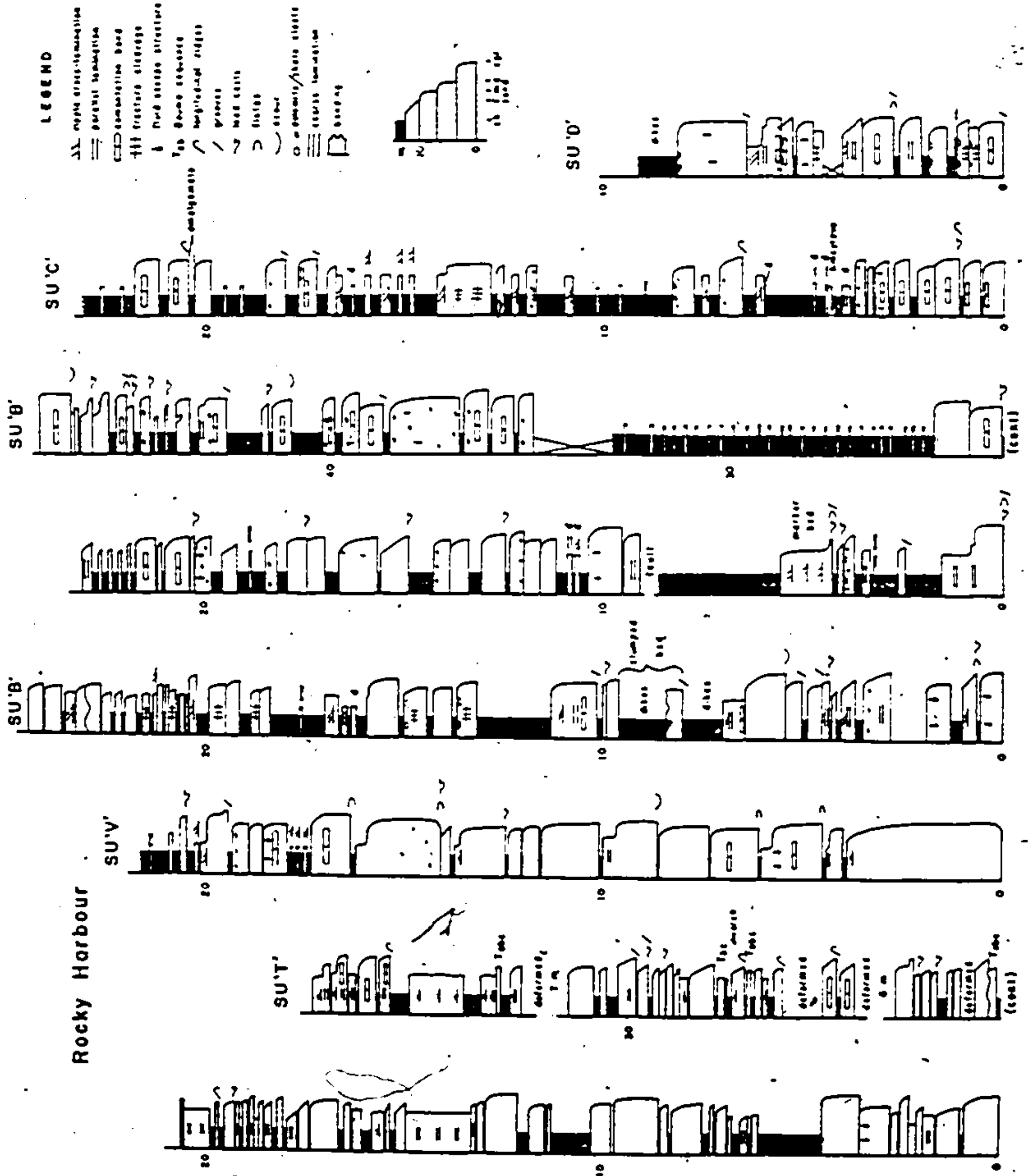
Nodular thick sandstone is characterized by the development of irregular and poorly defined nodules which stand out in relief thanks to differential weathering. The nodules appear - in many beds - to have been displaced through shearing of the bed (Figure 25c). In most of these beds fluid escape structures are present. The nodules may occupy the whole thickness of the bed or only its upper part, in which case the lower part of the bed may be banded or massive (Figure 24d).

The origin of nodular thick sandstones is thought to be the result of fluidization and shearing parallel to bedding. The formation of nodules may be akin to the formation of the fracture cleavage in slurried beds (described below).

Figures 26 to 27 present all the bed by bed sections that were measured in Rocky Harbour, Woods Island and Rocky Point. They are grouped to facilitate comparison of bedding characteristics. Thick sandstones are well represented in Figures 26 and 28, and less so in Figure 29.

Figure 26. Bed by bed sections measured in the Lobster Head Sandstone.

The structural units where the sections were measured are indicated at the top of each section. Sections are partial and do not cover all the exposed stratigraphic thickness of the Lobster Head Sandstone.



LEGEND
SU'D'
SU'C'
SU'B'
SU'B'
SU'V'
SU'T'
Rocky Harbour

Figure 27. Bed by bed sections measured in the Blow-me-down Brook Formation at Woods Island and in the Rocky Point sandstones at Rocky Point.

The section at Woods Island covers most of the exposed stratigraphic thickness of the Blow-me-down Brook Formation at that locality. For legend see Figure 26.

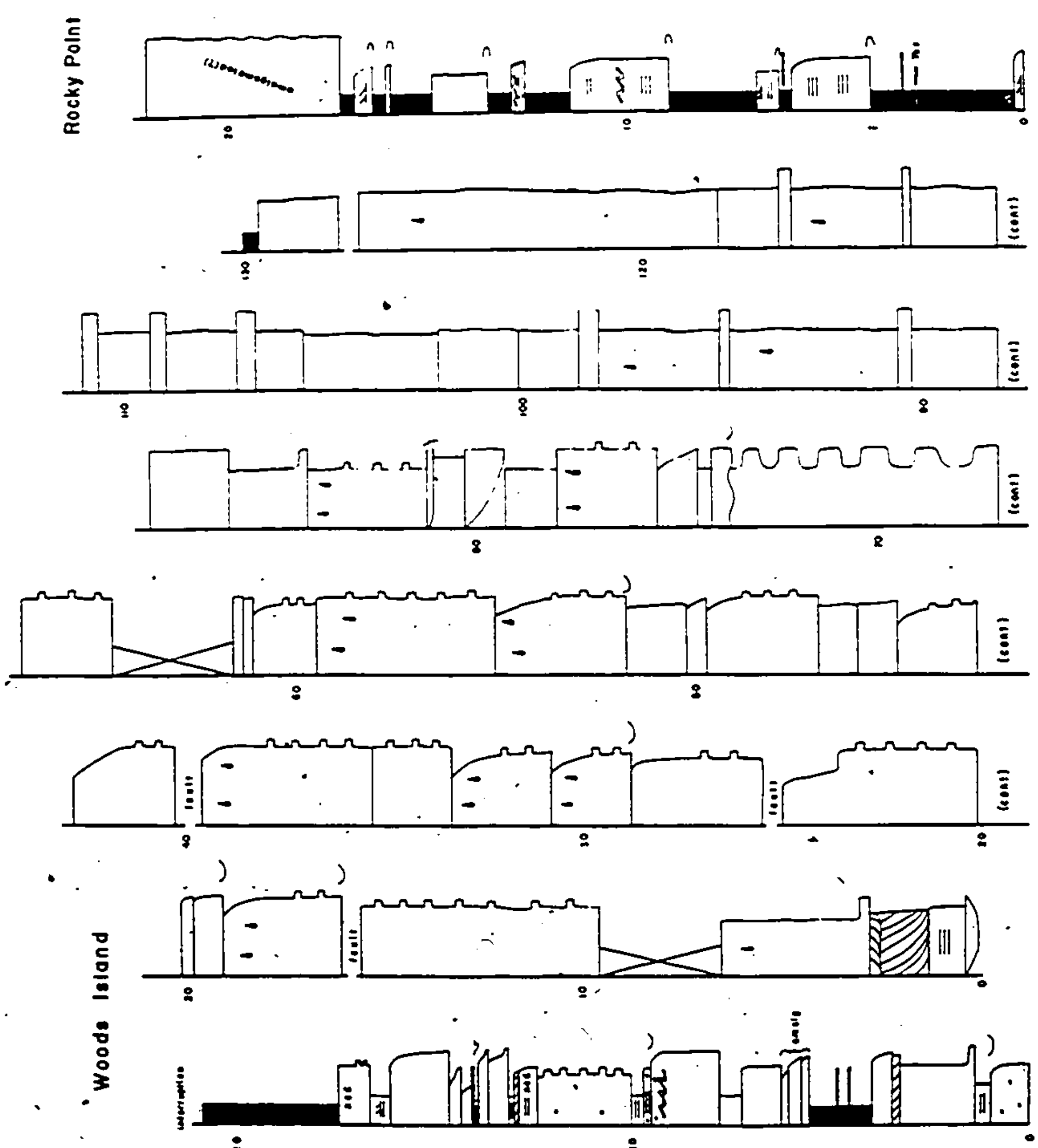

Rocky Point
Woods Island

Figure 28. Blow-me-down Brook Formation at Woods Island.

Shown is the only large-scale channel found in the Curling Group. Relative position of short bed by bed sections is shown in the sketch of the channel.

Abbreviations:

g - granules; c - coarse sand; m - medium sand; f - fine sand, dt - disperse texture; b - granulometric banding; fe - fluid escape structures.

Vertical arrows indicate the presence of normal grading:

d - distribution grading; c - coarse-tail grading (Blatt <u>et al</u>., 1972). Largest clast sizes are given in centimetres at different levels.

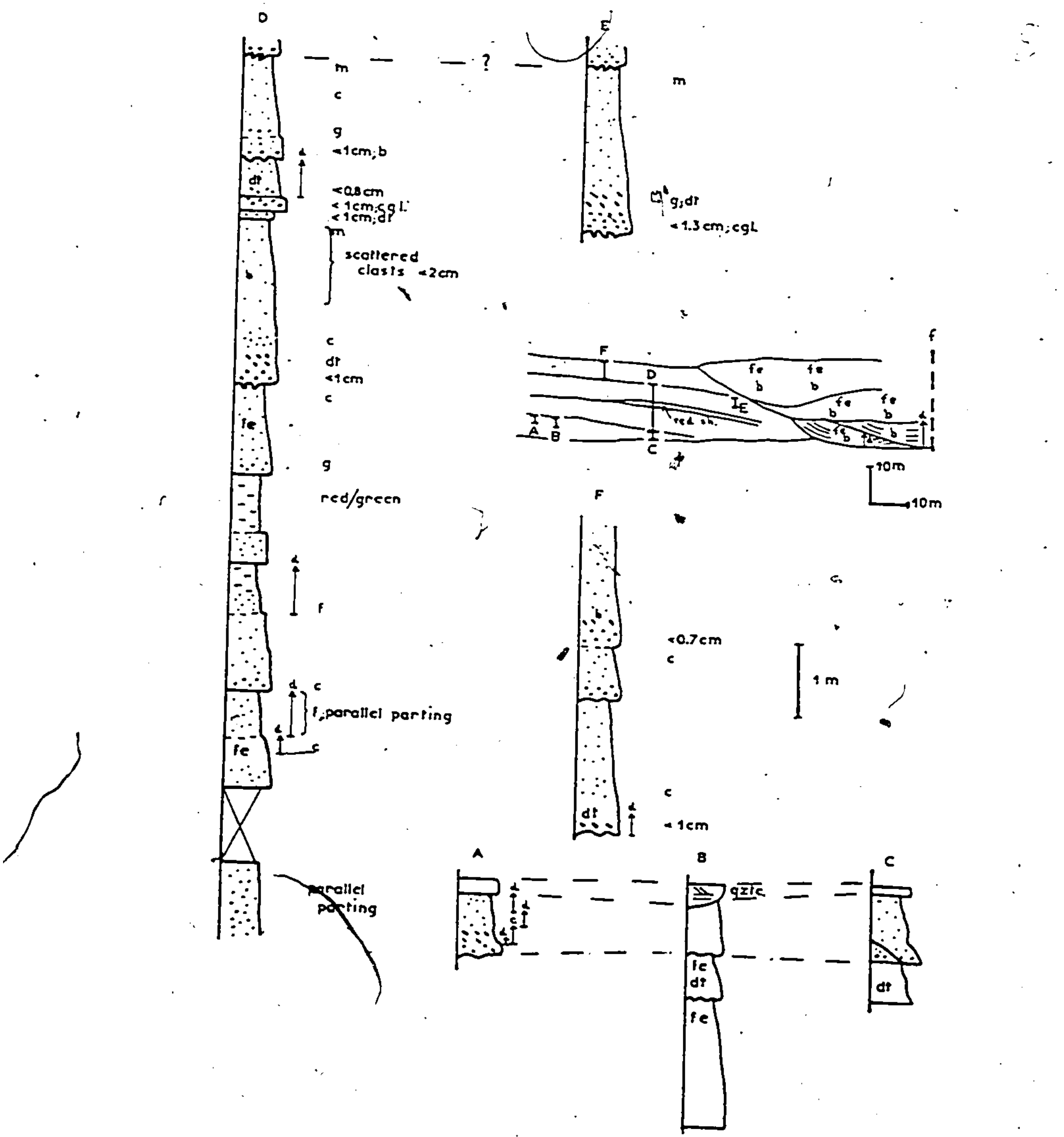
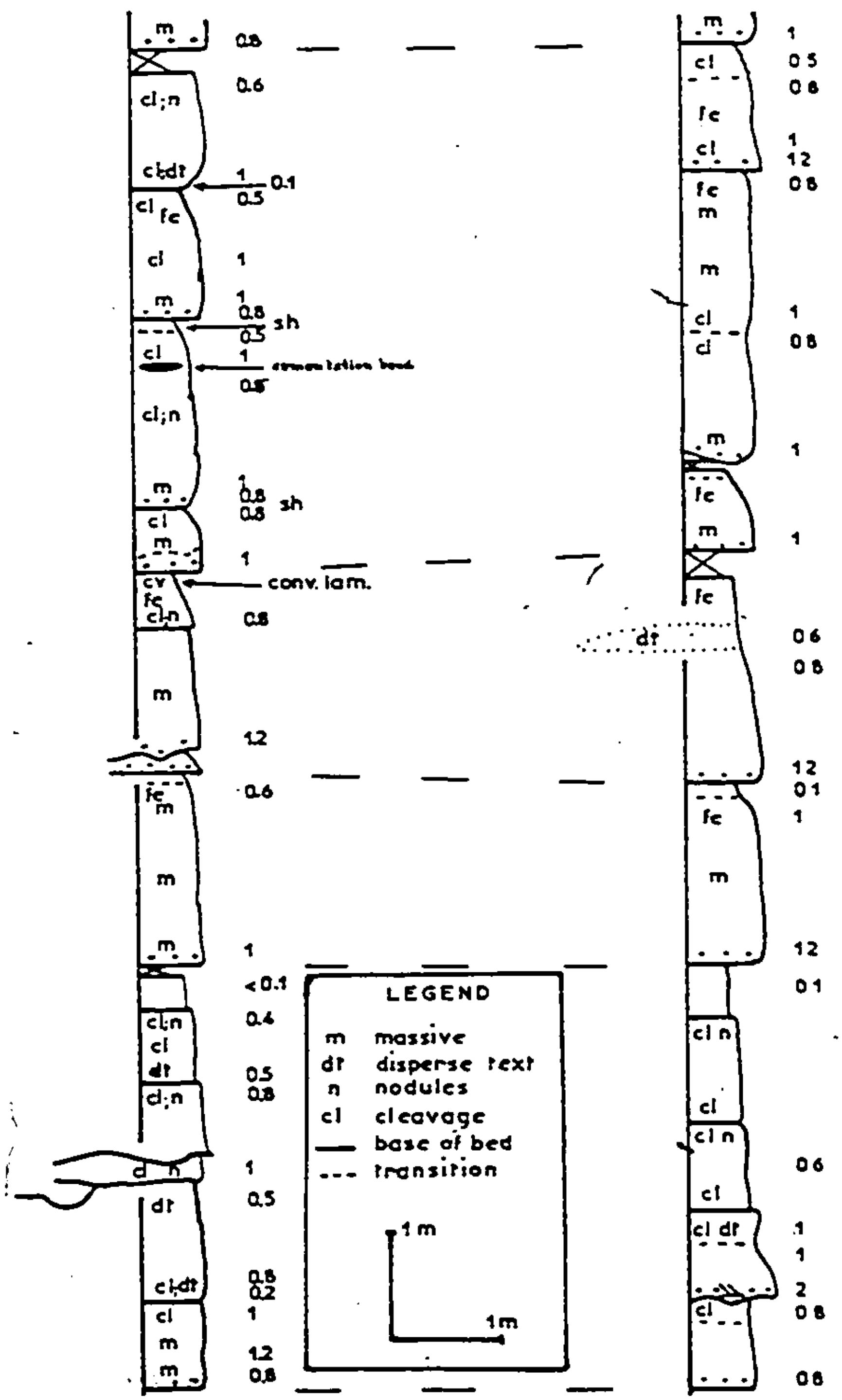

D
m
c
g
<1cm;b
dt
<0.8cm
<1cm;cgl.
<1cm;dt
m
scattered
clasts <2cm
b
c
dt
<1cm
c
fe
g
red/green
f
c
f, parallel parting
fe
c
parallel
parting
E
?
m
g;dt
<1.3cm;cgl.
F
D
E
A
B
C
red sh.
fe
b
f
10m
10m
F
b
<0.7cm
c
1 m
c
dt
<1cm
A
B
C
qztc
fe
dt
fe
dt

Figure 29. Bed by bed sections in the Lobster Head Sandstone (SU 'Z').

Sections are five metres apart but even so bed correlations can not be made in every case.


sh
conv. lam.
dt
LEGEND
m massive
dt disperse text
n nodules
cl cleavage
base of bed
--- transition
1 m
1 m

Cross-stratification in thick sandstones

Trough cross-bedding was seen in three beds of massive thick sandstones, one in each of the Rocky Harbour, Black Point, and Rocky Point sections. The largest is in the Lobster Head Sandstone, in SU 'B'. The bed is 1.5 m thick, coarse-grained, with a scoured base. The trough cross-set is 40 cm thick and about 10 m long, in a direction closely parallel to flow. Downflow of the cross-lamination passes to coarse parallel lamination. The sole of the bed shows large flutes which indicate flow in the same direction as the cross-set, that is, due west.

The other two occurrences are trough cross-sets about 20 cm thick and 50 cm across.

In the Woods Island section, there are several beds of white quartzite with tabular cross-stratification. The cross-sets are generally less than 30 cm thick but one is 1.5 m thick (Figure 25b). The beds have sharp bases and tops. They are siliceous quartz arenites. In the thicker bed, immediately above the major cross-set, are several small trough cross-sets about 30 cm thick which erode into the large cross-set. The large cross-set indicates flow to 140°, whereas two of the smaller cross-sets indicate flow to 100° and 170°.

Grading patterns and deposition of the thick sandstones

Grain-size grading in the thick sandstones can be studied best in massive thick sandstone because it is not obliterated by granulometric banding or nodules. Field observations indicate that there are two basic grading patterns. One shows a regular, uninterrupted, distribution grading throughout the bed. Maximum grain-size ranges from granule, at the base, to medium, at the top. This pattern develops in the thinner and finer-grained beds, and is relatively uncommon (Figure 30).

The second grading pattern also shows an overall normal distribution grading but with interruptions and reversals. The idealized pattern shows four main divisions (Figure 30).

Division I occupies the lower 10 to 30 cm of the bed and is characterized by a concentration of granules and pebbles to form a granule or pebble conglomerate (the lenses of oligomictic conglomerate are included in this division). Clasts may be well packed or slightly disperse; in the latter case, the pebbles may be imbricated. This deposit commonly infills a scour.

Division II consists of coarse sandstone lacking granules or pebbles. It follows immediately above Division I and the transition between the two is gradual but rapid.

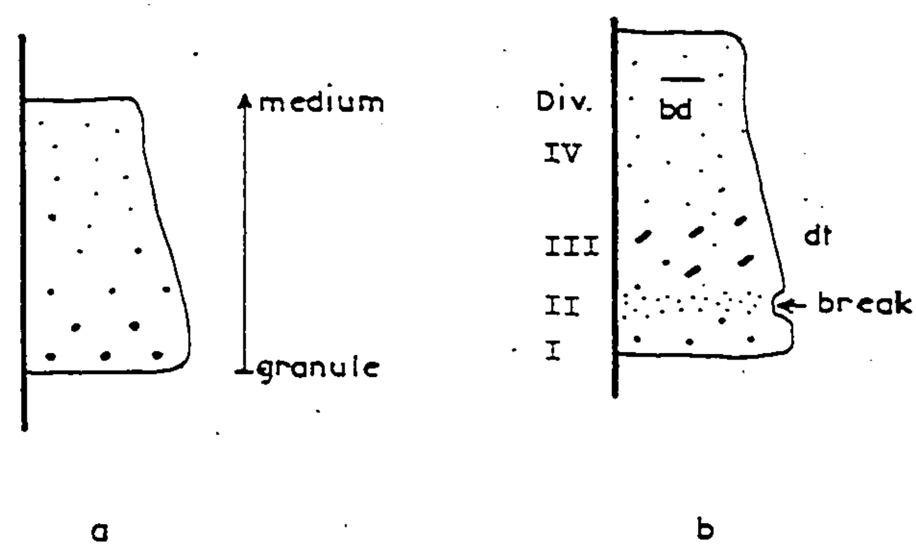


Figure 30. Basic grading patterns in massive thick sandstones.

Abbreviations:

d - distribution grading; dt - disperse texture; bd - granulometric banding.

Explanation in text.

Division II is generally less than 10 cm thick. Many beds show a break within Division II.

Division III is characterized by disperse texture, with scattered granules and small pebbles. Maximum grain-size is about the same as in Division I, but mean grain-size is clearly smaller. The pebbles are commonly well imbricated. Division III is roughly 30 to 50 cm thick. The lower boundary is located in the thin zone of inverse grading from Division II. The upper boundary is poorly defined; the passage to Division IV is slow and marked by the disappearance of the larger clasts and, consequently, of the disperse texture.

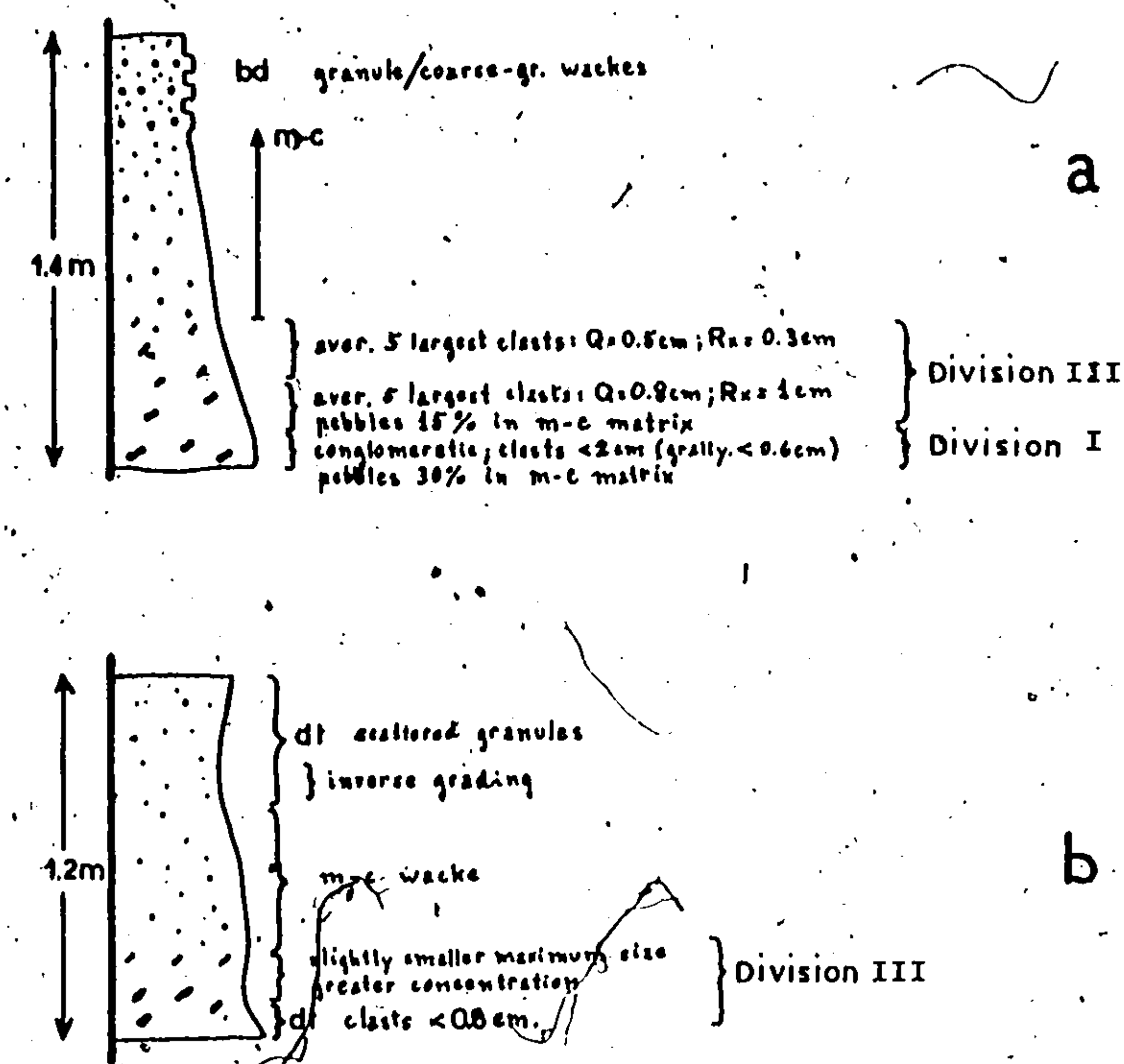
Division IV comprises the remaining upper part of the bed and is characterized by regular distribution grading, which may be slightly modified by granulometric banding.

The idealized pattern can be seen completely developed in many massive thick sandstone beds (Figure 25a), but deviations from this pattern are common. For example, Division II may be absent (Figure 25d). The pattern may appear truncated at the base, with Division I, or Divisions I and II absent. Or it may appear truncated at the top, with only Division I present, for example, the lenses of oligomictic conglomerate. Figures 28 and 31 illustrate some of these cases.

The abundance of small scours, the large-scale

Figure 31. Field sketches of two massive thick sandstones in the Blow-me-down Brook Formation at Woods Island.

Sketches show the grain size variations in these beds and the interpretation in terms of the basic grading patterns.


a
1.4m
bd granule/coarse-gr. wackes
m-c
aver. 5 largest clasts: Q=0.5cm; Rx=0.3cm
aver. 5 largest clasts: Q=0.8cm; Rx=1cm
pebbles 15% in m-c matrix
conglomeratic; clasts <2cm (grally <0.6cm)
pebbles 30% in m-c matrix
Division III
Division I
b
1.2m
dt scattered granules
inverse grading
m-c wacke
slightly smaller maximum size
greater concentration
dt clasts <0.8cm.
Division III

channeling, the normal grading, the fluid escape structures suggesting rapid deposition, are all features compatible with deposition from turbidity currents. The trough cross-sets in the upper parts of a few beds could also be produced by turbidity currents. On the other hand, the tabular cross-stratified quartzites with sharp bases and tops, and even more so, the cosets with divergent orientations of cross-sets, cannot be readily explained as formed by turbidity currents. These latter beds, which are very few in number, will be excluded from the following discussion. Turbidity currents, then, are proposed as a general mechanism for the transport and deposition of thick sandstones and associated oligomictic conglomerates.

The first grading pattern, showing regular distribution grading throughout the bed, represents the unmodified deposit from a turbidity current. Since beds with this grading pattern are thinner and finer-grained than those with the second pattern, it is possible that the former correspond to Division IV, but no direct evidence for this can be given. In any case, the flow was competent to maintain in suspension at least granule-size material, until the moment when the greater part of the load settled-out.

In the second pattern, Division I is interpreted as a bypassed deposit. That this is so can be clearly seen in Figure 32a. The flow must have lost its competency to maintain the largest clasts in suspension shortly before the greater part of the load settled out.

Figure 32a shows the grain-size distribution in a turbulent suspension. It can be seen that, for a specific grain-size, the proportion of that size decreases upwards from the bottom; for the larger clasts the decrease is exponential near the base of the flow. Division III generally shows a similar maximum grain-size as Division I, but with a lower proportion of that size. The decrease in the proportion of large clasts may be partly due to settling out of larger grains to form Division I, but, as indicated in Figure 32a, an exponential decrease is to be expected if the flow was fully turbulent.

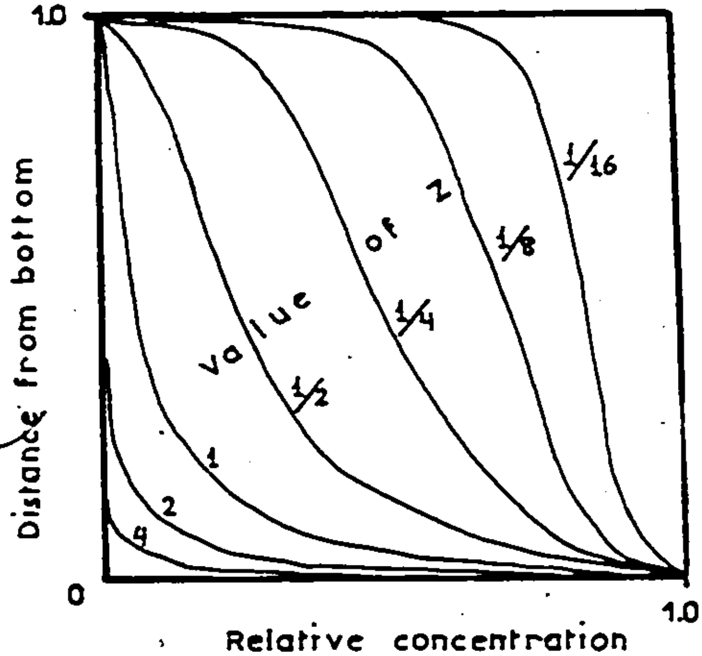
Division IV, with regular distribution grading, would be homologous to the first grading pattern and explained in the same fashion.

The depletion in coarser grains that characterizes Division II, might be due to settling out of grains to form Division I, or to displacement of the larger grains upwards and downwards, by grain interaction during shear ('dispersive pressure' of Bagnold, 1956). In turbulent flows in open channels, the effect of the bottom is to

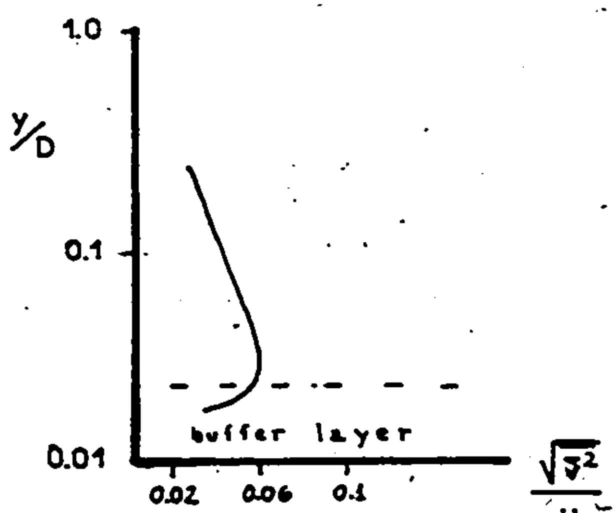
Figure 32.

(a) Variation in relative concentration of sediment in turbulent suspension, with distance from the bottom. For a given flow velocity and bottom roughness, Z is directly proportional to grain size (Blatt *et al.*, 1972).

(b) Plot of the vertical velocity component of turbulence against depth of flow. Data for flow in open channel taken from Raichlen (1967). y - distance above bottom; D - depth of flow; u - mean velocity; v - vertical velocity component.


1.0
0
1.0
Distance from bottom
Relative concentration
Value of z
1/16
1/8
1/4
1/2
1
2
4

a


1.0
y/D
0.1
0.01
buffer layer
0.02
0.06
0.1

b

produce a 'buffer layer' where the vertical velocity component of turbulence is smaller than in the flow above (Figure 32b; Raichlen, 1967). In rivers, the thickness of the buffer layer may be of the order of 2% of the depth. If a similar buffer layer developed in turbidity currents, it might explain the formation of Divisions I and II, for while the flow could be competent to maintain in suspension a given grain-size (say 1 cm in diameter) at the level where the vertical component of turbulence is largest, it would not be competent to do so within the buffer layer and the grains would settle out. Within the flow, then, the boundary between Divisions II and III would lie below the maximum in the curve.

The second explanation, involving shear and dispersive pressure, is supported by some direct evidence. For instance, many beds show a sharp break within Division II. Also, several beds show granulometric banding in Divisions III or IV (Figure 26c), which suggests that shear did take place. Both mechanisms possibly played a role in the formation of Division II, but it is not known which was the more important.

The grading patterns - it was said - can appear truncated. The most obvious example is given by the isolated lenses of oligomictic conglomerate. These lenses are interpreted as deposits bypassed by the main part of the flow. The base-truncated patterns, on the other hand, would have been formed by flows that had already deposited their coarser load.

The turbidity currents that deposited the massive thick sandstones should have been fully turbulent until the beginning of deposition.

Medium-bedded sandstone constitutes about 20% of the sandstone unit but is almost restricted to the Rocky Harbour section. The sandstones are olive green to gray. Bed thickness generally varies between 30 and 60 cm. Grain-size lies in the range medium to coarse sand, but shale chips about 1 cm long are commonly scattered throughout the beds. Two subtypes of medium-banded sandstones can be distinguished, they are: massive sandstones and slurried beds.

Massive sandstones are the most common of the medium-bedded sandstones. They show flat bases and normal grading to shale is present in the upper parts of the beds, but most of the bed is not graded (Figure 33a). A few beds show parallel lamination, or even less common, ripple lamination, in the upper parts. Inverse grading was noticed at the base of several beds, where it may occupy the lower centimetre or so. Amalgamated beds are rarely seen. Most frequent sole marks are load casts (about 50% of beds

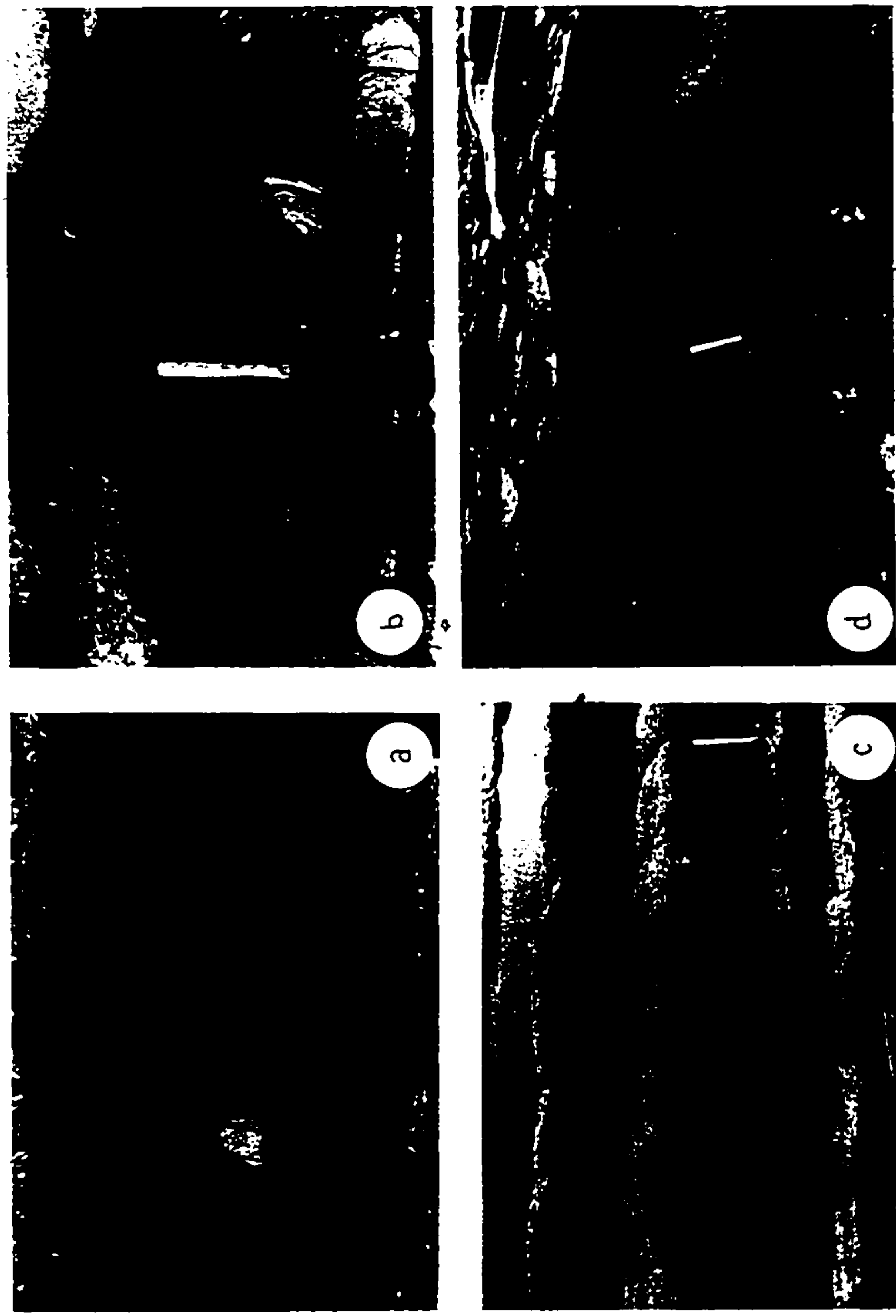
Figure 33.

(a) Medium bedded massive sandstones with break, Lobster Head Sandstone. Note lack of grading over most of bed.

(b) Slurried bed showing a sharp transition to the undeformed lower part, Lobster Head Sandstone. The planes of cleavage show an uncommonly high angle to the bedding. Large clast is of dolomitic siltstone. Note normal grading in lower part of bed.

(c) Slurried bed and fully rippled sandstones, Lobster Head Sandstone. Slurried bed (by hammer handle) shows fracture cleavage developed over the whole thickness of the bed. Normal grading is developed in the uppermost part of the bed. Fully rippled sandstones show climbing ripple-drift cross-lamination.

(d) Slumped bed, Lobster Head Sandstone. Base of bed by water; top is thin layer of sandstone above deformed part.


a
b
c
d

with sole marks), grooves (about 30%), longitudinal ridges and flutes (about 10% each). Fluid escape structures are uncommon. One bed showed fragments of dolomitic siltstone at the top.

A common feature in massive sandstones is the presence of yellow-weathering dolomitic cementation bands near the centre of the beds (Figure 14d). The thickness of the bands ranges between 2 and 10 cm; they are generally uniform and persistent but may be nodular or irregular in thickness. Upper and lower contacts are commonly gradational. In a very few bands parallel lamination was noticed. In thin-section, the bands show a siliciclastic framework and 30 to 40% micrite matrix with scattered rhombs of dolomite. The amount of micrite matrix is much higher than in the rest of the bed (cf. Chapter Five, Petrography).

The origin of these bands is uncertain. One possible explanation is that they are a primary depositional feature, but if so, they would be expected to occur near the top of the bed, where mean grain-size is finer. Another possibility is that they form after deposition by elutriation of mud from the lower part of the bed, as the pore water escapes upwards, but if so, fluid escape structures would be expected to be more common. Where they occur in these beds, fluid escape structures weather yellow suggesting enrichment in dolomitic mud.

Another feature present in several massive sandstones is a sharp and horizontal break, which is located at 5 to 15 cm from the base (Figure 33a). On the surface of the break may be found oriented graptolites or parallel lineations (parting lineation?).

This break is identical to the 'bedding joint' described by Parkash (1969) from sandstones in the Cloridorme Formation. In his opinion (p.189) the lower part of the bed formed by a rapid settling-out of sand from a turbidity current, early in the stage of deposition. The top of this partly consolidated deposit was sheared by the continuing flow of sand in the turbidity current, until the remainder of the sand load was deposited. The break would have been the result of shear at the top of the early deposit.

Medium-bedded sandstones are similar to 'facies C' of Walker and Mutti (1973), to the 'type 1 graywacke' of Enos (1969), and to the 'thin sandstones' of Hiscott (1977). Dolomitic cementation bands, however, appear to be exclusive to the Lobster Head Sandstone.

The bed-by-bed sections presented in Figures 26 and 29 illustrate the bedding characteristics of medium-bedded massive sandstones.

Slurried beds (Wood and Smith, 1959) share many of the characteristics of massive sandstones but have the following peculiar features: (a) the matrix content is about 10% higher than the average for massive sandstones; (b) they show a poorly developed fracture cleavage; (c) fragments of shale or dolomitic siltstone are commonly present at the top of the beds (Figures 33b, 33c, 34a). These features are now discussed further.

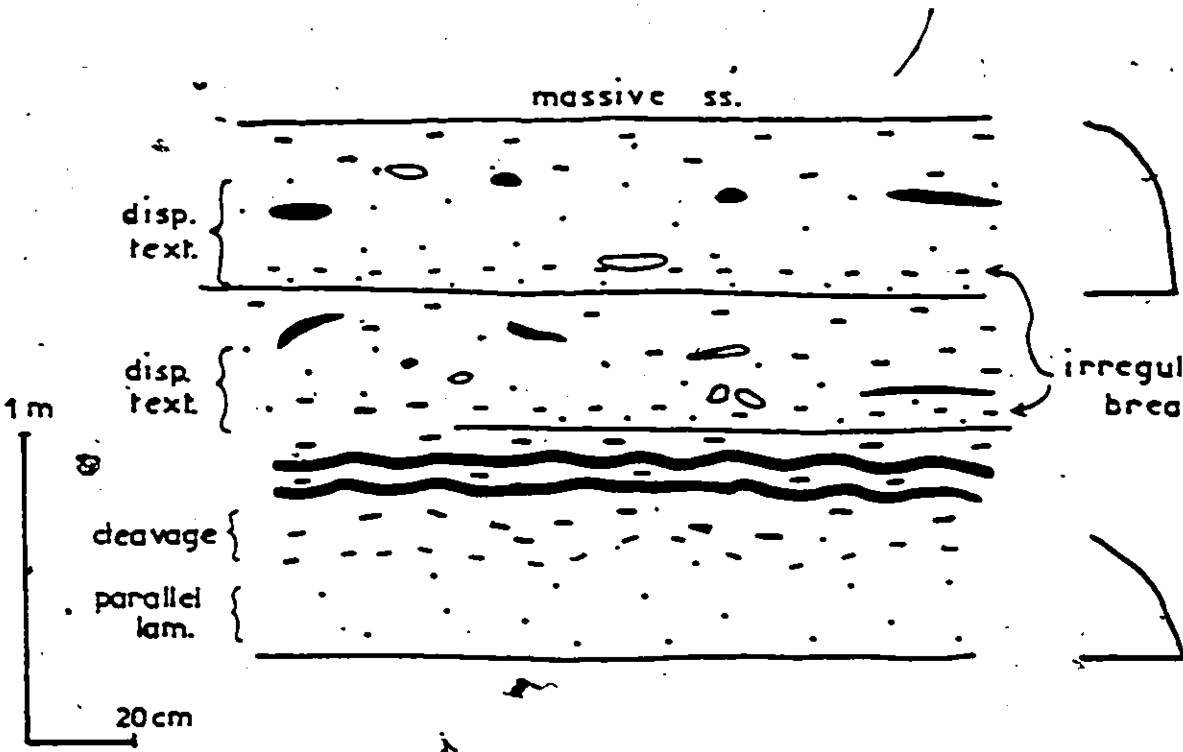
Slurried beds are more muddy than massive sandstones and show scattered grains of coarse sand which stand out from the matrix and convey the aspect of a 'disperse texture'.

The fracture cleavage may occupy the full thickness of the bed or, more commonly, only the upper half or two-thirds, leaving a basal part of undeformed sandstone. Transition from the undeformed part to the part with cleavage is very rapid but gradual over a couple of centimetres. Nonetheless, some beds show a sharp break at the base of the part with fracture cleavage. This break is identical to that described from the massive sandstones. The cleavage planes are discontinuous, curved, and vary in orientation from subparallel to bedding to an inclination of as much as 30° with respect to bedding. Intersecting cleavage planes give the bed a nodular aspect. Beds with fracture cleavage can be seen to pass laterally to massive

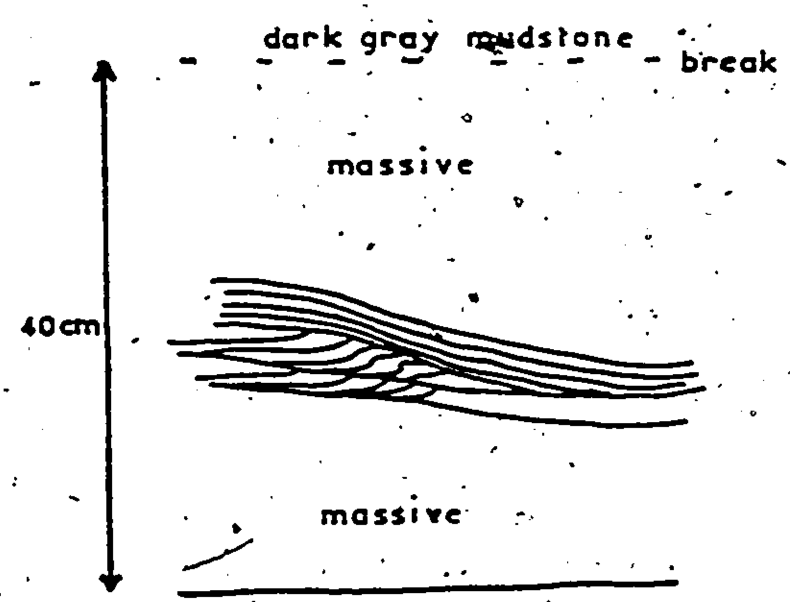
Figure 34. Field sketches.

(a) Slurried bed, below, and two massive medium bedded sandstones with break, above. Dark clasts are of dolomitic siltstone; white clasts are of shale; two thin dark beds, slightly folded, are dolomitic siltstones. Curves on the right illustrate the grading.

(b) Partly rippled sandstone.


massive ss.
disp. text.
disp. text.
irregular break
1 m
cleavage
parallel lam.
20 cm

a


dark gray mudstone
break
massive
40cm
massive

b

sandstones. The cleavage does not affect calcareous cementation bands occasionally present in these beds.

At the top of many slurried beds, flat fragments of dolomitic siltstone, and to a lesser extent of shale, about 10 or 15 cm long, may be present. These fragments come from interbedded shale and thin dolomitic siltstone (q.v.).

Slurried beds resemble the 'slurried beds' of Wood and Smith (1959), the 'slurry sandstones' of Hiscott (1977), and the 'type 2 graywackes' of Enos (1969).

Enos (1969) showed that his 'type 2 graywackes' are a lateral variation of his 'type 1 graywacke', which are similar to the medium-bedded massive sandstones of this thesis. Massive sandstones and slurried beds show several important features in common: bed-thicknesses are similar, both are massive, bases are flat in both, a break may be present in both, scattered shale chips may be present in both, and even fragments of dolomitic siltstone at the top of the bed may be present in both types of medium-bedded sandstone. These similarities suggest that the mechanism of deposition was the same for both. The greater matrix content could be explained - as did Enos (1969) - by a more distal position of the slurried beds.

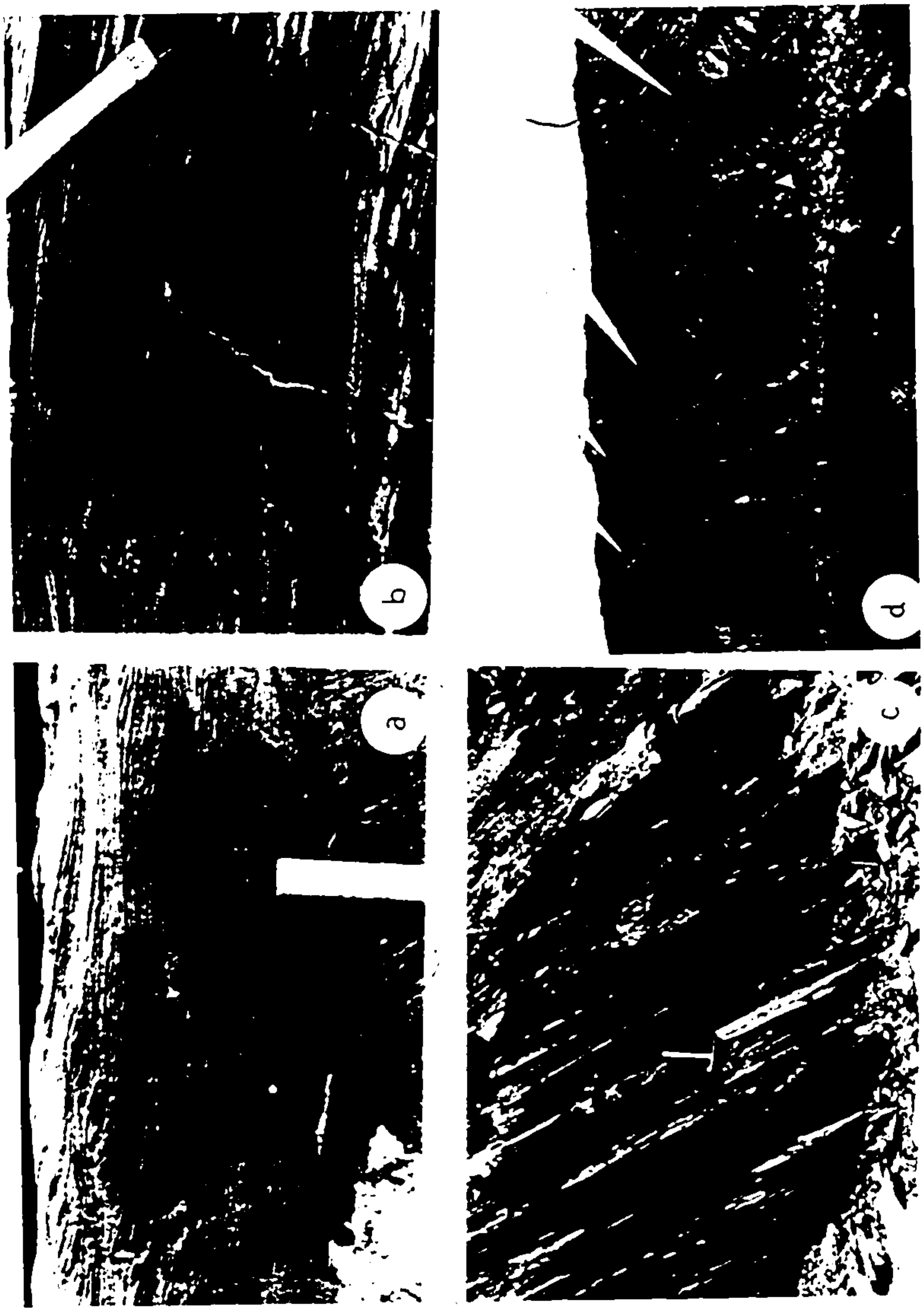
Figure 35.

(a) Partly rippled sandstone, Lobster Head Sandstone. Lower part is massive. Bed is dolomitic and weathers yellow.

(b) Fully rippled sandstone, Lobster Head Sandstone. View along flow direction to show numerous troughs and parallel lamination. At right angle from this view, bed shows climbing ripple-drift cross-lamination. Bed is calcareous.

(c) Thin dolomitic siltstone unit. The thicker siltstone beds show parallel lamination in the photo. Compare with the thinly-bedded dolomitic siltstone in Figure 19a. Base to the left.

(d) View of lower part of the Lobster Head Sandstone in SU 'B'. Sheared dolomitic mudstone of the Yellow Point Formation at extreme left. Several possible thickening-upwards cycles are indicated by triangles at top. Note units of thin dolomitic siltstone. Sandstones are medium bedded massive sandstones with cementation bands. Small arrow shows normal fault, possibly an early stage in the development of 'oblique sandstones'.


b
d
a
c

It is here postulated that massive sandstones and slurried beds were deposited by turbidity currents of relatively high density, and that the two features of slurried beds, namely the fracture cleavage and the fragments at the top, are post-depositional, but controlled by the greater amount of matrix in these beds. The fracture cleavage must be post-depositional because it does not affect cementation bands, which are early diagenetic. The incorporation of the fragments of dolomitic siltstone could not have preceded deposition of the bed of dolomitic siltstone above the slurried bed. In fact, incorporation may have occurred after lithification of the dolomitic siltstone, because a few slurried beds show relatively large (30 cm long) undeformed slabs of siltstone at the top. Figure 36a shows two beds of dolomitic siltstone intercalated in shale at the top of a slurried bed; these siltstones have been folded. The folds can be interpreted as caused by movement of the bed(s) above. Note that the bed immediately above shows mixture with shale at the base, as if it had loaded and slid on the shale.

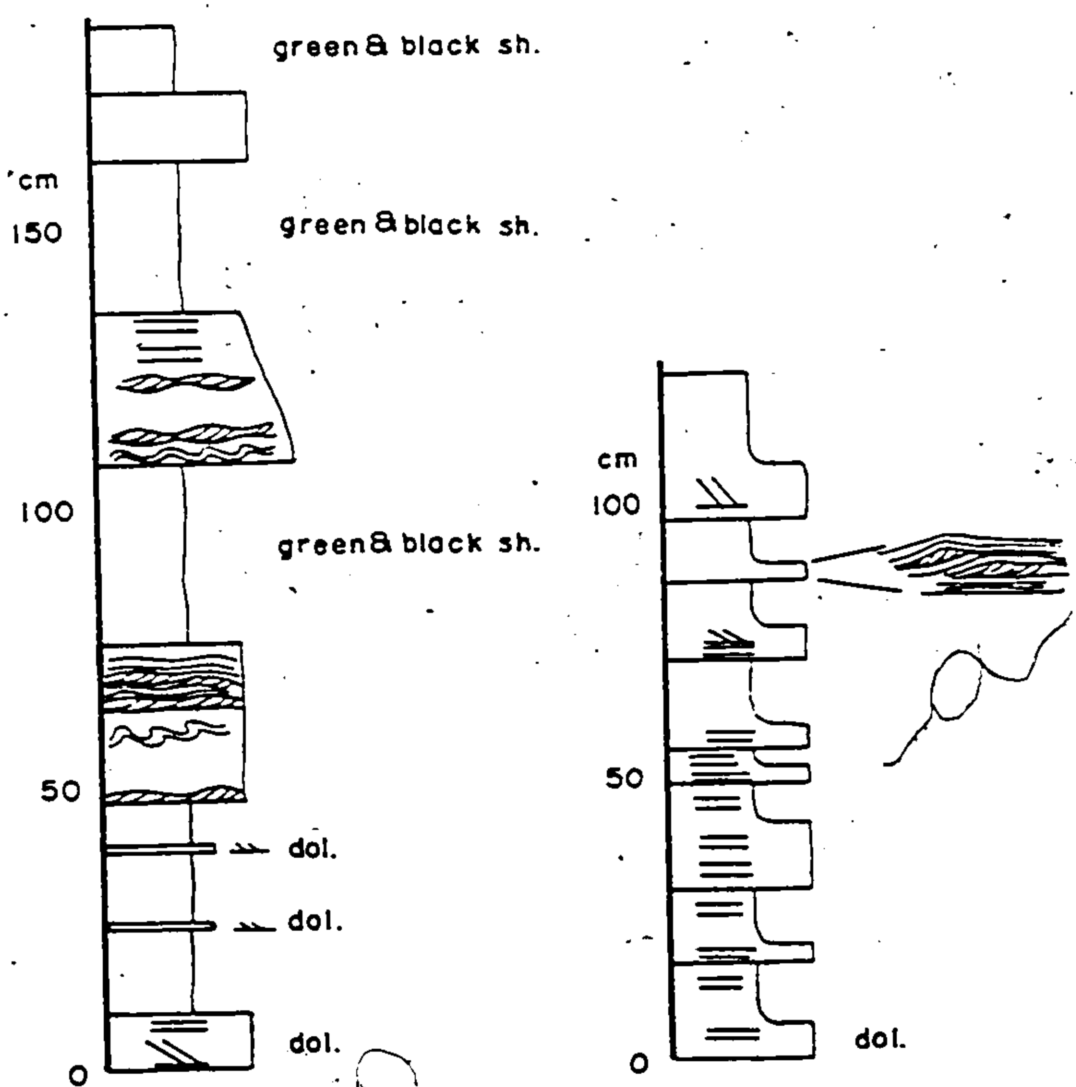
It is not known how long after deposition the fracture cleavage and the incorporation of fragments took place.

Figure 36: Two bed by bed sections in thin-bedded dolomitic siltstones in the Yellow Point Formation.

The section on the left shows two beds of fully rippled sandstone.

Symbols as in Figure 26.

thin-bedded dolomitic siltstones



Sandstones with large shale fragments. This is a very poorly represented rock type: only 5 beds of this type were seen. Beds range in thickness between 50 cm and 2 m, and are characterized by the presence of slabs of shale up to 10 m long (Figure 33d). The slabs are located in the central parts of the beds, parallel to bedding, surrounded by medium- to coarse-grained sandstone. Bases and, commonly tops, are flat. Beds generally show a layer of sandstone at the base and, in one case, a thin layer of sandstone is also present at the top. The contacts between the shale slabs and the sandstone are irregular; some fragments of shale are folded. Thin sandstone dikes, apparently originating in the basal sandstone layer, may cut the slabs of shale or intrude the underlying shale interbed.

Some of these beds resemble the 'prolapsed bedding' of Wood and Smith (1959), others resemble the 'slurried bedding' of Morris (1971). The origin of sandstones with large shale fragments is not clear.

Rippled sandstone. This rock type constitutes less than 5% of the sandstone unit and is restricted to the Rocky Harbour section. It is characterized by the presence of abundant ripple cross-lamination or ripple-drift cross-lamination of sinusoidal and type C varieties (Jopling and

Walker, 1968). Most beds are fine-grained, a few are medium-grained. The content of calcareous cement is high. Two subtypes can be distinguished according to whether ripple lamination occupies all the bed or only part of it.

Partly rippled sandstone shows a massive lower half or third, above which climbing ripple-drift cross-lamination or isolated sets of ripple trough cross-lamination develop (Figures 34b, 35a). At the top of the bed may occur a thin interval of wavy or parallel lamination followed by massive gray mudstone. Yellow dolomitic mud is commonly accumulated in the lee side of ripples.

Beds of this type are medium-bedded (20 to 60 cm), if only the sandstone part is considered, because the gray mudstone interbeds may be several metres thick. Bases are flat; flutes were seen but exposure of the bottoms is very poor. Beds show regular normal grading to the mudstone; a sharp break may separate the mudstone from the underlying sandstone but the break is a post-depositional feature because the bed grades in size across the break, and because the break disappears laterally. Cementation bands may be present.

The sharp bases, erosional sole marks, normal grading, and the vertical arrangement of sedimentary structures

(Bouma, 1962), strongly suggest that these beds were deposited by turbidity currents.

An aberrant variety of partly rippled sandstones consists of beds 1 to 5 m thick, coarse- or medium-grained, showing several yellow-weathering bands (3 to 10 cm thick) with ripple trough cross-lamination or ripple-drift cross-lamination, or with parallel lamination. The bands are separated by massive or laminated sandstones. Beds show flat bases and normal grading to shale.

These beds are restricted to the southern half of the Rocky Harbour section, near the base of the Lobster Head Sandstone. It is suspected that several of the exposures are part of one and the same bed, for which reason they have been distinguished as a 'marker bed' in Figure 7. If this is correct, this variety of partly rippled sandstone would be represented by only 2, or perhaps 3, beds.

Fully rippled sandstones generally show climbing ripple-drift cross-lamination throughout their thickness. A thin basal division with parallel lamination may be present in the thicker and coarser beds. Bed thickness ranges between 10 and 150 cm, but it is commonly about 20 cm (Figures 33c, 35b). The thicker beds are medium-grained, the thinner - much more abundant - are fine-grained.

Bases are sharp and flat, but several of the thin beds grade down to slurried beds. Tops are commonly sharp. The ripples have amplitudes of 1 to 3 cm and wavelengths of 1 to 20 cm. In plan view, most of the ripples show straight crests. Sinusoidal lamination and strongly convoluted lamination were seen.

Fully rippled sandstones and slurried beds generally occur together, in the sense that - within a certain stratigraphic interval - if one is abundant the other is abundant as well.

Fully rippled sandstones resemble the 'type 2 calcisiltites' of Enos (1969) and the 'facies 2a' siltstones of Hiscott (1977).

Deposition of these beds could be explained by turbidity currents, perhaps in a late stage of deposition, after the main load of sand had settled out.

Thin dolomitic siltstone. This rock type is restricted to the southern half of the Rocky Harbour section. It should not be confused with the thinly-bedded dolomitic siltstone of the Yellow Point Formation: both rock types resemble each other in composition and in the predominance of parallel lamination over other sedimentary structures. But the name 'thin dolomitic siltstone' is applied to well defined beds that may occur interbedded with shale or with sandstone, whereas the name 'thinly-bedded dolomitic siltstone' refers to banded rock units.

Thin dolomitic siltstones are conspicuous on cliff exposures because they weather yellow; on the platform the yellow coat is absent. Beds are 2 to 10 cm thick, with parallel lamination or parallel parting; only rarely is ripple cross-lamination present. Bases and tops are flat but not very sharp. Vertical and horizontal burrows are present, with horizontal predominating.

The siltstones may alternate with green-gray shale to form thick units (Figures 35c, 35d, 36), but may also occur individually.

A few medium-bedded massive sandstones and fully rippled sandstones were seen that rested directly on a bed of dolomitic siltstone. In these cases the contact is sharp and even, except for a few very small flame structures and scours.

From these siltstones come the fragments found within and at the top of slurried beds.

Shale. The shale interbedded with the sandstones and siltstones varies in colour between dark green and dark gray. Illite (muscovite type) and chlorite, are common constituents; dolomite or calcite may be present in varying amounts. The shale is mostly massive or faintly laminated, but in places it shows clear green and black, or gray and green, laminations.

Calcarenite and limestone. One bed of micritic limestone was found (Figure 27, SU 'C' 5 m from the base). Three beds of coarse-grained calcarenite were seen; all three show abundant trough cross-stratification in sets 20 cm thick and about 50 cm wide. All of these calcareous beds were found in the Rocky Harbour section.

DISTRIBUTION OF ROCK TYPES

The distribution of rock types will now be discussed separately for each section. No division into members was possible so the variations described are mostly lateral variations.

Rocky Harbour section

A marked difference in rock types exists between structural units north of SU 'A' and south of it. SU 'A', in turn, is peculiar and will be described at the end.

The structural units north of SU 'A' can be divided into two groups: one formed by SU 'R', 'S', 'T', and 'U', and the other formed by SU 'V', 'W', 'Y', and 'Z'; in other words, the outcrops from Lobster Cove to the north and those from Lobster Cove to the south. The northern group is finer-grained than the southern group. In the northern group, in order of decreasing abundance, medium-bedded massive sandstones, generally without cementation bands, partly rippled sandstones, gray mudstone, and fully rippled sandstones, are present. In the southern group, in order of decreasing abundance, thick sandstones, medium-bedded massive sandstones, generally without cementation bands, conglomerate (mostly in SU 'V'), shale, slurried beds, and fully rippled sandstones, are present.

In the structural units south of SU 'A', medium-bedded massive sandstones, generally with cementation bands, greatly predominate, followed by slurried beds, fully rippled sandstones, shale, thick sandstones, thin dolomitic siltstones, and slumped beds, in decreasing order of abundance. Several coarsening- and thickening-upwards cycles were recognized and are indicated in Figure 8.

The thin dolomitic siltstone may alternate with shale to form units or may occur isolated. This difference does not appear to be haphazard, but rather mutually exclusive. Units of dolomitic siltstone are found in sections where slurried beds and fully rippled sandstones are rare, while isolated beds of dolomitic siltstone are found in sections where slurry beds and fully rippled sandstones are abundant.

SU 'A' comprises all outcrops in Rocky Harbour Bay and is thought to constitute a thick conformable sequence. The lower quarter of the sequence shows broken beds of medium-bedded massive sandstones, some with cementation bands, surrounded by deformed gray mudstone.

The upper three-quarters of the sequence consist of well bedded green-gray mudstone alternating with light gray siltstones, or fine- to medium-grained sandstone in thin (about 3 cm thick) beds. The siltstone, or sandstone, beds are commonly laminated, show sharp and wavy bases, and grade to the overlying shale, ripple trough cross-lamination may be present, forming one or more sets. Many laminae are crowded with shale chips. A few thicker (less than 15 cm thick) beds of siltstone or sandstone are present, as well as isolated beds of dolomitic siltstone.

In the uppermost part of the sequence, along the south shore of the bay, thin siltstones, or sandstones, are absent. On the other hand, several medium-bedded, medium-grained sandstones are present, showing flat bases with flutes, and normal grading. Walking towards Paynes Head along strike, these sandstones become more common. Between Paynes Head and the cemetary, medium-bedded massive sandstones typical of the Lobster Head Sandstone, appear; here they overlie and are interbedded with, ribbon limestone, limestone breccia and green and black shale of the Yellow Point Formation. By the cemetary the marker bed is exposed.

In the absence of any evidence to the contrary, and in spite of its large thickness, the sequence in SU 'A' is interpreted as conformable, with sandstones at the bottom and at the top. Exposures, however, are not continuous, so the possibility exists that there are faults repeating part of the sequence.

The greater part of the sequence exposed in SU 'A' is identical in lithology to the Gadd's Point Formation. The resemblance can be best appreciated on the cliff exposures, for there weathering enhances the dolomitic bands typical of the Gadd's Point Formation. Moreover, at the base of SU 'A' are found blocks of limestone breccia that show the texture characteristic of the Table Head limestone breccia. The presence of these blocks suggests that SU 'A' originally lay on the Table Head Formation, as does the Gadd's Point Formation. If this inference is correct, the resemblance of the rocks in SU 'A' with the Gadd's Point Formation would be lithologic as well as stratigraphic.

If SU 'A' is restored to a position immediately above the Table Head limestone breccia, the sandstone beds at the base of SU 'A' would roughly lie on the Table Head breccias; such is the situation by Rocky Harbour Pond (Figure 3), where medium-bedded sandstones occur in the Gadd's Point Formation a short distance above the Table Head breccias.

Graptolites from Gadd's Point lithologies in SU 'A' (Figure 7, locality i) suggest a Late Llanvirnian age, that is, younger than the upper Table Head. In Chapter Two, the Table Head limestone breccia was tentatively correlated with the olistostrome on Neddy Hill and with the limestone breccia on Gadd's Point. If this correlation is valid and can be used as a time horizon, it follows that the Gadd's Point Formation is diachronous because at Gadd's Point most of its thickness is below the breccia, whereas at Rocky Harbour the reverse is true.

The age of the Lobster Head Sandstone is known to be Late Llanvirnian by graptolites in the sandstones and in the upper member of the Yellow Point Formation. With respect to the carbonate sequence, it is clear that the Lobster Head is wholly younger than the Table Head Formation.

Reconnaissance between Little Green Point and Wild

Cove showed that medium-bedded massive sandstone, without cementation bands, thick sandstones and polymictic conglomerates are present but no dolomitic siltstones were seen. Across the strait, near Gadd's Point and along South Arm, the South Arm Formation of Troelsen (1947) is exposed. Thick sandstones, uniformly coarse-grained, predominate; they are mostly green and gray, but also red, interbedded with green, and some red, shale. Fluid escape structures are common. In general, the South Arm Formation has a greater lithological and petrographical affinity with the Blow-me-down Brook Formation than with the Lobster Head.

Woods Island section

The sandstone unit in Woods Island is part of the Blow-me-down Brook Formation (Brückner, 1966). The thickness of the formation on Woods Island is about 100 m. At its base is a unit of pillow lavas and dikes that traverses the island.

The predominant rock types are, in order of decreasing abundance, light gray to green massive, or banded, thick sandstones, nodular thick sandstones, medium-bedded sandstones, cross-bedded quartzites, quartz pebble conglomerate, and gray-green or red shale.

Medium-bedded sandstones are almost restricted to the peninsula on the southwest corner of the island, where they are interbedded with silty mudstones and show a rusty weathering colour. On the basis of the structural geology, these beds are thought to be at the base of the formation; in addition, they resemble rock types in the Middle Arm Point Formation.

One large channel is present (Figure 28), filled with white beds of thick sandstone. Each bed is banded in its lower part and nodular in its upper part. Maximum grain-size is slightly larger than granule, despite the large thickness of the beds. Only one side of the channel can be seen. The channel appears to be at the top of the sandstone unit. Beds similar to those in the channel can be followed north and south of it, for a distance of about 300 m. The geographical boundaries of this 'channel facies' are uncertain, but it may account for 10 to 20% of the sandstone unit.

No fossils were found, and the age is given as Late Llanvirnian on the basis of the regionally conformable contact with the underlying Middle Arm Point Formation (Williams, 1973). An older age cannot be discarded, however, although it is unlikely that it can be older than Late Arenigian because the Middle Arm Point Formation contains Arenigian fauna.

Reconnaissance across the strait south of Woods Island showed that the Blow-me-down Brook changes in facies, for the only rock type recognized there was massive thick sandstone. South of Broad Cove (Figure 1) were seen massive thick sandstones, numerous quartzites with tabular cross-stratification, and one conglomerate unit whose clasts are all calcareous sandstone concretions.

The Blow-me-down Brook sandstones stand out from the rest of the sandstone unit because of their lighter colour and the exclusive presence of quartzites with tabular cross-stratification, nodular thick sandstones, and oligomictic conglomerates. Nonetheless, there are rock types in common with the rest of the sandstone unit, such as the banded thick sandstone and the massive thick sandstone.

Black Point section

The sandstone unit at Black Point is informally named the Black Point sandstone. The thickness of this unit is about 150 m.

Olive green, massive thick sandstones, in parts conglomeratic, are the almost exclusive rock type, interbedded with scanty gray silty mudstone; one slumped bed was seen.

The southern base of the Black Point sandstones appears to be a fault but of short displacement, separating it from the upper member of the shale unit. The northern base appears to be a sedimentary contact with the shale unit.

When discussing the shale unit at this same section, it was pointed out that there is reason to believe that the upper member of the shale unit has been eroded away, in part. If this is correct the Black Point sandstones would be filling an erosional channel.

No fossils were found. The age is given as Late Llanvirnian on the basis of correlation with better dated parts of the sandstone unit.

Rocky Point section

The sandstone unit at Rocky Point is informally names the Rocky Point sandstones. The unit is about 100 m thick.

In SU 'A' (Figure 12a), the predominant rock types are massive, or banded, thick sandstones, many of beds are conglomeratic, followed by coarsely laminated thick sandstones, green micaceous silty shale, and one bed of polymictic conglomerate. A rough vertical distribution of rock types is shown in Figure 13. In SU 'B' and 'C', massive thick sandstones, or micaceous coarsely laminated thick sandstones, with well developed parallel parting, predominate, followed by green micaceous silty shale.

Where the base of the Rocky Point sandstones is exposed it is transitional to the shale unit (Figure 26) with no evidence for large-scale erosion.

Graptolites from SU 'B' suggest a Late Llanvirnian age. (The graptolite-bearing bed was generously pointed out to the author by Dr. R.K. Stevens, Memorial University of Newfoundland.)

Reconnaissance showed the presence of micaceous coarsely laminated thick sandstones with well developed parallel parting, near Broad Cove, where the beds contain abundant glauconite. The finer-grained varieties of the micaceous coarsely laminated thick sandstones and the micaceous shale at Rocky Point, resemble rock types in the Crow Head sandstones.

CONCLUSIONS

Each of the areas where the sandstone unit was studied in detail (Rocky Harbour, Woods Island, and Port au Port) are characterized by a peculiar assemblage of rock types. In Rocky Harbour, the Lobster Head Sandstone shows polymictic conglomerates, massive thick sandstones, medium-bedded sandstones, and rippled sandstones; on Woods Island, the Blow-me-down Brook Formation shows almost exclusively thick sandstones - among which the nodular and the banded thick sandstones are outstanding - plus oligomictic conglomerates and quartzites with tabular cross-stratification; in the Port au Port area, thick sandstones predominate, the distinctive variety being the micaceous coarsely laminated thick sandstone.

These are the differences but the three areas also show some similarities. For instance, massive thick sandstones are present in all three areas; banded thick sandstones are common in the Rocky Point sandstones and in the Blow-me-down Brook Formation; polymictic conglomerates are present in the Port au Port area and in Rocky Harbour.

As the study was carried out in the three separate areas with little or no work at all being done in the intermediate, connecting areas, it is possible that transitional assemblages of rock types exist. Reconnaissance work showed that rock types in the South Arm Formation resemble facies of the Blow-me-down Brook Formation west of Frenchman's Cove. Also, the sequence exposed near Broad Cove shows rock types found in the Blow-me-down Brook Formation and in the Rocky Point sandstones. To be sure, these analogies require confirmation but they suggest the presence of transitional lithofacies.

Nonetheless, it is clear that assemblages of rock types change over short distances. For example, the Lobster Head Sandstone north of SU 'A' shows a predominance of thick sandstones, whereas south of SU 'A' medium-bedded sandstones predominate. Another example is that the Black Point sandstones mainly show massive thick sandstones, whereas the Rocky Point sandstones show mainly banded and coarsely laminated thick sandstones.

As regards the contact between the sandstone and the shale units, it is generally gradual and - with the possible exception of the Black Point sandstones - the sandstone unit does not erode into the shale unit.

The contact between the sandstone unit and the carbonate sequence is only exposed in the Bonne Bay area. Graptolites suggest that the Lobster Head Sandstone is wholly younger than the Gadd's Point Formation. The presence of coarse-grained sandstones above the olistostrome on Neddy Hill, sandstones that are identical to exposures of the Lobster Head Sandstone at Wild Cove, suggest a conformable contact between the Gadd's Point and the Lobster Head. The stratigraphic sequence exposed in SU 'A' suggests the same relationship.

The nature of the contact between the carbonate sequence and the sandstone unit is of paramount importance to the problem of nappe versus autochthonous hypothesis: a conformable contact would invalidate the nappe hypothesis.

Compared with the Tourelle and the Cloridorme Formations, the sandstone unit of the Curling Group show several rock types in common. In the Tourelle Formation (Hiscott, 1977; pers. observ.) only the nodular thick sandstones, the medium-bedded sandstones with dolomitic cementation bands, the partly rippled sandstones, and the polymictic conglomerates, appear to be absent, or at least very poorly developed. In field appearance, the Tourelle resembles the Lobster Head Sandstone in structural units V, W, X, Y, and Z; the Black Point sandstones and the Rocky Point sandstones, with the exception of the micaceous coarsely laminated thick sandstones in the latter.

The Cloridorme Formation (Enos, 1969; pers. observ.) has in common with the sandstone unit the medium-bedded sandstones with dolomitic cementation bands the thin dolomitic siltstones, and the fully rippled sandstones. In field aspect the Cloridorme resembles the Lobster Head Sandstone in structural units B, C, and D.

CHAPTER SIX

CURLING GROUP - PROVENANCE

This chapter deals with the mineralogical composition and paleocurrent patterns of the sandstone unit, with the main purpose of establishing the source area for the sandstones.

PETROGRAPHY

In this section are described the mineralogy and texture of the medium-bedded and thick sandstones. The composition of the sandstones was studied quantitatively in 48 thin-sections, in the manner outlined in Chapter One, and qualitatively in about 70 other thin-sections.

Quartz

Quartz groups all monocrystalline fragments of quartz; polycrystalline quartz was counted as rock fragments.

The percentage of quartz varies between 14 to 51%; the average for Rocky Harbour is 30%, for Port au Port it is 32%, and for Woods Island it is 45%. Bubbles or needle-shaped inclusions are common, but most grains are clear; very few have abundant sericite inclusions. Extinction is seldom homogeneous, undulose or patchy extinction predominate. Roundness generally ranges between subangular to subrounded but about 2% of quartz grains are well rounded. The well rounded quartz grains are conspicuous in hand samples. In addition, a very small number of grains show overgrowths that are thought to be relict because they are more limpid than diagenetic overgrowths in the same thin-section, or because they appear to be abraded.

Feldspar

Feldspar is albite or microcline. Feldspar content varies between traces and 9%; averages are 5% for Rocky Harbour, 3% for Port au Port, and 6% for Woods Island. The differences between averages are not statistically significant. The ratio of albite to microcline is about 1:10 in Woods Island, and about 10:1 in the other sections. Feldspar grains are subrounded to rounded, with microcline slightly better rounded than albite.

Microcline is generally unaltered. Albite (very low index of refraction) is more or less altered, with a dusty aspect (iron oxides?), and replacement by sericite. It is invariably twinned according to the albite law, with twins well developed and and undeformed. (A few grains appear untwinned; three of these were studied in the U-stage, and are albite oriented parallel to the albite twinning plane.) The composition of 35 grains in 12 thin-sections was determined by the Michel Levy method on the U-stage. The majority of the grains are pure albite, with a few slightly more calcic.

Perthite is present in trace amounts in most thin-sections.

Mica

Mica - other than chlorite which is classified under 'Rock fragments' - is present in trace amounts among the framework constituents. Muscovite and biotite are present; either one may predominate in different samples. The flakes show jagged ends. Muscovite is unaltered and colourless. Biotite may be fresh, with strong pleochroism from deep brown to almost colourless; more commonly it appears altered to chlorite, thus loosing part of the pleochroism.

Rock fragments

Rock fragments group all fragments composed to two or more clearly joined and distinct crystals, whether they are of the same or of different composition. In addition, single grains of chlorite were counted as rock fragments for reasons given below.

The percentage of rock fragments ranges between 5 and 58%; averages are 18% for Rocky Harbour, 34% for Port au Port, and 28% for Woods Island. The lower percentage for Rocky Harbour is attributed to the finer average grain-size in that section.

The proportion of different varieties of rock fragments was determined in 12 representative samples, according to the procedure outlined in Chapter Three. The results show a marked qualitative and quantitative difference in varieties of rock fragments between Woods Island and the other sections. This difference can easily be appreciated in the field. Each variety of rock fragment will now be described.

Metamorphic and plutonic rock fragments comprise - with few exceptions - fragments composed of quartz or quartz plus feldspar.

Rock fragments composed exclusively of quartz are the most abundant. Contacts between the component grains can be simple or sutured; grain-size distribution can be well sorted or poorly sorted; shapes of component grains can be equant or elongate; component grains range in size from medium- to very fine-grained. These textures resemble those of gneisses and schists.

Fragments composed of quartz and feldspar, or, in a few cases, feldspar alone, generally show twinned albite as the feldspar, but microcline may be present. Also present are very few grains of myrmekite, or with graphic texture. These grains were probably derived from gneisses, schists, and plutonic rocks.

Fragments probably derived from slates or phyllites were recognized by the relatively large and parallel oriented muscovite or biotite flakes; such fragments are very scarce.

There is one type of metamorphic rock fragment that is very conspicuous in thin-section, although present only in trace amounts. It consists of chlorite interlayered with muscovite on a microscopic scale; that is, it is not a mixed-layer structure. The chlorite is always more abundant than the muscovite, which forms thin, unaltered individuals. In most cases, the interlayered grains are by themselves but they were also found within quartz-feldspar rock fragments. The grains could have been

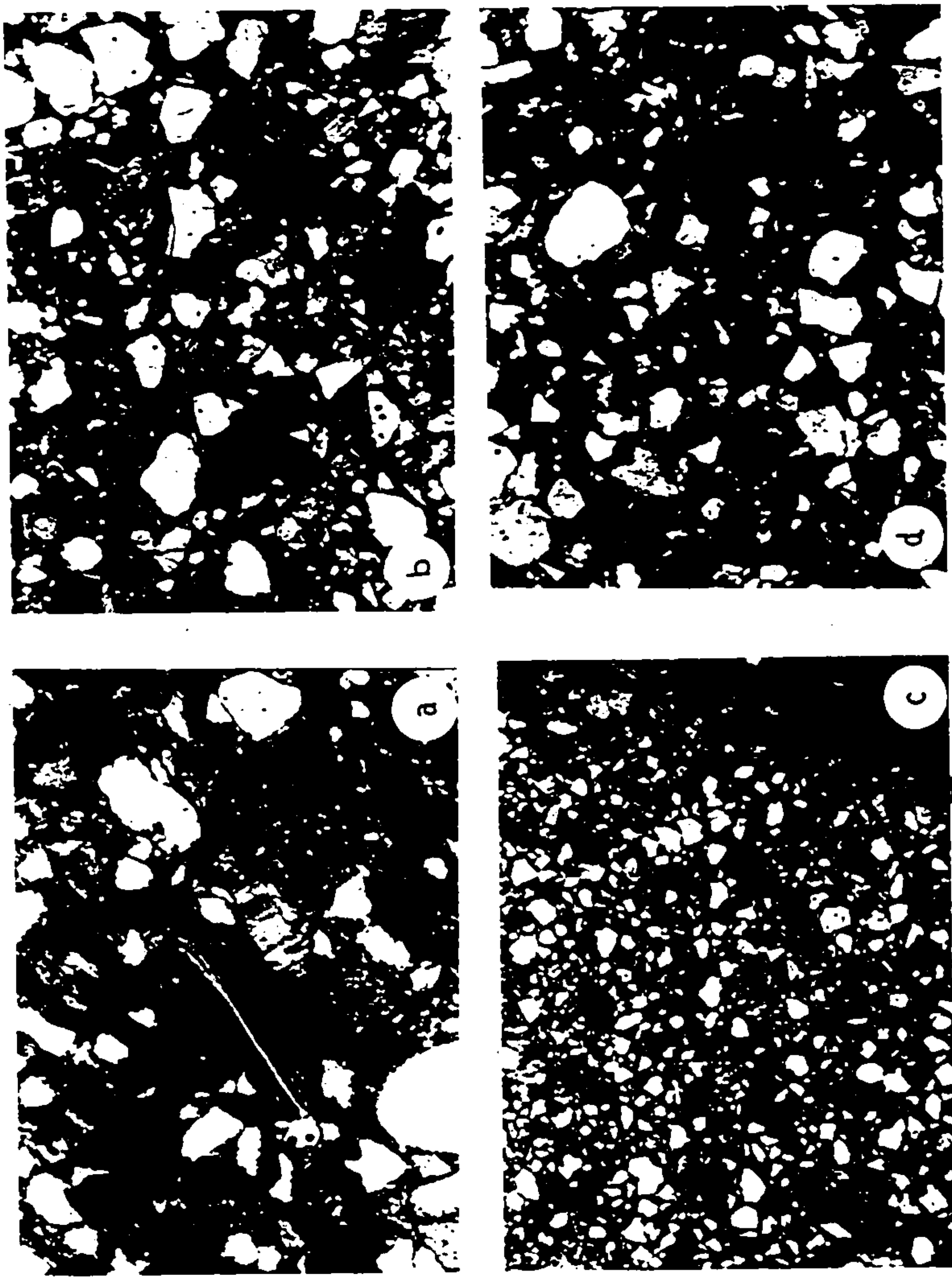
Figure 37. Microphotographs.

(a) Interlayered chlorite and muscovite in wacke from the Irishtown Formation, south shore of the Humber Arm, Bay of Islands. Similar grains are found in the sandstone unit of the Curling Group, but smaller and less rounded (x nicols; 80x).

(b) Texture of wacke from the Lobster Head Sandstone (// nicols; 20 x).

(c) Close-up of (b). Micaceous (metamorphic?) rock fragment (shown by arrow on left) and plagioclase (shown by arrow on right) (// nicols; 80x).

(d) Texture of wacke from the Lobster Head Sandstone. Well rounded grains of quartz (shown by arrows) contrast with overall subangular texture. Polycrystalline grain of quartz shown by arrow (x nicols; 80x).


b
d
a
c

derived from schists in the Fleur de Lys, which show biotite - more or less altered to chlorite - interlayered with muscovite.

Volcanic and hypabassal rock fragments are common except in the Woods Island section. There, none were found in thin-section and only a few were recognized in the field.

Most fragments in this group contain plagioclase laths. The laths commonly are very slender, with simple albite twins; some show the dove-tails of quenched crystals. Others are stubby and show irregular albite overgrowths. Textures range from pilotaxitic to diabasic; the mafic minerals, though, have been completely replaced by chlorite and iron oxide.

A few fragments consist of very fine-grained quartz crystals with irregular contacts; spherulites may be present. These fragments may have been derived from devitrified mesostasis of acid volcanics.

Chlorite fragments showing a decussate texture may have been derived from basaltic rocks. Some show pseudomorphs of sparry calcite after plagioclase laths. Some consist of chlorite surrounded by sparry calcite, or consist exclusively of chlorite. Pillow lavas in the Curling Group in Bonne Bay and in Fox Island River - the only outcrops of lava

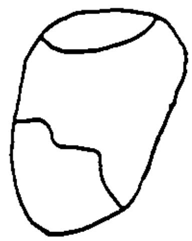
Figure 38. Sketches of grains under the microscope from wackes of the Lobster Head Sandstone (all 80x).

(a) Polycrystalline quartz; internal contacts not sutured; origin metamorphic or plutonic.

(b) Volcanic rock fragment. Plagioclase laths show dovetail structure. Dotted areas are altered plagioclase. Plagioclase is now albite but overall texture suggests derivation from a basaltic rock.

(c) Composite chlorite grain. Broken lines represent cleavage. Similar intergrowth structure is found in the biotite (more or less altered to chlorite) nodules of the nodular schists from the Fleur de Lys Supergroup.

(d) Polycrystalline quartz. Strongly sutured internal contacts suggest a metamorphic origin.



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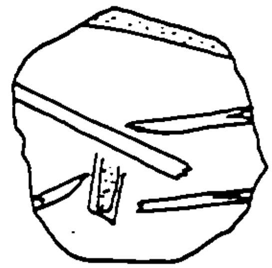

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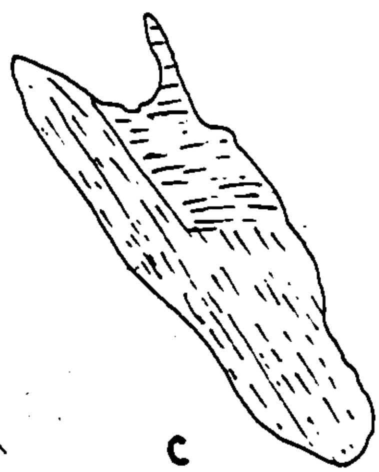

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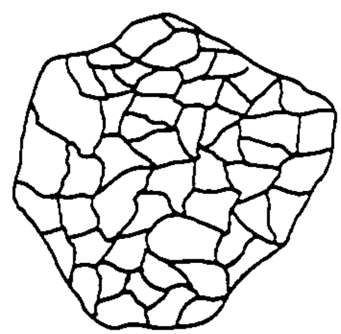


d

that were studied in thin-section - show extensive alteration to chlorite and many amygdules filled with chlorite. Perhaps the fragments described above were derived from similar rocks.

Sedimentary rock fragments are common except in the Woods Island section, where only one was found in thin-section and only a few were recognized in the field.

Most clasts are from shales and may contain scattered minute grains of opaque minerals that in some fragments are so abundant as to almost make them opaque.

Siltstone fragments are present, some of which show sparry cement and well rounded quartz grains.

Carbonate rocks are represented by pebbles or cobbles from intraclastic or bioclastic limestone, commonly micritic, oolitic limestone, and coarse-grained dolomite. Sand-sized limestone clasts are present but scarce.

Chert is common in polymictic conglomerates, where it can be readily recognized by its hardness and its green or black colour. It appears to form very few sand-sized grains because chert is almost absent from the thin-sections studied.

Matrix

The proportion of matrix varies between 9 and 48%; averages are 32% for the Rocky Harbour section, 21% for the Woods Island section, and 17% for the Port au Port sections. The larger value for Rocky Harbour could be due to the average finer grain-size in that section. Undoubtedly, some rock fragments may have been confused for matrix, so the matrix percentages are probably exaggerated by an unknown amount. In spite of this, it is safe to say that the proportion of matrix is generally higher than 10% and that these rocks are wackes in the sense of Williams, Turner and Gilbert (1954).

The matrix consists - in order of decreasing importance - of chlorite, iron oxides or opaque minerals, muscovite, quartz, and feldspar. The chlorite occurs as single crystals or forms patches with disordered texture. Contacts between the matrix and grains of quartz or feldspar in the framework are sharp; the chlorite in the matrix is flattened against the larger grains, forming a thin film of mica. Corrosion of framework grains is very weak, and the mica in the matrix does not penetrate the larger grains. In short, there is no evidence for extensive recrystallization of mica in the matrix. Nevertheless, the absence of clay-size material and the patches of chlorite with disordered texture suggest that some recrystallization occurred.

Cement

The average proportion of cement ranges between trace and 42%; averages are 13% for the Rocky Harbour section, trace for the Woods Island section, and 13% for the Port au Port sections. Calcite is the most common cement. The calcite is generally micritic but in parts it is sparitic. It is possible that most, or all, the micritic calcite was deposited as a calcareous mud and that it is homologous to matrix.

Quartz is a minor component of the cement. It forms overgrowths on framework quartz grains or patches in the matrix.

Accessory minerals

Accessory minerals were studied qualitatively in thin-section and semiquantitatively in heavy mineral separates.

Two heavy mineral separates were prepared, one from sandstones from the Lobster Head Sandstone, the other from sandstones from the Blow-me-down Brook Formation at Woods Island. Each separate was obtained from a composite sample: in each case five rock samples - representative of the different textures in each formation - were ground together, and the heavy minerals were separated from the mixture. Separation was carried out using tetrabromoethane as heavy liquid.

The weight proportion of heavy minerals was approximately 0.5 per mil in each separate. In the sample from the Lobster Head Sandstone, garnet is the most abundant component followed closely by chromite; epidote is common; tourmaline and zircon are rare. In thin-section, rounded glauconite grains are common, and one grain of hornblende was recognized. The presence of chromite was confirmed by X-ray diffraction. In the sample from Woods Island, garnet is the most abundant component; epidote is common; zircon and tourmaline are rare. Chromite appears to be absent from the Woods Island sample.

Diagenesis

Diagenesis appears to have resulted mainly in compaction, slight recrystallization of clays, and precipitation of cement. Compaction caused slight deformation of mica flakes and micaceous rock fragments, it obliterated the margins of some micaceous rock fragments rendering them indistinguishable from the matrix, and it may have caused some pressure solution of framework quartz.

Pressure solution may have been a source for the quartz cement. Other sources are also possible, such as the transformation of montmorillonite to illite (Steinberg et al., 1977) or to chlorite. Montmorillonite is common in sediments derived from volcanic terranes (Millot, 1964), such as may have been the source area for the Curling Group sandstones. A biogenic origin for the silica is also possible if the original matrix mud had incorporated radiolarians. For example, siltstones and sandstones of Delgada submarine fan, off the coast of California, contain reworked siliceous biogenic debris (McManus et al., 1970, p.19).

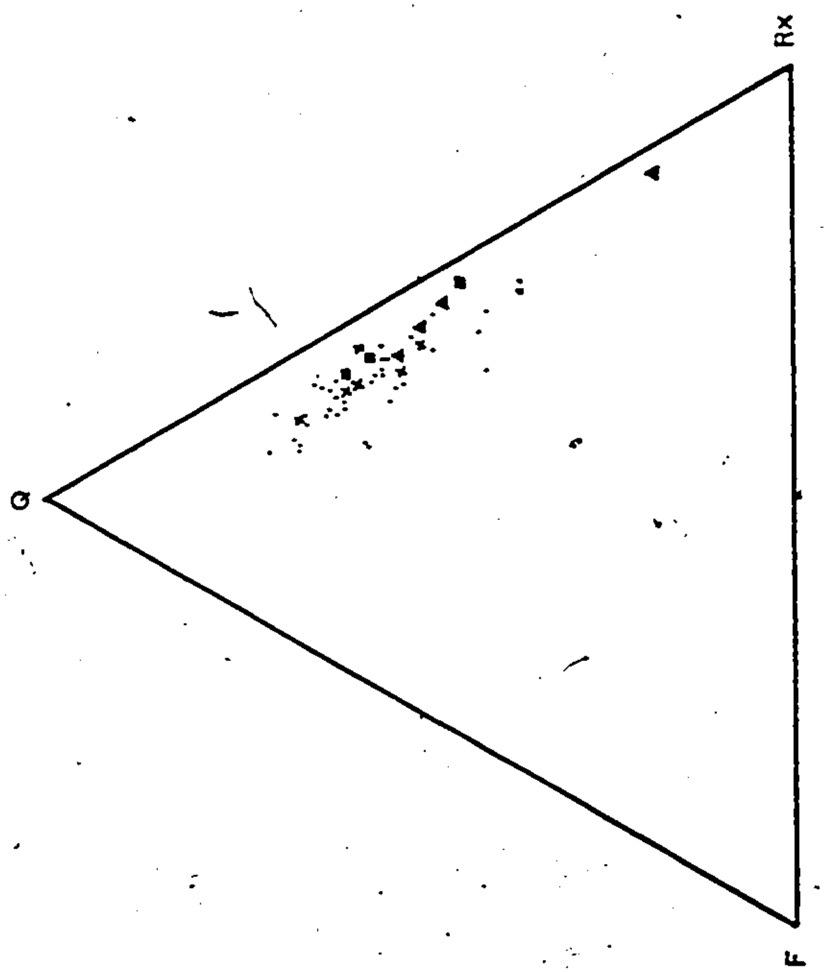
The source for the calcite cement could have been the carbonate bank. That is to say, the matrix mud could contain calcareous mud derived from the carbonate bank. During diagenesis a small part of the calcareous mud recrystallized to sparite. Some migration of calcite must have taken place to form the calcareous concretions in massive thick sandstones.

Figure 39 shows the composition of 50 samples from the sandstone unit of the Curling Group.

Figure 39. Quartz-total feldspar-rock fragments plot of 50 samples from the sandstone unit of the Curling Group.

Sample richest in rock fragments is granule-size, others are of coarse to medium grain size.

Dots - Lobster Head Sandstone; Crosses - Blow-me-down Brook Formation at Woods Island; Triangles - Black Point sandstones; Squares - Rocky Point sandstones.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Q
F

Discussion

Each of the areas studied in detail: Rocky Harbour, Woods Island, and Port au Port, shows a peculiar mineralogical composition. The main contrasts in mineralogy are: (a) pink feldspar (orthoclase or perthite) is common only in the Blow-me-down Brook Formation and in the Rocky Point sandstones; (b) sedimentary and volcanic rock fragments are almost absent from the Blow-me-down Brook Formation; (c) the Black Point and the Rocky Point sandstones show an unusually great variety of rock fragments, a variety that is appreciable in outcrop because of the colourful gamut of granules and pebbles.

As with the rock types, the contrast in composition between the different areas may be stressed by the lack of data from intermediate areas, and also by the difference in average grain-size between the areas. The greater abundance of sedimentary and volcanic rock fragments in the Port au Port area compared with the Rocky Harbour area, for example, may be due to the finer grain-size in the latter.

Another case in point is the presence of pink feldspar in the Blow-me-down Brook Formation and in the Rocky Point sandstones, which may be construed as evidence for a geographically restricted source lithology. This is not true, however, for pink feldspar is common in sandstones of the Cow Head Group exposed south of Martin Point; sandstones that occupy the same stratigraphic position as the sandstone unit of the Curling Group.

Nonetheless, the contrasts in composition between the different areas are valid and their significance should not be minimized. Among these contrasts, the most conspicuous is the near absence of sedimentary and volcanic rock fragments and of chromite in the Blow-me-down Brook Formation. In the field, this characteristic is reflected by the much lighter colour of the Blow-me-down Brook sandstones. This contrast can only be explained by assuming a marked difference in source lithology between the Blow-me-down Brook and the rest of the sandstone unit.

The contrasts in composition mentioned above may be due exclusively to geographical variations in the source lithologies but they may also be caused, in part, by changes in source lithologies with time. The sandstone unit is Upper Llanvirnian and the available data does not allow a more precise statement. Nonetheless, it is quite likely that all the formations are not exactly coeval. A possible example of variation in mineralogy with time is given by the pink feldspar. The Blow-me-down Brook Formation exposed west of Frenchman's Cove, seems to have no pink feldspar in the basal 200 m, approximately, but higher up pink feldspar appears and gradually becomes common. In addition, from a regional viewpoint, and within the Curling Group, pink feldspar occurs in the formations more to the west: Blow-me-down Brook and Rocky Point sandstones. If it is assumed that these sandstones were deposited in a sedimentary system that prograded westwards (the question of provenance direction is discussed in the next section) they might be tentatively considered younger than other parts of the sandstone unit. These two observations - badly in need of confirmation - suggest that pink feldspar makes it appearance at a relatively late time.

Comparison with the sandstones in the Tourelle Formation (Hiscott, 1977) reveals that, in the Tourelle, rock fragments composed exclusively of quartz ('polycrystalline quartz' in Hiscott, 1977) are fewer; quartz-feldspar fragments appear to be absent; sedimentary and volcanic rock fragments are similar, except for the presence of quartz porphyry fragments in the Tourelle; total feldspar content is slightly higher, feldspar species are the same, and the variety and percentage of accessory minerals is greater; in particular the proportion of chromite is higher. If rock fragments composed exclusively of quartz were allotted to quartz, the plot in Figure 39 would resemble very much the plot for wackes from the Tourelle (Hiscott, 1977, Fig. 6.2).

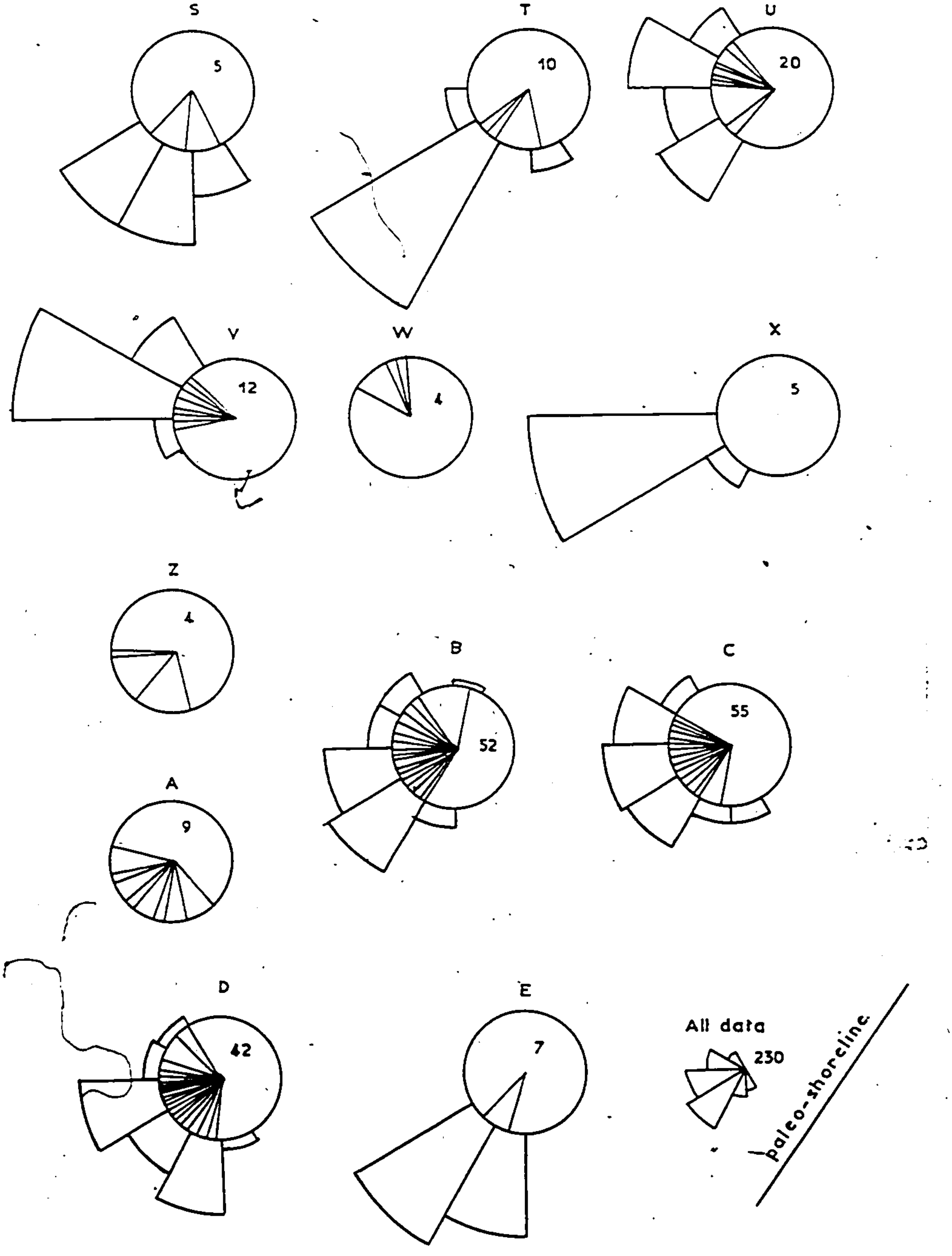
PALEOCURRENTS

Paleocurrent measurements have been corrected only for tilt of the strata by rotation about the local strike. Correction for plunge of fold axes was not considered necessary because the axes of large folds that could be measured are subhorizontal. As the structural units underwent an unknown displacement by sliding, it is possible that the structural units suffered rotation about vertical axes during sliding. If so, the error thus introduced cannot be corrected with the data available. Nonetheless, strata that did not undergo sliding, such as the Gadd's Point Formation, show a paleocurrent direction (south to southwest) that coincides with one of the dominant components of the paleocurrent patterns for the Lobster Head Sandstone. This coincidence suggests that rotation about vertical axes was relatively unimportant.

The Lobster Head Sandstone yielded 230 paleocurrent measurements, of which 101 are vectorial and the remainder are lineations that do not indicate the direction of movement. Two thirds of the total, 165 measurements, come from structural units A to E; the disproportion reflects better exposures in the south and the relative scarcity of sole marks in the thick sandstones, as compared with the medium-bedded sandstones that are predominant in the south

Figure 40. Paleocurrent distributions for the Lobster Head Sandstone.

Each plot corresponds to one structural unit, indicated by the letters. The number of measurements is indicated inside the circumference. Inside the circumference are plotted the individual vectorial measurements. Outside the circumference, all the data (vectorial plus non-vectorial) are plotted as percentages; the circumference is the zero value. The data is grouped in 30° intervals. For geographic location of the plots see Figures 6 and 7. The line in the lower right hand corner is parallel to the regional strike of the carbonate sequence and is taken to be parallel to the axis of the basin where the Lobster Head Sandstone was deposited.


S
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T
10
U
20
V
12
W
4
X
5
Z
4
B
52
C
55
A
9
D
42
E
7
All data
230
paleo-shoreline

(Figures 3 and 40).

Analyzing the structural units separately, there appears to exist a trend that, from north to south, is as follows: SU 'S' and "t" show paleocurrents towards south-southwest; SU 'U', while maintaining a mode to the south-west also shows a mode to the west; SU 'V' shows paleocurrents mainly to the west. In SU 'W' and 'X' scarce data suggests flow to the west, as in SU 'V'. No measurements were obtained from SU 'Y'. In SU 'Z', "a" and 'B', while retaining a westward component, the patterns show a component to the southwest; in SU 'C' and 'D' the westward component is strong, together with the southwestward component. The latter may become stronger in SU 'D' and it is the only component present in SU 'E'.

Summarizing the available information - which is quite scanty for some structural units - the average paleocurrent direction changes from mainly parallel to the basin axis (SU 'S' and 'T'), to mainly transverse (SU 'U', 'V' and 'X'), then again to longitudinal (SU 'Z', 'A' and 'B'), to transverse (SU 'C'), and finally to longitudinal (SU 'E'). As will be discussed in a later chapter, the geographical changes in the paleocurrent patterns suggest the presence of two dispersal systems.

North of SU 'A', transverse (westward) components occur in structural units where bedding is thicker and grain-size coarser. South of SU 'A' no such correspondence is apparent: SU 'B' is thicker bedded and coarser grained - overall - than SU 'C' or 'D', which show transverse components as strong, or stronger, than SU 'B'.

The Blow-me-down Brook Formation on Woods Island yielded 107 paleocurrent measurements. As the great majority of the measurements are vectorial - the exception being a few taken on sheet-like fluid escape structures - the rose diagrams do not show lineations separately (Figure 9).

The paleocurrent pattern from Woods Island is peculiar in that it shows components to the east. The measurements have been separated geographically with the purpose of isolating the different components.

In the north, the northeastward component comes from sandstones of the 'channel facies'. Measurements are mainly of imbricated granules or pebbles less than 1 cm long. Imbrication is difficult to measure accurately and is less reliable than sole marks, but it does not seem warranted to attribute this component to errors in measurement or to post-depositional alteration or the fabric of the sandstones. In fact, a northeasterly trend is supported by the orientation of the eroded walls of the channel, which show orientations of 20 to 30°.

The mode developed between 90 and 150° is strong and is not found elsewhere in the sandstone unit. Some of these measurements come from sandstones that are not of the 'channel facies', but it was not possible to decide whether all are not.

Measurements from the central area show a very strong southwestward mode; this mode comes mostly from scour axes, which are very coherent in orientation. This pattern is parallel to the axis of the basin, or longitudinal..

Measurements from the southern outcrops show a strong southerly, or longitudinal, component, but also a component to the southeast.

Reconnaissance paleocurrent measurements near Broad Cove, in Blow-me-down Brook lithologies (three beds of quartzite with tabular cross-stratification), gave: 250°, 300°, and 330°. These few measurements suggest provenance from the east and agree with data from other parts of the sandstone unit.

The provenance direction of the sandstones of the Blow-me-down Brook Formation is in doubt. The well developed components towards the east in the paleocurrent patterns, suggest derivation from the west, opposite to that for the Lobster Head Sandstone. A different provenance direction would explain the contrast in composition between the Blow-me-down Brook and the rest of the sandstone unit.

On the other hand, the measurements from Broad Cove suggest derivation from the east. If so, the paleocurrent components directed broadly eastwards would be local features. The northeastward mode, from the channel facies, could be the result of a strong meander in the channel; measurements in the southeast quadrant could have resulted from local meanders or from deflection deviation of turbidity currents by local highs.

The reasons for the presence of such discordant components remain unknown, but the possibility of having such components in a dispersal system that is mainly oriented towards the west or southwest, should not be neglected. For instance, the paleocurrent pattern for the Tourelle Formation (Hiscott, 1977) shows precisely the same anomalies (Figure 41).

Only 11 measurements - all vectorial - were taken from the Black Point sandstones. A southward and a westward component are present (Figure 10).

The Rocky Point sandstones yielded 39 measurements, all vectorial. The greater part of the measurements fall in the south to southwest sector but a small number form a component towards the east (Figure 10).

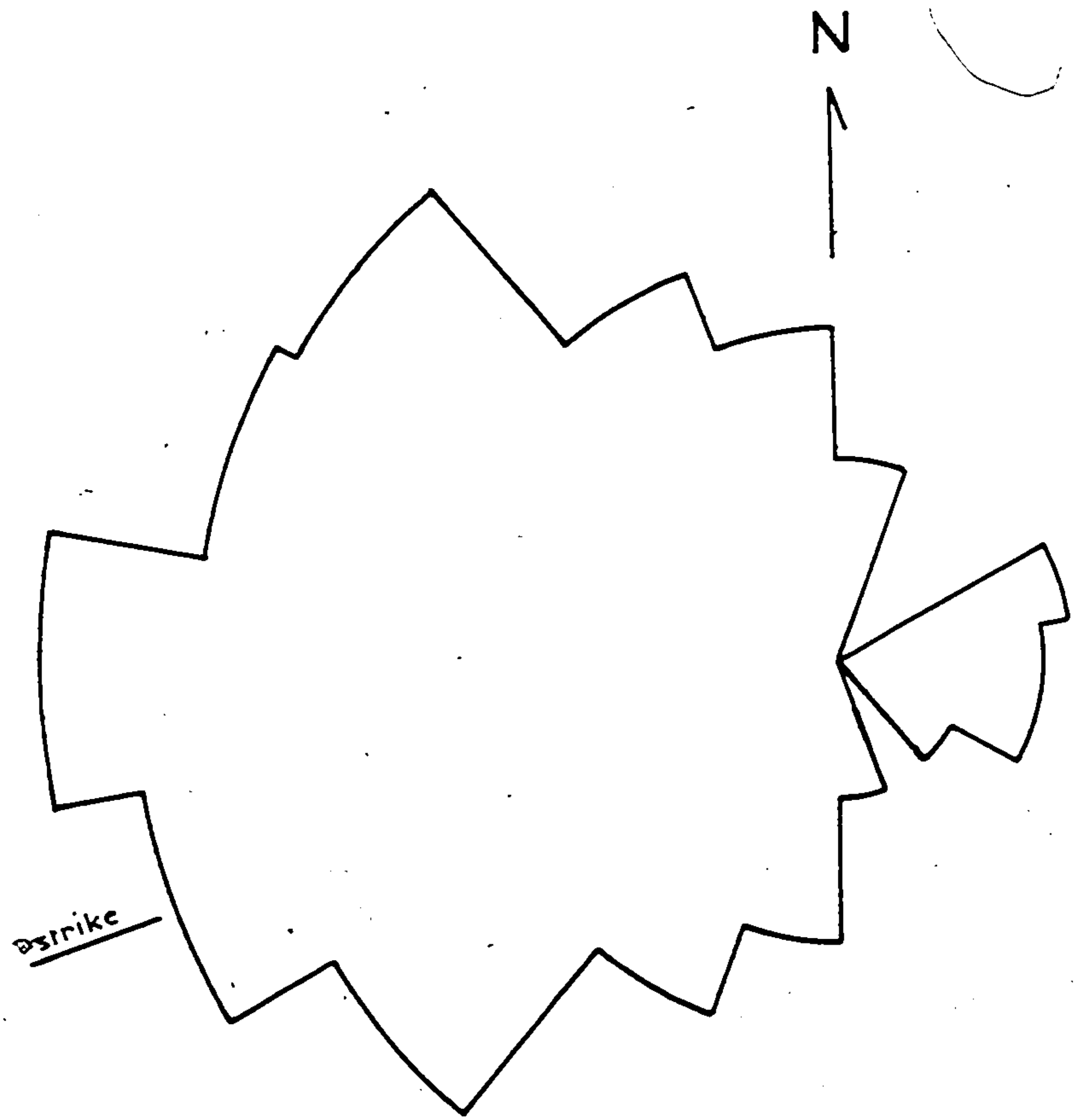


Figure 41. Plot of paleocurrent measurements from the Tourelle Formation, Quebec, taken from Hiscott (1977, Fig. 7.6). Note the presence of a northeasterly and a southeasterly paleoflow component.

In summarizing the paleocurrent data it is possible to say firstly, that the eastward component is present in those exposures of the sandstone unit that occur farther to the west, and secondly, that the Black Point and Rocky Point sandstones show much stronger southwards components than does the Lobster Head Sandstone.

PROVENANCE

The mineralogical composition of the Upper Llanvirnian sandstone unit of the Curling Group will now be used to determine the possible parental lithology for the sandstones.

One possible choice as source lithology is the Grenville basement, which at present is exposed both to the west and to the east of the Curling Group. The Grenville basement (cf. Chapter Two) is characterized by the abundance of rocks of granitic to tonalitic composition. Judging from the composition of the sandstones in the Bradore Formation (Labrador Group), which are mainly arkoses, the eroded cover of the Grenville basement was mainly of granitic composition, or at least, not essentially different from what is now preserved as Grenville.

In contrast, in the Upper Llanvirnian sandstones, total feldspar content is low and the plagioclase is exclusively albite. Consequently, direct derivation from the Grenville basement seems unlikely. Nonetheless, the abundance of rock fragments probably derived from gneisses, and the presence of scarce plutonic rock fragments of granitic composition and of trace amounts of perthite, indicate that the Grenville could have been an indirect source lithology. In other words, that the Upper Llanvirnian sandstones might contain second cycle detritus from the Grenville basement.

A second possible choice as source lithology is the Fleur de Lys Supergroup (Kennedy, 1975).

The Fleur de Lys Supergroup flanks the carbonate sequence along the east. Its stratigraphic position and lithology suggest that it is largely a lateral equivalent to the Precambrian (?)-Lower Cambrian of the carbonate sequence (Kennedy, 1975). The only detailed study of the Fleur de Lys is by Kennedy (1975), who worked on the northernmost outcrops of this unit, in the Burlington Peninsula. He described the rocks as metamorphosed sandstones and shales, with minor metaconglomerates and marbles. Metamorphism is generally of intermediate grade, locally reaching high-grade. Muscovite-albite, biotite-muscovite-albite, and muscovite-garnet-albite, are common assemblages; oligoclase may be present. Texturally, schists are predominant. The Fleur de Lys Supergroup includes two suites of igneous rocks: "A basic/ultrabasic association related to mafic volcanism and a series of granitic and porphyry intrusions related to silicic volcanism" (Kennedy, 1975, p.54).

The author studied seven thin-sections of Fleur de Lys rocks exposed around Deer Lake, immediately east of the Long Range Plateau. (The thin-sections were generously lent to the author by Dr. Richard Hyde, Newfoundland Geological Survey.) The stratigraphic position of these samples within the Fleur de Lys Supergroup is unknown.

Two of the thin-sections are metaconglomerates; two are nodular, muscovite-biotite-albite schists; one is a muscovite-biotite micaschist; one is a muscovite schist; and one is a chlorite-muscovite phyllite. The biotite shows deep brown to almost colourless pleochroism, but may appear slightly chloritized; biotite flakes may reach 2 mm in length. The muscovite is generally finer-grained than the biotite. In the muscovite schist, finely crystalline muscovite forms equant crystals, that is to say, not flakes, similar to the mesostasis in the meta-arkose described above.

Special features in the nodular schists and the metaconglomerates will now be described. One sample of nodular schist shows about 40% mica - 30% of which is biotite (plus chlorite) - 40% quartz, 15% albite, and traces of alkali feldspar, opaque minerals and others. Rock fragments appear to be present, composed solely of quartz, or quartz and feldspar. Grain-size ranges between one-twentieth of a mm to 2 mm. Contacts between quartz grains are strongly sutured. The nodules are formed by large biotite flakes clustered with different orientations and intergrown. It is common to see muscovite and biotite (or chloritized biotite) interlayered.

The metaconglomerates show pebbles up to 1.5 cm long. The pebbles are mostly of polycrystalline quartz but a few consist of clusters of twinned and untwinned albite. Some untwinned feldspar grains in these clusters showed twinning upon rotation in the U-stage; two that did not show twinning gave positive optic angles of 86° (measured directly) and 87°. These clusters of albite crystals might have resulted from albitization of pebbles of K-feldspar or perthite. The matrix of the conglomerate is recrystallized to a biotite-muscovite assemblage. Muscovite interlayered with biotite can be seen.

Three features of the Fleur de Lys samples must be remarked because they have been found in rock fragments in the Curling Group sandstones. One is the common occurrence of biotite interlayered with muscovite. The second is the presence of nodular schists with nodules of biotite. The third is the development of patches of fine-grained, equant, muscovite.

Another feature of the Fleur de Lys rocks is the absence (?) of K-feldspar or perthite. If, as it seems reasonable to assume, it was derived from the Grenville basement, it would be expected to contain a noticeable proportion of K-feldspar or perthite. A possible explanation for the absence of these two minerals is that they have been transformed to albite during metamorphism. Albite is an ubiquitous product of metamorphism in the Fleur de Lys (Kennedy, 1975) and it may have replaced K-feldspar or perthite. Recall that the study of thin-sections from Lower Cambrian sandstones of the carbonate sequence supported such a conclusion (cf. Chapter Two).

It will be postulated tentatively that the albite was not derived from the Grenville basement but was newly formed in the Fleur de Lys rocks during metamorphism, and furthermore, that (in Middle to Late Ordovician time) the only source for abundant albite was the Fleur de Lys Supergroup. The albite in sandstones of the Curling Group should, then, have been derived from erosion of Fleur de

Lys rocks.

The sedimentary rock fragments could all be intra-basinal and are interpreted as such. The volcanic rock fragments could have been derived from volcanic rocks in the Fleur de Lys Supergroup or from younger volcanic rocks. Among the accessory minerals, glauconite is probably a first cycle product, as well as epidote, which may have been associated with the volcanic rocks; zircon and tourmaline could be second cycle products; garnet forms equilibrium assemblages in the Fleur de Lys, but it is also present in the Grenville, so it could be first or second cycle product.

Mineralogically, then, the Fleur de Lys Supergroup is a possible source lithology for the Upper Llanvirnian sandstones. The next question is whether the geologic history of the Fleur de Lys allows such a postulate. The more recent and detailed study of the Fleur de Lys Supergroup was done by Kennedy (1975). He postulated that the sediments in the Fleur de Lys were deposited over the time interval Late Precambrian to Middle Cambrian; that by Late Cambrian to Tremadocian time, deformation of these sediments started; and that by the Arenigian, the Fleur de Lys had been deformed and uplifted to form the Burlingtonian Orogen, which subsequently provided detritus for the Curling Group. The latter, Arenigian, age could be younger, that is to say, it could be Llanvirnian (Kennedy, 1977, pers. comm.).

Paleocurrents show that most of the sandstone unit was derived from the east. Consequently, both the petrography and the paleocurrents point to the Fleur de Lys terrain as a source area for the sandstone unit of the Curling Group.

At this point it is necessary to discuss the provenance of the Blow-me-down Brook Formation. This unit shows a paleocurrent pattern with a strong eastward component and a mineralogical composition that differs from that of the rest of the sandstone unit in the virtual absence of sedimentary and volcanic rock fragments and of chromite. The significance of the paleocurrent pattern may be diminished if it is considered that the Rocky Point sandstones also show an eastward paleocurrent component. As regards the composition, although it is true that there are important differences, there are also similarities with the rest of the sandstone unit. For example, the presence of albite and of chlorite interlayered with muscovite (though only one grain was found). There are also similarities in rock types, as well as important differences. Finally, the available information indicates a similarity in age between the Blow-me-down Brook and the rest of the sandstone unit. The evidence gathered to date from Newfoundland is not sufficient to postulate provenance from the west for the Blow-me-down Brook Formation, but it does throw doubts on the current idea of derivation from the east for this unit (Stevens, 1970; Williams, 1975).

Lithofacies found in the Curling Group are found in Quebec, the Tourelle and the Cloridorme Formation have already provided several examples. More specifically, lithofacies of the Blow-me-down Brook Formation are found in the Armagh Group and in the St. Roch Formation (Hubert, 1973; P. Strong, 1978, pers. comm.). The similarities include the presence of banded and massive thick sandstones, of quartzites with tabular cross-stratification, of similar grading patterns in the massive thick sandstones. Mineralogically there are similarities as well, in the presence of polycrystalline quartz rock fragments, in the common occurrence of albite (but also oligoclase and andesine), K-feldspar and perthite, in the scarcity of sedimentary and volcanic rock fragments and, perhaps, in the presence of biotite interlayered with muscovite, which Hubert (1973, Pl. IIc) described from the Armagh as "biotite altered into hematite and colorless mineral". The similarities between the Armagh, the St. Roch, and the Blow-me-down Brook appear to be sufficiently strong to suggest a common provenance direction.

Unfortunately, the Quebec rocks are as poorly understood as the Blow-me-down Brook. Hubert (1973) measured paleocurrent directions indicating provenance from the southeast (homologous to provenance from the east in Newfoundland) but recently P. Strong (1978, pers. comm.) reported a consistent set of measurements indicating provenance from the northwest; Strong studied only a small outcrop area of the St. Roch Formation.

The Armagh-St. Roch sequence is thought to range in age from the Early Cambrian to Early Ordovician. An Early Cambrian age would support derivation from the northwest; that is, from the Grenville craton, by analogy with the Lower Cambrian of the carbonate sequence in Newfoundland and because a source area to the southeast (east in Newfoundland) at this early date is quite impropable considering that the Fleur de Lys was being deposited. But the only fossils not in clasts found in the Armagh-St. Roch sequence are Lower Ordovician, so the Cambrian age for part of this sequence should not yet be taken for granted.

In conclusion, the question of provenance direction for the Blow-me-down Brook Formation must be left undecided. The Lobster Head Sandstone and the Black Point sandstones, on the other hand, were certainly derived from the east. The Rocky Point sandstones are considered to have been derived from the east on the basis of affinities in rock types, petrography, and age, with the Lobster Head and the Black Point.

The provenance direction of the sediments in the shale unit is difficult to determine due to the absence of paleocurrent indicators. The ribbon limestones, calcarenites, limestone breccias, and the associated black (and red?) shale, it is here postulated, were derived from a carbonate bank, but the relative geographic position of this bank is uncertain.

The green shale is suspected of being definitely terrigneous and possibly derived from the Burlingtonian Orogen. This idea is based firstly on the apparent association of green shale with siliciclastic turbidites in the upper members of the shale unit at Black Point and at Rocky Point, and with dolomitic siltstones in the upper member of the Yellow Point Formation. Secondly, the idea is based on the stratigraphic position of the green shale: immediately preceding in time the sandstone unit, which suggests that deposition of green shale is the result of initial emergence of the Burlingtonian Orogen.

With regard to the dolomitic siltstones, it is possible that their source lithology is exposed in the carbonate sequence. Along the eastern shore of East Arm of Bonne Bay, is exposed a brown-weathering, thinly-bedded, rippled, calcareous and dolomitic siltstone, showing thin intercalations of dark shale; the rock is strongly bioturbated with vertical and horizontal burrows. These rocks belong to the Labrador Group (Lower Cambrian). In thin-section they show silt-sized, subangular, quartz cemented by finely crystalline to micritic dolomite. Erosion of this rock unit may have provided detritus for the dolomitic siltstones. This Lower Cambrian rock type has not been seen south of Bay of Islands, its absence would agree with the absence of dolomitic siltstones in the southern part of the Curling Group basin.

CHAPTER SEVEN

THE NAPPE HYPOTHESIS

Before passing on to the discussion of the sedimentological evolution of the Curling Group, it is necessary to provide a critical analysis of the nappe hypothesis. Such an analysis is wanting for Newfoundland and there is now sufficient information to render it worthwhile. The term 'nappe hypothesis' is employed here in a broad sense, encompassing not only a tectonic interpretation but also the many sedimentological and stratigraphic corollaries that follow from such a tectonic interpretation.

The nappe hypothesis was first proposed in the beginning of this century to explain structural relations of rocks in the Taconic Mountains in New York State (see Rodgers, 1970, for a historical background). The hypothesis was extended to western Newfoundland in 1963 by Rodgers and Neale. In 1941, Johnson had postulated that some Ordovician shales exposed along the western shore of Newfoundland, north of Bonne Bay (these shales form part of the Cow Head Group), had been thrust westwards for a long distance, but Johnson did not generalize this idea.

Debate about the validity of the nappe hypothesis for the Taconics, began immediately after its proposal and continued strong until 1956 (Lochman, 1956), when it abruptly ended. There was no winner at that time, but as the years passed and new challenge did not come forth, the nappe hypothesis gradually came to be accepted by geologists at large.

Western Newfoundland and the Taconic region, have become examples of areas showing nappe tectonics and both are used repeatedly as standards for extrapolation of the nappe hypothesis to other areas, even areas outside the Appalachians. The nappe hypothesis has reached a position of pre-eminence. In recognition of this fact, the following discussion will start by enunciating the nappe hypothesis in detail. This done, the immediate and more important corollaries, or expected consequences, will be critically analyzed.

The evolution of central western Newfoundland, within the framework of the nappe hypothesis, would have been as follows. By the late Precambrian, the Grenville basement constituted a continental margin deepening to the east. The Precambrian (?)-Lower Cambrian clastic sediments of the carbonate sequence were deposited on the platform, while the Fleur de Lys Supergroup clastic sediments were - more or less contemporaneously - deposited on the slope and basin floor off this continental margin. Transport of sediment was eastwards from the Grenville craton across the platform.

The Middle Cambrian to Arenigian (up to and including the Table Head Formation) carbonate rocks of the carbonate sequence, were deposited on the platform, constituting a carbonate bank facing east. East of this carbonate bank, on the slope and basin floor, the shale unit of the Curling Group was deposited. Transport of sediment was eastwards off the carbonate bank.

During Table Head time the platform area began a rapid subsidence: the carbonate bank was drowned and deposition of limestone ceased. The upper member of the Table Head Formation, composed of graptolitic shales, represents a pelagic deposit free of carbonate detritus.

During deposition of the Table Head Formation, central Newfoundland, that is, the internal part of the geosyncline was undergoing deformation and uplift. One of the consequences of this orogenesis was the detachment of several nappes. Detachment of these nappes, or slices, followed a regular order. The first slice to become detached was obducted oceanic crust; as it moved westwards it overrode Lower Cambrian clastic sediments (Fleur de Lys equivalents) which, in turn, became detached. The assemblage of two slices moved westwards overriding Lower Ordovician sediments (shale unit of the Curling Group), which became detached. The new assemblage of three slices continued its westward movement.

As the three-tier nappe advanced, it was undergoing erosion. The detritus accumulated as the sandstone unit of the Curling Group, conformably on the shale unit. The Gadd's Point Formation and the Piccadilly Beach sandstones, accumulated as distal facies of the sandstone unit on the, now submerged, carbonate platform. Transport of sediment during this time was from east to west.

A final phase of transport emplaced the composite nappe on top of the distal deposits of the Gadd's Point Formation and Piccadilly Beach sandstones. The time of final emplacement of the nappe occurred before deposition of the Long Point Formation, because the latter overlies the Curling Group unconformably (Rodgers, 1965; Stevens, 1970; Williams, 1975).

The strongest criticism of the nappe hypothesis is based on the graptolite ages reported in this thesis. This data is new and it greatly modifies the previous stratigraphic correlation between the Curling Group and the carbonate sequence.

Graptolites indicate that the uppermost beds of the Yellow Point Formation are Upper Llanvirnian, that the sandstone unit is wholly Upper Llanvirnian, that the upper member of the Table Head Formation is Lower Llanvirnian, and, finally, that the Gadd's Point Formation and the Piccadilly Beach sandstones probably span the time between the late Early Llanvirnian and the early Late Llanvirnian.

These ages are supported by lithological correlations: the upper member of the Yellow Point Formation shows intercalations of Gadd's Point lithologies; the upper member of the shale unit in the Black Point section shows sandstone beds similar to those in the Piccadilly Beach sandstones. In addition, the stratigraphic sequence exposed in SU 'A' of the Rocky Harbour section and at Neddy Hill, strongly suggest that the Lobster Head Sandstone is younger than the Gadd's Point Formation.

The main conclusions to be drawn from these data are: (a) that the Gadd's Point Formation and Piccadilly Beach sandstones are correlative with the upper part of the shale unit of the Curling Group, (b) that the sandstone unit is wholly younger than the Table Head Formation, and (c) that the sandstone unit is partly younger than the Gadd's Point Formation and the Piccadilly Beach sandstones, and may be wholly younger.

These conclusions conflict with the nappe hypothesis on two points. One is that the Gadd's Point and Piccadilly Beach deposits can not be interpreted as distal deposits of the sandstone unit, or at least not in a straightforward manner. The other conflict is more important and follows from the statement by Rodgers and Neale (1963) to the effect that all strata in the Curling Group that "are as old or older" than the Table Head Formation are to be considered part of the nappe; the sandstone unit, being younger than the Table Head, does not meet this requirement.

As the Curling Group is assumed to tectonically overlie the Gadd's Point and Piccadilly Beach deposits, the upper age limit for the nappe sequence would be slightly younger than the top of the Table Head Formation. This extension, however, does not eliminate the conflict.

Modification of the nappe hypothesis to incorporate the Upper Llanvirnian sandstone unit into the nappe, leads to serious paleogeographical problems. The sandstone and shale units of the Curling Group constitute a conformable sequence. Necessarily, then, both units must have been deposited in the same basin and the final phase of transport of the nappe must have taken place after all the sandstone unit had been deposited. Furthermore, it is now known that the uppermost part of the shale unit is partly coeval with the Gadd's Point and Piccadilly Beach deposits. To accommodate these two restrictions into the nappe hypothesis, it becomes necessary to postulate a reversal of the regional slope before the end of the time of deposition of the shale unit. This stems from the interpretation of the Gadd's Point and the Piccadilly Beach deposits as derived from the east. Such a reversal could have taken place, for example, at the time when limestone deposition ceased in the shale unit and the upper members started to be deposited.

Such a reconstruction, however, is quite implausible for there is no evidence for a change in provenance direction at any level within the shale unit. To be sure, there is a partial change in rock types with the upper members, but in the Yellow Point Formation it can be clearly seen that Lower Ordovician rock types persisted into the Middle Ordovician upper members: for example, the dolomitic siltstones and the green and black shale.

This is the strongest objection to the nappe hypothesis, that it cannot explain the stratigraphic relationships borne out by the new graptolite ages. On the other hand, the weakness of the objection lies precisely in that graptolite ages are scanty.

The petrography of the Curling Group imposes another set of restrictions on the nappe hypothesis. The conglomerates in the sandstone unit contain abundant clasts of limestone. As the sandstone unit would have been deposited in a basin to the east of the carbonate bank (St. George-Table Head) and derived from farther east, it becomes necessary to have a source for limestone.

This problem has already been discussed by Stevens (1970), who suggested that a carbonate bank might have developed on top of the advancing nappe. Field study of the limestone clasts in the sandstone unit suggests that the types of limestone represented match rock types in the Table Head Formation, and possibly some of the fauna, such as the calceola coral (cf. Chapter Two). If this resemblance holds true, Stevens' suggestion would imply the development of similar rock types in two very different geologic settings: one a subsiding, well established carbonate platform, the other a rising, tectonically unstable island chain.

It is more reasonable, with the available information, to assume that the limestone clasts in the sandstone unit were derived from the Table Head Formation and not from another, hypothetical carbonate bank. This interpretation, of course, finds no place in the nappe hypothesis.

Stevens (1970, p.175) stated that the sandstone unit contains "abundant ophiolitic fragments, especially chromite". This statement has never been documented despite the fact that it is the basis for the proposed stacking order of the slices. The Lobster Head Sandstone contains chromite in trace amounts, presumably the Black Point and the Rocky Point sandstones contain chromite as well, but to speak of 'ophiolite detritus' in the sandstone unit is a misleading statement. There are no rock fragments, except for those volcanic, that could, with any certainty, be attributed to the erosion of ophiolites.

The bulk of the sandstone unit (with the possible exception of the Blow-me-down Brook Formation) was derived from a source area rich in quartz and with lesser amounts of albite and mica. According to the nappe hypothesis this source area consisted of uplifted sediments now represented by the Summerside and the Irishtown Formations, exposed in the region of Bay of Islands. These formations are assumed to be Lower Cambrian and, at least in part, equivalent to the Fleur de Lys Supergroup. These units are unmetamorphosed and consist mainly of shale, with coarse-grained sandstone abundant only locally, in the Irishtown Formation. It is possible to postulate that the coarser deposits were eroded away to form the sandstone unit, but it must be accepted that as presently exposed, the Summerside-Irishtown sequence is not an adequate source lithology for the sandstone unit. Moreover, in Chapter Nine, it will be shown that the Early Cambrian age for the Summerside-Irishtown sequence is inadequately documented and that these units could well be Ordovician.

In the section on Provenance (Chapter Six) it was shown that the Fleur de Lys lithologies match well with the lithologies represented by the detritus in the sandstone unit. The Fleur de Lys is a metamorphic sequence and if it was the source for the sandstone unit, it follows that metamorphism occurred prior to deposition of the sandstone unit. Kennedy (1975) postulated that deformation of the Fleur de Lys rocks led to the uplift of the Burlingtonian Orogen, immediately to the east of the St. George-Table Head carbonate bank. Clearly, the presence of such an uplift would constitute a barrier to the passage of the nappe. In order to eliminate this barrier, Williams (1975, p.1892) states: "More likely, there was no Fleur de Lys orogen before Lower Ordovician slice assemblage; rather, it formed contemporaneously and at depth during the slice-assembly process. This proposal implies that metamorphism and deformation within the Fleur de Lys zone formed as a consequence of the same phenomenon that led to slice transport". In this way he eliminated the Fleur de Lys as a source lithology without suggesting an alternative adequate source for the sandstone unit.

Conclusions stemming from the petrography of the sandstone unit, then, lead to conflict with the nappe hypothesis, a conflict that, it seems, can not be circumvented by modifying the hypothesis.

A further set of objections to the nappe hypothesis originates from lithological comparisons between the Curling Group and the carbonate sequence.

The clastic and the carbonate sequences show many similarities in rock types. Some similarities are of a general character, for instance, ribbon limestone, calcarenite, limestone breccia, and chert, are present in the shale unit and in the central part of the carbonate sequence. Other similarities are more specific and localized. For example, in Port au Port, where red shale is abundant in the Arenigian part of the shale unit, the St. George Group shows red limestones in its upper part. Or, for example, the Rocky Point sandstones are partly similar to the Crow Head sandstones; the Piccadilly Beach sandstones are like sandstones in the upper member of the shale unit at Black Point; Gadd's Point rock types occur in the upper member of the Yellow Point Formation, and in SU 'A' of the Rocky Harbour section, which would form part of the nappe, rock types predominate that are identical to those found in the Gadd's Point Formation, exposed nearby. In addition, in SU 'A' the Gadd's Point lithology appears to pass conformably to the Lobster Head Sandstone. These relationships indicate either that the Lobster Head was deposited in the same basin as the Gadd's Point, or that Gadd's Point lithology developed also in the far removed basin to the east. These two alternative sites of deposition, tens of kilometres apart, should have had markedly different tectonic settings, so the development of identical rock types in the two sites must be judged improbable.

Notice that many of the similarities are restricted geographically, that is, the Piccadilly Beach sandstones do not resemble any deposits in the Yellow Point Formation, nor do rock types in the Gadd's Point Formation appear in the region of Port au Port. In other words, in the areas of Rocky Harbour, Black Point, and Rocky Point, one finds pairs of similar lithofacies, one element of the pair belonging to the nappe, the other to the autochthon. If as the nappe hypothesis states, the sites of deposition of the Curling Group and the carbonate sequence were many kilometres apart (at least 50 km), and the two sequences were brought into contact through a long-distance tectonic transport, it is difficult to explain the superposition of pairs of similar lithofacies.

A final objection concerns the time of emplacement of the nappe. Rodgers and Neale (1963) stated that the nappe should have been emplaced before the beginning of deposition of the Long Point Formation. The base of the Long Point lies close to the Llanvirnian-Llandeilian time boundary and may reach into the Late Llanvirnian (cf. Chapter Two). The well dated Lobster Head Sandstone is wholly Late Llanvirnian in age. As tectonic transport of the Lobster Head Sandstone could not have begun until after deposition of the Lobster Head had ended, the period of time available for transport and emplacement is a fraction of graptolite zone 10 of Berry (1968) (Table III). The data at hand does not allow a calculation of the actual time available but the possibility exists that it is very short.

The objections presented above are those judged to be the more important, those that are based on positive evidence. Others may be mentioned that are based on the absence of features that can be reasonably expected to be present. For instance, why is the sandstone unit so fine-grained? Erosion of an advancing nappe is expected to yield abundant coarse detritus and not a sandstone unit where the overall average maximum grain-size is around granule-size, and where detritus coarser than pebble-size is so scarce. In fact, the coarsest clasts are of limestone, limestone presumably derived from a carbonate bank developed on the advancing nappe. Why, then, the absence of coarse detritus from other lithologies of the nappe?

Or the case of the Crow Head sandstones, which should record the prolapsed westward journey of the nappe; a journey that brought it to rest alongside the Crow Head sandstones. In spite of this, polymictic breccias, olistostromes, soft-sediment deformation contemporaneous with emplacement, are all absent. Not even a coarsening-upward sequence is developed in the upper part of the Crow Head sandstones (the lower part is coeval with the sandstone unit and thus must have been deposited before the sandstone unit had become part of the nappe). On the contrary, the Crow Head sandstones become shaly and pass gradually to the Long Point Formation.

In conclusion, as presently formulated the nappe hypothesis does not hold for central western Newfoundland. Reformulating it to accommodate the objections raised above forces the adoption of a number of unfounded supporting hypotheses. The author suggests, instead, that the autochthonous hypothesis be considered as an alternative.

The autochthonous hypothesis states that the Curling Group was deposited in a basin flanked to the east by a narrow carbonate bank. Farther east, the carbonate bank would pass to deeper waters where the Fleur de Lys Supergroup and younger rocks were deposited. The western edge of the Curling Group basin would now be covered by the waters of the Gulf of St. Lawrence but judging from exposures of Lower Ordovician carbonate rocks on Anticosti Island and in other regions of the Appalachians, this edge would also have been fringed by a carbonate bank.

This version of the autochthonous hypothesis agrees in all the essential points with the version put forward by Lochman (1956). The basic premise of the autochthonous hypothesis, the absence of long-distance tectonic transport, had been the working premise of the pioneer Appalachian geologists but only after the nappe hypothesis began to take shape did it become reasonable to talk of an autochthonous hypothesis. Lochman's publication is the clearest statement of the autochthonous hypothesis.

The evolution of the Curling Group basin from the viewpoint of the autochthonous hypothesis will be discussed in later sections. At this point it is necessary to analyze the objections that Rodgers and Neale (1963) raised against the autochthonous hypothesis.

There are three main objections: (a) that the contrast in lithofacies between the carbonate sequence and the Curling Group is so great that it would require an unacceptably rapid facies change; (b) that the carbonate sequence regionally appears to dip under the Curling Group as would be expected if the latter were lying tectonically on the carbonate sequence; and (c) that no transitions have been found between the carbonate sequence and the Curling Group.

The first objection - the contrast of lithofacies - is greatly weakened now that the sandstone unit is known to be younger than the Table Head Formation, and the limestone-free upper members of the shale unit can be suspected of being younger than the middle member of the Table Head Formation (the middle Table Head contains the youngest carbonate sediments in the carbonate sequence). Nonetheless, there remains the need for a more or less rapid facies change between the carbonate sequence and the shale unit. How rapid depends on the depth of deposition of the shale unit. It was argued in Chapter Four that chert, ribbon limestone, and graptolitic shale, are not - neither individually nor as an assemblage - unequivocal indicators of great depths of deposition. It may well be that the shale unit was deposited in only a few hundred metres of water depth. The problem, however, remains unsolved.

The second objection - that the carbonate sequence dips under the Curling Group - could be taken as an apparent relationship, due to the fact that the sandstone unit is younger than the carbonate sequence and might partly overlap it, and to tectonic deformation that resulted in the Curling Group being compressed and folded against the tilted carbonate sequence.

The third objection - the absence of transitional facies - is a weak objection for much of western Newfoundland must still be studied in detail. What would be the transition zone according to the autochthonous hypothesis is covered by the sandstone unit or it has been more or less obliterated by the deformation that generated the F_1 faults. The transition zone would have been the slope leading down from the bank to the basin, that is, an unstable region, prone to synsedimentary deformation, that could be interpreted as the zone of detachment for the slides related to the F_1 faults.

In spite of all this, the transitional facies are represented by the limestone breccias and ribbon limestones of the shale unit. What may be lacking is an unbroken, continuous passage between the carbonate sequence and the Curling Group. In the area between Rocky Harbour Bay and Neddy Hill, however, it is possible that an unbroken transition is exposed from the Lobster Head Sandstone to the Gadd's

Point Formation.

The case autochthonous versus nappe hypothesis has not been solved, it has only been revived. More detailed work is needed, as well as a new appraisal by other geologists. The author judges that the autochthonous hypothesis explains better than the nappe hypothesis the presently known structural and stratigraphical relationship between the carbonate sequence and the Curling Group. For this reason, the section on the evolution of the Curling Group basin will be written assuming that the autochthonous hypothesis is correct.

CHAPTER EIGHT

CURLING GROUP - CONDITIONS OF DEPOSITION

Schuchert and Dunbar (1934, p.97) postulated that the sediments in the Curling Group (Their 'Humber Arm series') had been deposited in very shallow marine and, possibly, deltaic environments. In support of this conclusion they mentioned the abundance of mudcracks and the coarseness of the sandstones. Coarse deposits are no longer regarded as indicative of neritic or continental environments, so the presence of conglomerates and coarse sandstones in the Curling Group need not imply shallow water. Their mention of "repeated zones of mudcracking" is puzzling. The present author found only one occurrence of possible dessication structures in a thick bed of coarse sandstone (Figure 42)!

All later authors have interpreted the Curling Group as deposited in deep water (Johnson, 1941; Rodgers and Neal, 1963; Stevens, 1970; Williams, 1975).

The question of depth of deposition was dealt with in Chapters Four and Five, when discussing the lithologies of

Figure 42. Top of thick sandstone bed in the Lobster Head Sandstone (SU 'Z'), showing polygonal structures that resemble dessication cracks.

the Curling Group. It was concluded that there are no reliable depth indicators, but that the available data point to bathyal depths. To be sure, the shale unit with marine fauna, abundant shale, regular bedding, and lack of scouring, of wave ripples, and of dessication cracks, were deposited below any influence of wave action. The same holds true for the sandstone unit, unless the tabular cross-stratified quartzites are interpreted as deposited by storm-generated bottom currents. In any case, it appears safe to state that the minimum depth of deposition for the Curling Group was greater than 100 m. Abyssal depths, below the carbonate compensation depth, can also be discarded with some confidence because of the abundance of calcareous sediments.

If the autochthonous hypothesis is correct, it is possible to estimate a water depth from a hypothetical topography. The shale unit was deposited on the slope and basin flanking the St. George-Table Head carbonate bank. The present distance from the westernmost exposures of the lower Table Head to the westernmost exposures of the shale unit, measured normal to the strike of the Table Head, is about 3 km at Rocky Harbour and about 1 km at Black Point. These values will be taken as the horizontal distance separating - in the Arenigian - the edge of the carbonate bank and the base of the slope.

The Bahamas Bank is bordered by a slope that ranks among the steepest presently known. From the bathymetric map presented by Bornhold and Pilkey (1971, Figure 2) for the Columbus Basin, in the Bahamas region, it can be estimated that over a distance of 3 km from the edge of the bank, the depth increases to between 300 and 1000 m, depending on the geographic position where the measurement is made. As a first approximation, then, the depth of the Curling Group basin should not be greater than about 1000 m.

There exists a sedimentological argument that puts a further constraint on the depth of deposition. The St. George-Table Head sequence shows very clearly that the vertical passage from shallow-water (stromatolitic) limestones to ribbon limestones, takes place gradually, without any break, and with an intermediate facies of bioclastic limestone (lower Table Head); there are no limestone breccias intercalated. Ribbon limestones are considered to be relatively distal, base of slope deposits (Wilson, 1969). The gradual vertical facies change suggests that the lateral facies change took place across a gentle slope and not an abrupt shelf edge as exists in the Bahamas Bank. (Wilson's, 1969, interpretation of ribbon limestones in general was that they were deposited at the base of a gentle slope.) The depth of deposition for the shale unit was probably considerably shallower than 1000 m.

THE CURLING GROUP BASIN

As envisaged in this thesis, the Curling Group Basin was a moderately deep, elongate basin, oriented roughly north-south, and bordered by carbonate banks to the east and to the west.

The eastern side of the basin was flanked by the St. George-Table Head carbonate bank. If the present outline of the outcrops of the lower Table Head is an indication of the original edge of the bank, the coastline between Bonne Bay and Port au Port would have formed an irregular semicircumference, with large embayments (Figure 2).

The western edge of the basin is not exposed. The presence of massive bioclastic limestone of unknown age (but associated with typical Curling Group facies) at Broad Cove; of Tremadocian ribbon limestones and of limestone breccias with Upper Cambrian fauna in the clasts 16 km north of Broad Cove (Kindle and Whittington, 1965); the presence of Tremadocian (?) ribbon limestones at York Harbour, at the entrance of Bay of Islands (Williams, 1973); are lithofacies that suggest the existence of another carbonate bank along the western side of the basin. On Anticosti Island the Grenville basement is covered by Lower Ordovician carbonate rocks. Perhaps this outcrop is a relict of a much larger bank that shed the detritus described above.

The northern and southern limits of the basin are unknown. It must have extended considerably farther to the north because the Cow Head Group shows so many lithologic similarities to the Curling Group, that both must have been deposited in the samebasin. To the south, the Port au Port Peninsula is formed by a sharp westward turn of the edge of the carbonate bank. It is possible that the carbonate bank completely enclosed the basin in this region, but there is no other evidence than the projection of the Port au Port Peninsula, in support of this idea.

DEPOSITION OF THE SHALE UNIT

The shale unit was deposited in this basin commencing at the latest in the Late Tremadocian. During the Tremadocian and Arenigian, deposition took place on the slope and basin adjacent to the St. George—Table Head carbonate bank. From this bank were derived the ribbon limestones, marls, calcarenites, and limestone breccias; the shales can be interpreted as hemipelagic with contribution of organic matter from the bank. The influx of carbonate detritus was greater in the area of Rocky Harbour than in the area of Black Point, and it was almost nil in the area of Rocky Point.

In the area of Rocky Harbour, the bottom-waters were poor in oxygen, which led to the deposition of black shale. Instead, in the south, black shales are scarce in Black Point and absent in Rocky Point. There are two immediate explanations for this difference. It can be assumed that the oxygen content in the bottom-waters was everywhere the same but influx of organic matter was greater in the north. Thus, while all the organic matter could be oxidized in the south, some was preserved and buried in the north. In fact, this first alternative is artificial because in areas where the influx of organic matter is high, the water is impoverished in oxygen through reaction with organic matter. Alternatively, it can be assumed that influx of organic matter was everywhere the same, but bottom-waters were richer in oxygen in the south.

Now if the carbonate bank was the main supplier of organic matter, and if the influence of the bank was greater in the north, it is reasonable to conclude that the difference in colour is related to the rate of influx of organic matter.

The absence of dolomitic siltstone in the southern part of the basin may be the result of the lack of an adequate source lithology. Perhaps the green shale and the fine-grained turbidites take the place of the dolomitic siltstones, in the upper members of the shale unit at Black Point and Rocky Point. In general terms, dolomitic siltstone, green shale, and turbidites, are all taken as evidence for the initial emergence of the Burlingtonian Orogen with its sedimentary cover.

Rapid subsidence led to the drowning of the carbonate bank and to cessation of limestone deposition in the Curling Group basin. Sedimentation became exclusively terrigenous during the Lower Llanvirnian. The Gadd's Point Formation and the Piccadilly Beach sandstones were deposited on the subsided carbonate bank and the upper members of the shale unit were deposited in the deeper part of the basin.

DEPOSITION OF THE SANDSTONE UNIT

The large majority of the sandstone beds in the sandstone unit can be interpreted as deposited by turbidity currents in a submarine environment. The paleocurrent patterns are compatible with flow in lobate sedimentary systems. The geographical changes in rock type assemblages and in composition suggest the more or less contemporaneous activity of several independent sedimentary systems. Taken together these features point to deposition of the sandstone unit as several small submarine fans or lobes.

Submarine fans or lobes, formed by turbidity currents, are found in three sedimentary systems: (a) deltaic, (b) fan-delta, and (c) submarine fan. The deltaic system consists of a proximal portion deposited in subaerial or shallow water environments and a distal portion: the prodelta, deposited in deeper water and where turbidity currents may be active. Deltas develop in subsiding platforms provided that the rate of subsidence is not greater than the rate of sedimentation.

The fan-delta system may develop when a subaerial fan debouches into the sea. Detritus eroded from the nearby mountain range and that bypasses the subaerial fan, may accumulate to form a submarine fan or lobe. Debris flows or turbulent suspensions may develop into turbidity currents acting on the submarine lobe. Compared with the deltaic system, a fan-delta is expected to show a less extensive proximal portion. The fan-delta system accumulates on a subsiding platform. It may develop even if the rate of subsidence is greater than the rate of sedimentation. In fact this appears to be a necessary condition or it will evolve into a delta.

The submarine fan system (s. str.; Walker and Mutti, 1973) develops at the base of a slope and is fed through canyons cutting across the slope. It does <u>not</u> develop on a platform. Rate of subsidence is not an important constraint for its development as long as the source area is not drowned.

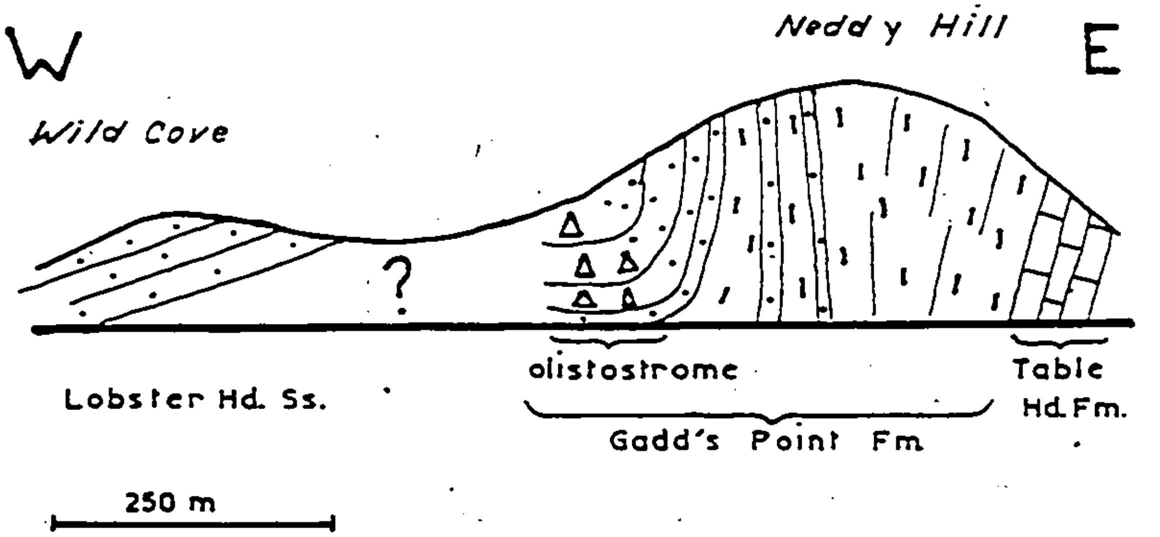
A major difference in setting exists between the submarine fan system and the other two, which develop on a platform. This matter will now be examined with regard to the sandstone unit.

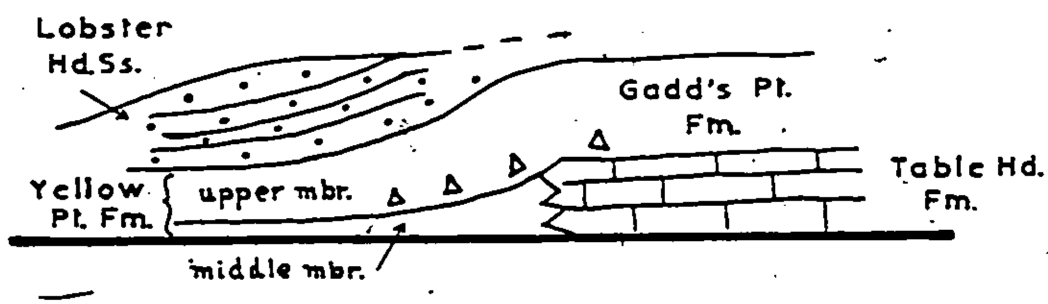
Figure 43a shows a schematic cross-section of the carbonate and clastic sequences in Bonne Bay. The strata are vertical so the sequence from the lower Table Head to the olistostrome is a vertical stratigraphic sequence; the olistostrome appears to form a syncline and the Lobster Head Sandstone is much deformed. Figure 43b illustrates the suggested reconstruction, which taken into account the new graptolite ages for the Lobster Head and the apparent field relationships.

Figure 43b shows that the Gadd's Point Formation

Figure 43 (a) Schematic cross-section in the Bonne Bay area showing field relationship between the carbonate sequence and the Curling Group.

(b) Suggested reconstruction of the margin of the Curling Group basin.


W
Neddy Hill
E
Wild Cove
?
olistostrome
Lobster Hd. Ss.
Table Hd. Fm.
Gadd's Point Fm
250 m


Lobster Hd.Ss.
Gadd's Pt. Fm.
Table Hd. Fm.
Yellow Pt. Fm.
upper mbr.
middle mbr.

was deposited on the carbonate shelf, and that in the basin it is represented by the upper member of the Yellow Point Formation. The Lobster Head Sandstone is developed mainly in the deeper part of the basin but coarse sandstones could have been deposited on the Gadd's Point Formation and later eroded away, as is suggested by the coarse-grained sandstones in the olistostrome on Neddy Hill and by the few medium-grained sandstone beds in the Gadd's Point Formation near Rocky Harbour Pond.

The vertical sequence, then, passes from carbonate shelf deposits to turbidites in the Gadd's Point Formation, which is not in agreement with the submarine fan model. This formation is better interpreted as the deposit from a delta or a fan-delta.

The Lobster Head Sandstone accumulated mostly at the base of the gentle slope but it may have onlapped the whole slope and the shelf edge. As the Gadd's Point Formation appears to be wholly older than the Lobster Head, the former cannot be interpreted as a slope deposit coeval with a Lobster Head submarine fan. In fact, the setting of the Lobster Head - which is known only imprecisely - suggests that it was deposited partly on the shelf, partly in the basin, and thus, in this respect, shares features of the submarine fan as well as the delta or fan-delta systems.

The Gadd's Point Formation, with fine- and medium-grained turbidites, is coarser-grained than the, equivalent, upper member of the Yellow Point Formation, deposited on the slope and basin. Such a variation of facies fits better in a delta or fan-delta system than in a submarine fan, where the opposite would be expected.

The littoral portions of the sandstone unit were nowhere found. (A possible exception are the outcrops on Portland Hill, north of Cow Head, in the Cow Head Group.) Deltas or fan-delta systems could have existed.

A situation could be envisaged where delta, or fan-deltas, lobes crossed the carbonate shelf, and the gentle slope, reaching the basin. First, the Gadd's Point Formation, Piccadilly Beach sandstones, and the upper members of the shale unit, would have been deposited, followed by the sandstone unit, which accumulated mainly in the basin area. The coarser grain-size in the sandstone unit could be explained by progradation of the lobes, or increased relief in the source area, or a greater gradient across the shelf due to further uplift of the Burlingtonian Orogen.

CONCLUSIONS

The three major conclusions from this chapter are: (1) that the Curling Group accumulated in an elongate basin, (2) that the Curling Group was probably deposited in a moderate water depth (say 200 to 600 m), and (3) that the sandstone unit might have been deposited as several fan-delta systems.

The first conclusion is based on the predominance of longitudinal paleocurrents. The second is based on comparison with examples from the literature and on the study by Jansa (1974) of the Cow Head Group (cf. Chapter Four). The third is based on the stratigraphic relationship between the carbonates and the Gadd's Point Formation, and the younger age of the Lobster Head Sandstone relative to the Gadd's Point Formation. Rejection of the nappe hypothesis would constitute a strong support for all three conclusions, but it is not a necessary condition for their validity.

If the autochthonous hypothesis is accepted as valid, it is possible to elaborate further on these conclusions, towards a more detailed reconstruction of the Curling Group basin. Such a reconstruction will now be attempted.

The Curling Group basin was bounded along the east, and probably along the west, by a carbonate bank. The bank and the basin were connected by a gentle slope. During deposition of the Tremadocian and Arenigian portion of the shale unit, the bank was active and provided calcareous detritus to the basin. For reasons unknown the proportion of limestone in the shale unit is much greater in the northern half of the Curling Group (Yellow Point and Cooks Brook Formations) than in the south. As suggested above, this may have indirectly led to the deposition of black shale in the north and red shale in the south.

By the Early Llanvirnian, carbonate deposition in the Curling Group basin had ceased - apparently because the carbonate bank had subsided too rapidly and died - and sedimentation became wholly terrigenous with the upper members of the shale unit. Dolomitic siltstones are abundant in Bonne Bay and in Bay of Islands (Middle Arm Point Formation) but absent in the south where, instead, silici-clastic siltstones are an important constituent. Contemporaneously, in the carbonate sequence, the Gadd's Point Formation and the Piccadilly Beach sandstones were being deposited. Overall average grain-size decreases from the platform to the basin.

The shale unit shows two chert units, one in the

Lower Arenigian, the other in the latest Lower, or earliest Upper, Llanvirnian. Formation of the youngest chert unit is coeval with extrusion of lavas found in Bonne Bay and on Woods Island immediately below the sandstone unit. It is not known whether the oldest chert unit is temporally associated with volcanism. In neither case is there an obvious spatial relationship between chert and volcanism.

Conformably on the shale unit follows the sandstone unit, which is probably conformable on the Gadd's Point Formation and Piccadilly Beach sandstones, as well. The sandstone unit could have been deposited as several delta, or fan-delta, lobes.

The setting and aspect of the sandstone unit before F_1 faulting may have been like that of the Crow Head sandstone (cf. Chapter Two). Both units show similar rock types, especially with the Rocky Point sandstone, similar paleocurrent patterns, similar substratum, and both are roughly of the same age.

These considerations lead the author to postulate that the Crow Head sandstone is simply an undeformed portion of the sandstone unit and that it too was deposited in the Curling Group basin.

CHAPTER NINE

SYNTHESIS AND CONCLUSIONS

ABOUT THE EXISTENCE OF LOWER CAMBRIAN IN THE REGION OF BAY OF ISLANDS

In the region of Bay of Islands, two stratigraphic units have been defined: the Summerside and the Irishtown Formations (Lilly, 1965; Stevens, 1965; Brückner, 1966), which are now generally assigned to the Lower Cambrian (Lilly, 1967). In the years before 1963, these rocks were regarded as being Middle Ordovician and post-Table Head (Schuchert and Dunbar, 1934; McKillop, 1961; Lilly, 1963). In this section, the evidence in favour of an Early Cambrian age will be reviewed. Information for the following discussion is drawn largely from the literature cited above; the writer carried out reconnaissance work around the city of Corner Brook and along the shore of the Humber Arm.

Evidence cited in favour of an Early Cambrian age for the Summerside-Irishtown sequence is the following: (1) alleged conformable contact with overlying Cooks Brook

Formation (Middle Cambrian-Lower Ordovician); (2) presence of limestone clasts with Early Cambrian fossils, in conglomerates; (3) mineralogical composition suggesting derivation from the Grenville basement; and (4) non-specified lithologic resemblance to documented Lower Cambrian in the Taconic region, eastern United States. The first three will now be discussed in order. The fourth will not be considered because the author has never visited the Taconic region.

The contact Cooks Brook-Irishtown is exposed at McIver's, on the northeast shore of the Humber Arm. The Irishtown is strongly folded and at its top it passes to broken ribbon limestone and black mudstone typical of the Cooks Brook Formation, with a marked rotation of the strike. Elsewhere the contact is not exposed or consists of a wide zone of deformation. At Cox's Cove, on the south shore of Middle Arm, the easternmost beds of the Cooks Brook dip east and may close a large anticlinorium that extends from Cox's Cove to Middle Arm Point, but the first exposures of Irishtown rocks are about 1 km farther east. South of McIver's, at Big Head, Cooks Brook and Irishtown lithologies occur as a mélange. Along the eastern shore of Humber Arm, from Frenchman's Head to Fox Point, at least, it appears that the Cooks Brook is flanked along the west by the

Irishtown. The attitude of the strata suggests that the Irishtown underlies the Cooks Brook. The contact is exposed at Frenchman's Head, where it consists of a wide zone of deformation. At this locality, however, Irishtown lithologies crop out west of Frenchman's Cove and form part of an unbroken sequence leading up to the Blow-me-down Brook Formation (Figure 9). The same situation exists on Woods Island. These exposures suggest that the Irishtown and the Middle Arm Point Formations are partly equivalent.

The possibility exists, then, that the contact Irishtown-Cooks Brook around the Humber Arm is structural, with an inversion of stratigraphy and a zone of deformation at the contact, a situation that would be like that at Rocky Harbour.

The second evidence cited in favour of an Early Cambrian age for the Summerside-Irishtown rocks is the presence of limestone clasts with Early Cambrian fauna at two localities: one, reported by Schuchert and Dunbar (1934, p.21), "in two conglomerate layers in the Ordovician strata of Middle Arm of Bay of Islands", the other at McIver's, reported by Stevens (1965). Schuchert and Dunbar did not state whether they had local evidence for an Ordovician age.

To be sure, these clasts would not be taken as evidence for an Early Cambrian age were it not for Kindle and Whittington's (1968) paper on the Cow Head limestone breccia. There they found that clasts and matrix in breccia beds are roughly coeval; the oldest breccias studied by them are Middle Cambrian. This interesting observation can be explained assuming a growing carbonate bank that shed coarse and fine detritus. Extrapolation of these conclusions to the Early Cambrian and, moreover, to a siliciclastic sequence in which some conglomerates contain limestone clasts, should be done only with extreme caution. On the other hand, Lilly (1963, p.69) may have found Ordovician clasts in the Irishtown: "One of these (quartzite) sequences contains large blocks of limestone with twig-like algal pseudomorphs which are similar to the limestones of the St. George group".

One strong faunal evidence for a Middle Ordovician age for at least part of the Irishtown Formation, was presented by Schuchert and Dunbar (1934, p.98). They found graptolites west of the town of Curling which are "probably far up in the Humber Arm succession", though not younger than Middle Ordovician. Unfortunately they did not specify the locality nor the lithology in which the fossils were found. Their lithological description of exposures west of Curling (p.88) does not mention the occurrence of graptolites.

This description, however, corresponds to Irishtown lithologies, and this area was mapped as Irishtown by Stevens (1965).

The third evidence cited in support of an Early Cambrian age is that the mineralogical composition of the Summerside-Irishtown suggests derivation from the Grenville basement. This is undisputably correct, but it does not necessarily imply a first cycle derivation from the craton. The Llanvirnian sandstones largely consist of recycled Grenville detritus. Moreover, the mineralogy of the Summerside-Irishtown sandstones appears to be qualitatively and quantitatively different from known Lower Cambrian sandstones, as will now be shown.

For the Summerside Formation, Stevens (1965) reported about 5% feldspar in medium- to fine-grained sandstones, and 1 to 2% of grains of chlorite interlayered with muscovite; he called these sandstones subarkosic. For the Irishtown Formation he gave no quantitative data but described the sandstones quartzites, and also reported grains of chlorite-muscovite.

Three thin sections from the Irishtown were studied. One from a fine-grained wacke in Bowaters Park, and two from two consecutive beds exposed in a roadcut 500 m south of John's Beach. One thin-section from a medium-grained wacke at Bowaters Park shows subrounded quartz grains (about

60%), quartzose and micaschist rock fragments (about 10%), subrounded grains of chlorite with a blue-gray interference colour interlayered with unaltered muscovite (less than 5%), about 20% matrix, and traces of feldspar. One sample from John's Beach is from a fine-grained wacke and shows 60% subrounded quartz, 15% rock fragments, 15% matrix, trace of feldspar, and accessory chlorite-muscovite grains. The other sample is a medium-grained arenite with 85% subrounded quartz and 15% clay cement. To be noted is the scarcity of feldspar and the presence of subrounded grains of chlorite-muscovite grains. The chlorite-muscovite grains are very conspicuous and consist of chlorite with a blue-gray interference colour in which are thin layers of unaltered muscovite; the grains are rounded, some appear deformed by compaction, and it is clear that the grains are detrital.

The scarce mineralogical data suggests that the Summerside-Irishtown has a much lower feldspar content than well-dated Lower Cambrian (see Chapter Two), and the presence of chlorite-muscovite grains suggest an affinity with the Llanvirnian sandstone unit, in which similar grains are present.

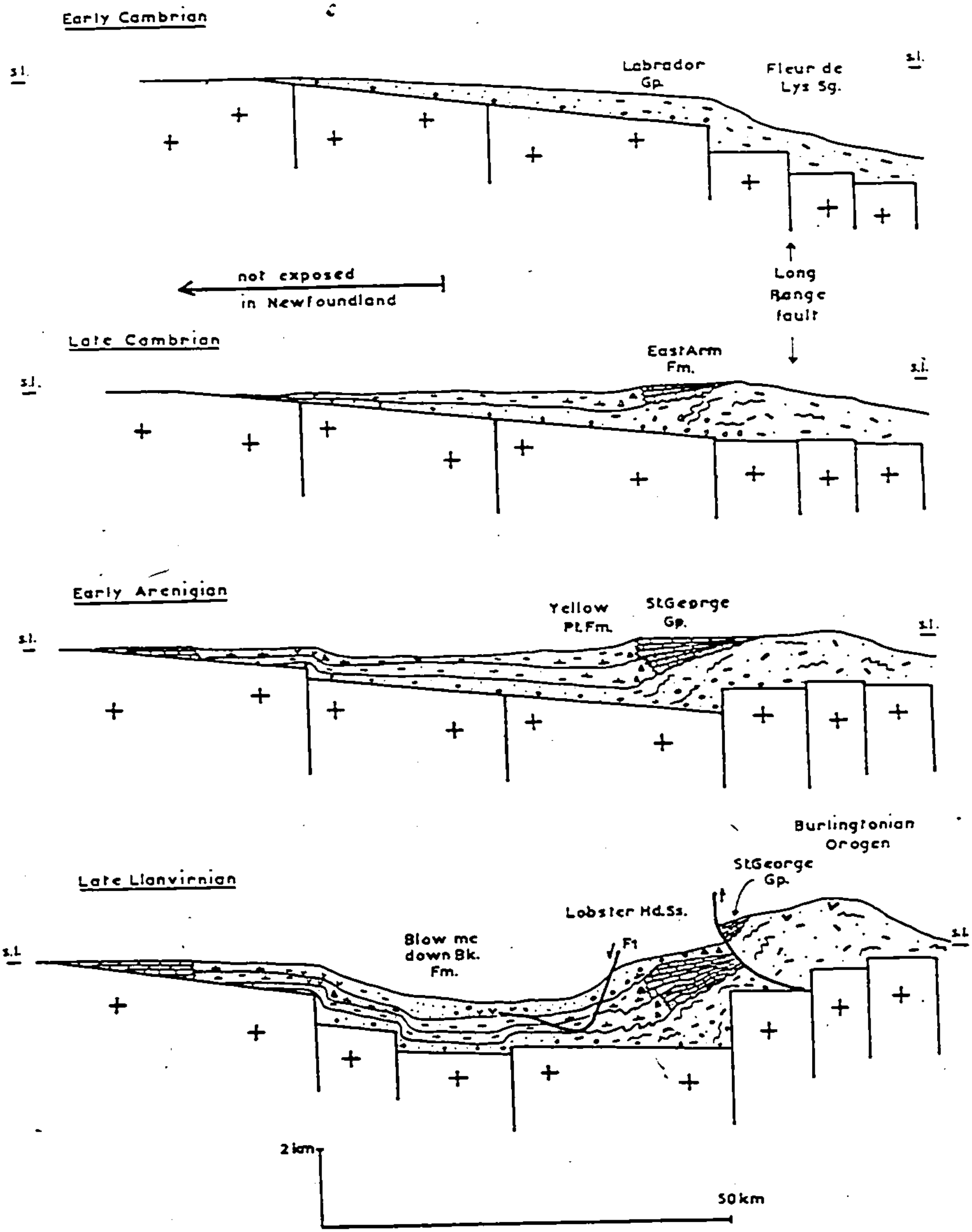
Finally, there is the superposition of the Irishtown on the Table Head, east of Corner Brook. The nappe hypothesis postulates that this contact is structural but it could well be sedimentary, and the sequence would then be much like the sequence Table Head-Gadd's Point or Table Head-Piccadilly Beach sandstones, with an upward and lateral passage to the coarser sandstone unit.

EVOLUTION OF CENTRAL WESTERN NEWFOUNDLAND

The Grenville basement was finally consolidated about 800 m.y. ago. During the late Precambrian and Early Cambrian, this basement was eroded to form an extensive platform sloping gently toward central Newfoundland. The edge of this platform lay at about the position of the Long Range fault (Figure 2), from where it passed to a slope that descended eastward to the large basin of the 'central mobile belt' of Williams (1969). The detritus eroded from the Grenville basement accumulated on the platform as the Bradore, Mt. Musgrave, and Kippens Formations, and on the slope and basin as the Fleur de Lys Supergroup (Figure 2).

The greater thickness of the Precambrian-Lower Cambrian in the region south of Bonne Bay to approximately Corner Brook, suggests that subsidence was faster there. Perhaps a block within the Grenville basement subsided more rapidly, forming a graben. Such a graben would explain

Figure 44. Cross-sections illustrating the possible evolution of the Curling Group basin from its inception until the time when it began to be colmated by coarse detritus eroded from the Burlingtonian Orogen. Reconstruction follows the autochthonous hypothesis. Behaviour of the Grenville basement is hypothetical.


Early Cambrian
s.l.
Labrador Gp.
Fleur de Lys Sg.
s.l.
not exposed in Newfoundland
Long Range fault
Late Cambrian
s.l.
East Arm Fm.
s.l.
Early Arenigian
s.l.
Yellow Pt. Fm.
St George Gp.
s.l.
Burlingtonian Orogen
Late Llanvirnian
St George Gp.
Lobster Hd. Ss.
Blow me down Bk. Fm.
F1
s.l.
s.l.
2 km
50 km

not only the greater thickness of sediment but also the absence of outcrops of basement between the latitudes of Bonne Bay and Port au Port.

During the Middle and Late Cambrian, a carbonate bank started to develop along the edge of the platform, on the Lower Cambrian. By the end of the Cambrian this bank came to be firmly established (St. George Group) and persisted until about the Middle Arenigian.

A possible explanation for the development of the carbonate bank along the internal side of the platform is that deformation in central Newfoundland had already started and that it caused a slight uplift of the Grenville basement with its Lower Cambrian cover. Thus, shallow water conditions ensued allowing the bank to develop. This explanation would account for the disconformity at the top of the Lower Cambrian.

The western edge of the carbonate bank would have lain approximately at the position of the western boundary of St. George exposures, that is, at the contact between the carbonate sequence and the Curling Group.

West of the carbonate bank, the shale unit of the Curling Group was being deposited in a moderately deep (bathyal) basin. The oldest rock types are black shale, ribbon limestone, and limestone breccia (Cooks Brook, Yellow Point - oldest part - Formations), derived mainly from the carbonate bank. In Arenigian time, green shale and dolomitic siltstone become important (Yellow Point, Middle Arm Point Formations), and continue to be deposited into the Early Llanvirnian. The influx of green shale and dolomitic siltstone is taken as an indication of the initial emergence of the Burlingtonian Orogen.

During the Late Llanvirnian, coarse sandstone units derived from the Burlingtonian Orogen, covered the area. They were deposited in a shallow bathyal basin, possibly as several delta or fan-delta lobes.

Concomitantly with the uplift of the Burlingtonian Orogen, all the carbonate sequence was gradually being tilted more and more to the west. By the end of the Late Llanvirnian, the shelf became sufficiently tilted to cause a series of slides, from Bonne Bay to Port au Port. The slides probably were submarine because they were immediately unconformably covered by the Long Point Formation. In places where sliding did not affect the sediments, deposition of sandstones continued and a conformable contact with the Long Point Formation can be seen (Crow Head sandstones; cf. Chapter Two).

The Curling Group basin must have been almost filled by deposition of the sandstone unit because immediately after the reefal Long Point Formation was deposited. The Clam Bank Formation is shallow marine or continental and marks the end of the Curling Group basin.

CONCLUSIONS

The critique of the nappe hypothesis - although not an original aim of this thesis - grew to be a major concern. Its validity conditions all sedimentological conclusions, from the interpretation of each sedimentary system, to the reconstruction of the basin. Confrontation with the nappe hypothesis arose naturally from comparison between the carbonate sequence and the Curling Group. Perhaps, if the Curling Group had been studied in isolation, the confrontation might have been fended off, but such an isolation is hardly possible in central western Newfoundland, where both rock sequences are well exposed side by side.

In spite of the criticisms presented, the case autochthonous versus nappe hypothesis remains unsettled. These criticisms might, at the most, stir waters that have remained unjustifiably calm for too many years. Further comparative studies of the major tectonostratigraphic units are necessary, studies that should include the igneous rocks as well.

One other indirect conclusion from this work is that the 'Taconic' orogeny was very protracted in time and affected different areas at different times. This, again, is not a novel statement, for Rodgers (1971) had already said as much.

Using the term 'Taconic' in an unrestricted and informal way, it may be said that the 'Taconic' orogeny first affected the Fleur de Lys Supergroup, probably starting in the Middle Cambrian. These deposits were progressively deformed and gradually uplifted so that they partially emerged, and - by the Arenigian - started to contribute detritus to the Curling Group basin.

The uplift and associated tectonic movements caused the detachment of parts of the Curling Group, which slid westwards for a few kilometres, from the edge of the basin towards its axis, in the late Late Llanvirnian. In spite of the strong deformation that resulted from the sliding, this deformation should not be regarded as a 'climax' in the 'Taconic' orogeny; it was more an accident. The Long Point Formation is conformable on units that did not undergo sliding, such as the Crow Head sandstones, showing that this deformation was not regional in nature.

Strong folding of Curling Group rocks took place some time after the sliding. It was concentrated along the eastern edge of the Curling Group basin, at the contact with the carbonate sequence, and resulted in large-scale isoclinal folds, vertical or with vergence towards the east. This folding could not be dated; given the absence of Upper Ordovician sediments in the folded belt it is suspected that folding took place approximately within the Llandeilian, but a younger age cannot be discarded.

The Long Point and Clam Bank Formations, although not included in the Curling Group, are the youngest units of a conformable sequence deposited in the Curling Group basin. They are also folded and it is possible that this folding is as well the result of the 'Taconic' orogeny. It is a matter of opinion whether this deformation should be separated as the Acadian orogeny (Williams, 1969), as there is no evidence for a period of tectonic calm separating it from the Ordovician deformation.

Rocks of the carbonate sequence - more sensitive to changes in water depth - record two disconformities. One at the top of the Lower Cambrian, the other between the St. George Group and the Table Head Formation. A major erosional unconformity occurs below shallow-water marine Carboniferous carbonates that locally overlie the St. George Group.

In synthesis, the 'Taconic' orogeny in central western Newfoundland appears to have spanned a time ranging from Middle Cambrian to Devonian. The initial effects of this orogeny were felt in the east, but the area affected gradually expanded westwards until it included all of central western Newfoundland. The unconformity below the Carboniferous could be taken to indicate the end of the 'Taconic' orogeny for, afterwards, uplift of the whole region followed. But any definition of 'climaxes' or of time limits to the 'Taconic' orogeny will necessarily be arbitrary.

The bulk of the thesis is descriptive. Detailed maps and cross-sections are presented for the Curling Group, accompanied by lithologic descriptions. In some areas, such as Rocky Harbour, this is done for the first time. The regional structural geology and stratigraphy of the Curling Group is given, as well, and although some important problems remain to be solved, it is the first such synthesis. The glossary of stratigraphic names complements the discussion of the stratigraphy and might be helpful for workers not familiar with the yet-not-too-cumbersome stratigraphic nomenclature of central western Newfoundland.

Toutes les choses sont dites déjà
mais comme personne n'écoute,
il faut toujours recommencer.

A. Gide

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APPENDIX I

GRAPTOLITES FROM ROCKY HARBOUR, W. NEWFOUNDLAND

Locality	Fauna	Age
a	Clonograptus sp. indet.	Upper Tremadocian
	Adelograptus sp. indet.	
	Bryograptus sp. indet.	
b	Phyllograptus anna Hall	Lower Arenigian
	Tetragraptus fruticosus (4 br.) (Hall)	
	Didymograptus sp. indet.	
c	Didymograptus patulus (Hall)	Lower Arenigian
	Tetragraptus quadribrachiatus (Hall)	
d	Dictyonema sp. indet.	Upper Llanvirnian
	?Desmograptus sp. indet.	
	Loganograptus logani (Hall)	
	Phyllograptus sp. indet.	
	Didymograptus sp.(p) indet.	
	Holmograptus spinosus (Ruedemann)	

Locality	Fauna	Age
d	Paraglossograptus 'etheridgei' (Harris)	Upper Llanvirnian
	'Trigonograptus' ensiformis (Hall)	
	Cryptograptus schaferi (Lapworth)	
	Amplexograptus sp. indet.	
e	Bryograptus ? crassus (Harris and Thomas)	Lower Arenigian
	?Tetragraptus fruticosus (Hall)	
	Didymograptus sp. indet.	
f	Dichograptid gen. et sp. indet.	Arenigian or Llanvirnian
	Tetragraptus quadribrachiatus (Hall)	(? Lower Arenigian)
g	Didymograptus cuspidatus Ruedemann	Upper Llanvirnian
	Didymograptus pennatulus (Hall)	
	Holmograptus lentus (Törnquist)	
	Isograptus forcipiformis Ruedemann	
	Pseudoclimacograptus sp. indet.	
	?Amplexograptus sp.	
	'Trigonograptus' ensiformis (Hall)	

Locality	Fauna	Age
h	Tetragraptus quadribrachiatus (Hall)	Arenigian (? Lower Arenigian)
	?Tetragraptus fruticosus (Hall)	
i	Dictyonema sp. indet.	Llanvirnian
	Glossograptus hincksii (Hopkinson)	(? Upper Llanvirnian)
	Amplexograptus sp. indet.	
	Pseudoclimacograptus sp. indet.	
	?Glyptograptus sp.	
j	Amplexograptus sp.	Upper Llanvirnian
	Diplograptus ?decoratus Harris and Thomas	
	Cryptograptus schaferi (Lapworth)	
k	Didymograptus pennatulus (Hall)	Upper Llanvirnian
	Didymograptus sp.(p) indet.	
	Phyllograptus sp. indet.	
	'Amplexograptus' modicellus Harris and Thomas	
	Paraglossagraptus 'etheridgei' (Harris)	

Locality	Fauna	Age
l	?Sigmagraptus sp.	Lower Arenigian
	Phyllograptus ilicifolius Hall	
	Phyllograptus ?anna Hall	
	Tetragraptus serra (Brongniart)	
	Didymograptus extensus (Hall)	
	Didymograptus nitidus (Hall)	
	Didymograptus ?patulus (Hall)	
	Didymograptus protobifidus Elles	
m	Didymograptus pennatulus (Hall)	Upper Llanvirnian
	Didymograptus ?dubitatus Harris and Thomas	
	Holmograptus spinosus (Ruedemann)	
	Glossograptus hincksii (Hopkinson)	
	Amplexograptus sp. indet.	
	'Amplexograptus' modicellus Harris and Thomas	
n	Amplexograptus sp.	Llanvirnian (? Upper Llanvirnian)
o	?Didymograptus sp.	Arenigian or Llanvirnian (? Lower or Middle Arenigian)
	Didymograptus sp. indet.	

Locality	Fauna	Age
p	?Amplexograptus sp.	Llanvirnian (? Upper Llanvirnian)
q (south of Little Green Point	?Tetragraptus sp. Didymograptus protobifidus Elles ?Didymograptus sp.	Lower Arenigian

GRAPTOLITES FROM ROCKY POINT, W. NEWFOUNDLAND

Locality	Fauna	Age
SU 'B'	Didymograptus sp.(p) indet.	Llanvirnian
	Pseudoclimacograptus sp. indet.	(? Upper Llanvirnian)
	?Paraglossograptus 'etheridgei' (Harris)	

Comment:

The fauna is generally of the same age as the younger of the two faunas in the Rocky Harbour area.

GRAPTOLITES FROM THE PICCADILLY AREA, PORT AU PORT

Locality	Fauna	Age
a	Didymograptus ?compressus Harris and Thomas	Llanvirnian
	Glossograptus hincksii (Hopkinson)	
	?Cryptograptus sp.	
	Diplograptus sp. indet. (? nov. sp.)	
	Pseudoclimacograptus sp. indet.	
b	Glyptograptus sp. indet.	Llanvirnian
c	Amplexograptus ?differtus Harris and Thomas	Llanvirnian
	Glossograptus sp. indet.	
	inarticulate brachiopod	

Comment:

The seven collections from the Piccadilly area are all of Llanvirnian age. Poor preservation, which prevents specific identification in many instances, and the limited amount of material from each locality, together preclude a more precise age assessment. On the basis of the material supplied, it is not possible to give a relative positioning of the seven collections - all are Llanvirnian and that is as much as one can say.

GRAPTOLITES FROM THE BLACK POINT AREA

Locality	Fauna	Age
a	Didymograptus sp. indet. Isograptus sp. indet.	Middle or Upper Arenigian or Llanvirnian
b	'Trigonograptus' ensiformis (Hall) ?Cryptograptus sp. Glossograptus hincksii (Hopkinson) 'Amplexograptus' ?modicellus Harris and Thomas Glyptograptus sp. indet.	Llanvirnian
c	Amplexograptus sp. indet. Glyptograptus ?intersitus Harris and Thomas ?Cryptograptus sp.	Llanvirnian
d (north of Black Point)	Clonograptus flexilis (Hall) ?phyllocarid fragments ?Tetragraptus sp.	Lower Arenigian

Comment:

The preservation of the Black Point locality material is appalling and was made worse by the fragmented condition of the specimens on arrival in St. John's. Hence, the relatively large number of 'sp. indet.' listings given above!

As with the collections which I examined earlier (Rocky Harbour and Piccadilly areas), the Black Point collections are of two ages:

(a) Lower Arenigian

(b) Llanvirnian

APPENDIX II

GLOSSARY OF CAMBRO-ORDOVICIAN STRATIGRAPHIC NAMES FOR CENTRAL WESTERN NEWFOUNDLAND

This Glossary is a compilation of stratigraphic names presently in use for Cambrian and Ordovician strata exposed over central western Newfoundland, between Bonne Bay and the Port au Port Peninsula. Only stratigraphic units of formational rank, or higher, are described and listed alphabetically. Informal names are not listed. Igneous stratigraphic units are not listed, but see Williams (1975).

Name. If a stratigraphic unit has received different names through time, the latest name is used as heading.

Source of name. The publication where the name was first presented as it appears in the heading, is referenced immediately below the heading.

Type locality. If a type locality is not mentioned in the original source or in other publications, the general outcrop area is given; these cases are denoted by the use of Type area.

Remarks. Acclaratory comments and mention of conflicting data, if pertinent, are grouped under Remarks. Also given are the previous names for the unit, which are superseded by the heading.

Additional references. Additional publications where the unit is described.

Other subtitles do not require comment.

BLOW-ME-DOWN BROOK FORMATION

Brückner, 1966

<u>Type area</u>. Bay of Islands, south shore and at entrance to humber Arm.

<u>Thickness</u>. Under 300 m; about 100 m at Woods Islands.

<u>Contacts</u>. Base is conformity: overlies the Middle Arm Point Formation. Top is fault (?): underlies the Bay of Islands Complex (not in this Glossary, see Williams, 1975).

<u>Lithology</u>. Medium- to thick-bedded, green, quartzose feldspathic wackes, with intercalated green and red shale.

<u>Age</u>. Stratigraphic relations suggest a Late Llanvirnian age, but evidence is not conclusive.

<u>Remarks</u>. Contains the Woods Island Member at its base (at Woods Island), with agglomerates and pillow lavas; this member supersedes the Woods Island Formation of Stevens (1970). Part of the Curling Group.

<u>Additional references</u>. Williams (1971).

COOKS BROOK FORMATION

Brückner, 1966

Type area. Bay of Islands, from the mouth of the Humber Arm to Middle Arm.

Thickness. 300 m.

Contacts. Base uncertain: it could be conformable above the Irishtown Formation (Brückner, 1966; Stevens, 1970), or it could be covered. Top is conformity: underlies the Middle Arm Point Formation.

Lithology. Thinly-bedded, alternating black shale and light gray limestone; limestone breccias present.

Age. Middle Cambrian to Tremadocian. Based on graptolites (Stevens, 1970; Williams, 1975).

Remarks. Supersedes Penguin Arm limestone of Lilly (1963), and Cooks limestone of Walthier (1949). Part of the Curling Group.

Additional references. Lilly (1965), North (1971), Williams (1973).

CORNER BROOK FORMATION

McKillop, 1963

Type section. Humber Gorge of the Humber Arm of Bay of Islands.

Thickness. 550 m.

Contacts. Base is conformity: overlies the Hughes Brook Formation. Top may be conformity: underlies the Table Head Formation.

Lithology. Interbedded dolomite and limestone, in parts metamorphosed to marble.

Age. Early Ordovician.

Remarks. Upper part of the St. George Group.

Additional references. Lilly (1963), Brückner (1966), Stevens (1970).

CURLING GROUP

Stevens, 1970

Type locality. Curling, on the south shore of the Humber Arm of Bay of Islands.

Thickness. About 1700 m.

Contacts. Depending on the structural interpretation, the base would be a fault and the group would overlie the St. George-Table Head sequence, or it would be an unconformity over the Grenville basement (Stevens, 1970; Williams, 1975).

Remarks. Comprises the following formations, in stratigraphical order:

Blow-me-down Brook
Middle Arm Point
Cooks Brook } plus { Irishtown
Summerside

The relationship between the two groups of formations is uncertain. Stevens (1970) located the Summerside-Irishtown sequence at the base of the Curling Group, but data are not conclusive. Part of the Humber Arm Supergroup.

EAST ARM FORMATION

Troelsen, 1947

Type area. East Arm of Bonne Bay.

Thickness. 150 m.

Contacts. Base is disconformity (?): overlies the Labrador Group. Top is conformity: underlies the St. George Group.

Lithology. Thin-bedded limestones and dolomites, interbedded with shales.

Age. Middle and Late Cambrian. Based on stratigraphic relations and scarce fossils.

GADD'S POINT FORMATION

Stevens, in Neale, 1972

Type locality. Gadd's Point in Bonne Bay.

Thickness. About 200 m.

Contacts. Base is conformity: overlies the Table Head Formation. Top uncertain: may be conformity below the Lobster Head Sandstone, or may be fault separating it from the Lobster Head Sandstone (Stevens, 1970).

Age. Early and Late Llanvirnian. Based on graptolites and stratigraphical relations.

Remarks. Supersedes Gadd's Point slates of Troelsen (1947).

GRAND LAKE BROOK GROUP

McKillop, 1963

Type locality. Grand Lake Brook, about 15 km southeast of Corner Brook.

Thickness. Under 1000 m.

Contacts. Base not exposed. Top is conformity: underlies the St. George Group.

Lithology. Marbles, phyllites, graywackes, and arkoses; progressively more metamorphosed eastwards.

Age. Latest Precambrian (?) to Late Cambrian, poorly defined.

Remarks. Includes the Mount Musgrave and the Forteau Formations. McKillop (1963) located it above the Mount Musgrave, but Lilly (1965) stated that it passes laterally to the Mount Musgrave. Supersedes Grand Lake Brook series of Walthier (1949).

Additional references. Lilly (1967).

HUGHES BROOK FORMATION

McKillop, 1963

<u>Type locality</u>. East side of Hughes Brook, north of the Humber River.

<u>Thickness</u>. 850 m. Decreases to 200 m at Goose Arm.

<u>Contacts</u>. Base may be conformity on Upper Cambrian shales (see St. George Group). Top is conformity: underlies the Corner Brook Formation.

<u>Lithology</u>. Medium- to thick-bedded dolomites.

<u>Age</u>. Early Ordovician.

<u>Remarks</u>. Part of the St. George Group.

<u>Additional references</u>. Brückner (1966), Lilly (1963), Whittington (1968), Williams (1969).

HUMBER ARM SUPERGROUP

Stevens, 1970

<u>Type area</u>. Humber Arm of Bay of Islands.

<u>Remarks</u>. Comprises the Curling Group and the Cow Head Group, which are lateral equivalents. Supersedes Humber Arm series of Schuchert and Dunbar (1934).

<u>Additional references</u>. Williams (1975).

IRISHTOWN FORMATION

Brückner, 1966

Type locality. Irishtown, north shore of the Humber Arm of Bay of Islands.

Thickness. Estimates vary between 200 and 450 m.

Contacts. Base is conformity: overlies the Summerside Formation. Top is uncertain: may be conformity (Brückner, 1966; Stevens, 1970) or fault; underlies the Cooks Brook Formation.

Lithology. Mainly dark shales with interbeds of siltstones, quartzites, graywackes, and pebble conglomerates. Partly metamorphosed to slate or phyllite.

Age. Early Middle Cambrian (Williams, 1975), but evidence is not conclusive.

Remarks. Part of the Curling Group.

Additional references. Lilly (1963, 1965).

KIPPENS FORMATION

Walthier, 1949

Type locality. Romaine (Kippens) Brook, in the St. George's Bay area.

Thickness. 300 m.

Contacts. Base is unconformity: overlies Grenville basement. Top is conformity: underlies the March Point Formation.

Lithology. Gray and black shales interbedded with gray limestone; quartzites and arkoses near base (Lilly, 1965). Stromatolites occur at several levels.

Age. Early Cambrian. Based on diverse fauna trilobites and cephalopods.

Additional references. Brückner (1966), Riley (1962), Williams (1969).

LABRADOR GROUP

Johnson, 1941

Type locality. South shore of Labrador, between Blanc Sablon and Forteau Bay.

Thickness. 800 m.

Contacts. Base is unconformity: overlies Grenville basement. Top is uncovered by erosion type locality; in the Bonne Bay area top is disconformity (?) below the East Arm Formation.

Age. Early Cambrian. Based on fossils and stratigraphic relations.

Remarks. Comprises the following formations, given in stratigraphical order:

Hawke Bay

Forteau

Devils Cove

Bradore

Supersedes Labrador Series of Schuchert and Dunbar (1934). The Labrador Series did not include the Devils Cove Formation.

Additional references. Brückner (1966), Williams (1969).

LOBSTER HEAD SANDSTONE

This thesis

Type locality. Lobster Head, 3 km north of entrance to Bonne Bay (by lighthouse).

Thickness. 200 m.

Contacts. Base is conformity: overlies the Yellow Point Formation and possibly the Gadd's Point Formation. Top is fault in parts: underlies the Yellow Point Formation, or is uncovered by erosion in other parts.

Lithology. Medium-grained wackes with interbedded shales; scarce conglomerates.

Age. Late Llanvirnian. Based on graptolites.

LONG POINT FORMATION

Rodgers, 1965

Type locality. Long Point of the Port au Port Peninsula.

Thickness. 750 m.

Contacts. Base is unconformity where it overlies the Curling Group, but a conformity where it overlies the 'Crow Head sandstones' (not in Glossary because it is an informal stratigraphic unit; see text). Top is disconformity (?): underlies the Clam Bank Formation (Rodgers, 1965).

Lithology. Limestones at base, passing upwards to green shales and sandstones.

Age. Middle Ordovician (Chazy and Porterfield). Based on brachiopods and bryozoan.

Remarks. Supersedes Long Point Series of Schuchert and Dunbar (1934) and Long Point Group of Riley (1962).

MACKENZIE BROOK FORMATION

Troelsen, 1947

Type locality. Course of the MacKenzie Brook, which debouches at the head of South Arm, in Bonne Bay.

Thickness. Uncertain. About 200 to 300 m.

Contacts. Base not exposed. Top is conformity: underlies the South Arm Formation.

Lithology. Thin-bedded gray limestones and dolomitic siltstones, buff-weathering, interbedded with black shales; limestone breccias present.

Age. Early Ordovician. Based on comparison with the Yellow Point Formation which shows a similar lithology and a similar stratigraphic position.

MARCH POINT FORMATION

Schuchert and Dunbar, 1934

Type area. Cape St. George in the Port au Port Peninsula.

Thickness. 240 m.

Contacts. Base conformity: overlies the Kippens Formation. Top is conformity: underlies the Petit Jardin Formation.

Lithology. Basal third shows white and reddish sandstones; above follow limestone and dolomites, with shale partings and few intraformational conglomerates. Mud-cracks and stromatolites present near the top.

Age. Middle Cambrian. Based on trilobites from middle of sequence.

Remarks. The present upper limit is an arbitrary time horizon (Lilly, 1963). Schuchert and Dunbar (1934) considered it of Late Cambrian age.

Additional references. Brückner (1966), Riley (1962), Williams (1969).

MIDDLE ARM POINT FORMATION

Brückner, 1966

Type locality. Middle Arm Point, on south shore of entrance to Middle Arm of Bay of Islands.

Thickness. 150 to 300 m, depending on where boundaries are set.

Contacts. Base is conformity: overlies the Cooks Brook Formation. Top is conformity: underlies the Blow-me-down Brook Formation.

Lithology. Laminated green and black shale with intercalations of thin-bedded buff-weathering dolomitic siltstone.

Age. Arenigian. Based on graptolites.

MOUNT MUSGRAVE FORMATION

McKillop, 1963

Type locality. Mount Musgrave, east of Corner Brook.

Thickness. 1500 m.

Contacts. Base not exposed; may be unconformity on Grenville basement. Top is conformity: underlies the Reluctant Head Formation.

Lithology. Wackes and arkoses in lower part, passing upwards to mainly shales; few pebble conglomerates. Largely metamorphosed to phyllites, schists, and, locally, gneisses.

Age. Late Precambrian to Early Cambrian. Based on stratigraphic relations.

Remarks. Partly correlative of the Grand Lake Brook Group (Lilly, 1967).

Additional references. Brückner (1966), Williams (1969).

PENGUIN COVE FORMATION

Lilly, 1963

Type locality. Penguin Cove, in Goose Arm of Bay of Islands.

Thickness. 150 m.

Contacts. Base uncertain: overlies the Labrador Group. Top may be conformity where it underlies the St. George Group but may be unconformity where it underlies the Reluctant Head Formation.

Lithology. Interbedded siltstones, quartzites, dolomites and limestones; stromatolites present locally.

Age. Early Cambrian. Based on stratigraphical relations.

Additional references. Lilly (1965).

PETIT JARDIN FORMATION

Walthier, 1949

Type area. Cape St. George, in the Port au Port Peninsula.

Thickness. 90 m.

Contacts. Base is conformity: overlies the March Point Formation. Top is conformity: underlies the St. George Group.

Lithology. Thin-bedded limestone, plus siltstone and silty dolomite. Oolitic beds present.

Age. Late Cambrian. Based on trilobites from lowest beds.

Remarks. Base is an arbitrary time horizon (Lilly, 1963). Top 60 m are transitional to the St. George Group and Walthier (1949) and Lilly (1965) suggested this part be included in the St. George Group.

Additional references. Brückner (1966), North (1971), Riley (1962).

RELUCTANT HEAD FORMATION

Lilly, 1963

Type area. East of Corner Brook.

Thickness. Decreases from 200 to 20 m, from east to west.

Contacts. Base is fault: overlies the Mount Musgrave Formation. Top is conformity: underlies the St. George Group..

Lithology. Thin-bedded and nodular limestones alternating with shales; limestone breccias present.

Age. Late (? to Middle) Cambrian. Based on poorly preserved fossils and stratigraphic relations.

Remarks. North (1971) gave thickness as 1000 m.

Additional references. Brückner (1966), Lilly (1965).

ST. GEORGE GROUP

Brückner, 1966

Type locality. St. George Bay, south of the Port au Port Peninsula.

Thickness. 1200 m at type locality; 600 m at Bonne Bay.

Contacts. Base is conformity: overlies the Labrador Group. Top is disconformity: underlies the Table Head Formation.

Lithology. Comprises the following formations in stratigraphic order:

Corner Brook

Hughes Brook

Age. Tremadocian to Arenigian (Canadian); basal part may extend into the Late Cambrian (Kindle and Whittington, 1965).

Remarks. Supersedes the St. George Series of Schuchert and Dunbar (1934), and the St. George Formation of Gillis (1966).

Additional references. Riley (1962), Troelsen (1947), Williams (1969).

SOUTH ARM FORMATION

Troelsen, 1947

<u>Type area</u>. South Arm of Bonne Bay.

<u>Thickness</u>. Uncertain; about 200 m.

<u>Contacts</u>. Base is conformity where it overlies the MacKenzie Brook Formation, and may be conformity or fault where it overlies the Gadd's Point Formation. Top is uncovered by erosion.

<u>Lithology</u>. Coarse-grained sandstones and scarce interbedded shales.

<u>Age</u>. Llanvirnian. Based on stratigraphical relations but evidence is not conclusive.

SUMMERSIDE FORMATION

Brückner, 1966

Type locality. Summerside, on the north shore of the Humber Arm of Bay of Islands.

Thickness. About 250 m.

Contacts. Base not exposed. Top is conformity: underlies the Irishtown Formation.

Lithology. Dark shales at base, passing upwards to brownish quartzites, and then to red and green shales at the top. Partly metamorphosed to slates.

Age. Mainly Early Cambrian (Stevens, 1970; Williams, 1975) but evidence is not conclusive. Part of the Curling Group.

TABLE HEAD FORMATION

Gillis, 1966

Type locality. Table Point, south of Hawke Bay.

Thickness. 420 m at type locality; 120 m on the Port au Port Peninsula.

Contacts. Base is disconformity: overlies the St. George Group. Top is conformity: underlies the Gadd's Point Formation, the Piccadilly Beach sandstones and the Crow Head sandstones (the latter two informal names not in Glossary; see text).

Lithology. Lower part mainly rubbly gray limestone; central part shows thin-bedded gray limestone interbedded with dark shale; upper part mostly dark shales.

Age. Late Arenigian to Early Llanvirnian (Morris and Kay, 1966). Based on diverse fauna.

Remarks. Supersedes the Table Head Series of Schuchert and Dunbar (1934), and the Table Head Group of Johnson (1941).

Additional references. Riley (1962), Stevens (1970), Whittington and Kindle (1963).

YELLOW POINT FORMATION

This thesis

Type locality. Yellow Point, 2.5 km north of entrance to Bonne Bay.

Thickness. At least 150 m.

Contacts. Base not exposed. Top is conformity: underlies the Lobster Head Sandstone.

Lithology. Black and laminated green and black shale, thin-bedded gray limestone, buff-weathering dolomitic siltstones, chert, and scarce limestone breccias.

Age. Late Tremadocian to early Late Llanvirnian. Based on graptolites.