1976

Lower Paleozoic Evolution Of West Newfoundland

Robert Keith Stevens

LOWER PALEOZOIC EVOLUTION OF WEST NEWFOUNDLAND

by

Robert Keith Stevens

Department of Geology

Submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy

Faculty of Graduate Studies
The University of Western Ontario
London, Ontario

March, 1976

ABSTRACT

How did the Appalachian orogen in west Newfoundland form? The first workers, Logan and his associates concluded that at least two distinct groups of Cambro-Ordovician rocks existed in the area. The first group formed in shallow water on a continental shelf while the second group formed in deeper water on an ancient continental slope. The latter have since been thrust towards the continent and now rest on the shallow water rocks. The forces responsible for the transportation were thought to have caused at least some of the deformation of the orogen. Until recently, later workers did not accept these views mainly because the supposed age equivalence of the two sequences and the postulated thrusting were difficult to prove. A new understanding of how recent orogens form has led to a revival of the old ideas.

It is suggested that west Newfoundland formed a segment of the Lower Paleozoic continental margin of North America. After initial volcanism, a sequence of shallow water sediments accumulated on the continental shelf while a succession of turbidites and pelagic shales accumulated on the continental rise. During the early Ordovician, flysch from newly formed tectonic lands to the east of the margin flooded over the continental rise and spread onto the shelf by the mid Ordovician. Just before the onset of flysch sedimentation both the rise and shelf sank, perhaps to oceanic depths. After the flysch, slabs of oceanic lithosphere (ophiolites) moved over the collapsed rise and shelf taking with them wedges of sediment trapped under them. The slice assembly finally came to rest in mid Ordovician times and was covered by shallow water sediment.

The assembly and transport can be compared to the formation of a thrust complex at the inner trench slope of a subducting trench. Long transport by gravity sliding need not be invoked.

Major uncertainty exists concerning the history of the Fleur de Lys but it is concluded that the western Fleur de Lys is part of a metamorphosed continental rise prism that was never far removed from the continental margin.

Detail of fossils collected from west Newfoundland are given in an appendix.

ACKNOWLEDGEMENTS

Many people have materially assisted the writer both in the field and in discussion. Dr. W.R. Church at the University of Western Ontario has made this thesis possible and to him special thanks are offered. Drs. G.M. Young and A. Lenz, also at Western, offered encouragement and help at critical times. My colleagues at the Memorial University of Newfoundland all have contributed something to this thesis by their friendly, if at times heated, discussion. Special acknowledgement is given to my coworkers Drs. D.F. Strong, H. Williams, J. Malpas and N. James and to the numerous students who have assisted the writer in the field. Dr. W.H. Poole of the Geological Survey of Canada and Dr. E.R.W. Neale arranged some support for the writer in the field. Dr. J.T. Wilson provided time to think about many problems. Mrs. J. James typed the thesis from a virtually illegible manuscript and my wife drafted the figures.

In addition to these, many other geologists and Newfoundlanders have provided support and ideas without which this thesis would not have been possible. To all of these my thanks are offered.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1 - GENERAL REVIEW

1.A Introduction

An early achievement of geological science was the recognition that certain areas underlain by deformed and metamorphosed rocks are the ancient, eroded analogues of present day mountain systems. One such area is Newfoundland, which forms the northern extremity of the Appalachians. If one allows the validity of Uniformatarianism, the forces that made modern mountains also moulded the Appalachians. A major problem in writing this thesis has been the remarkable and rapid changes in our understanding of the origin of modern mountains during the writer's harried attempts to commit pen to paper. Studies in Newfoundland during this time have played no small part in the application of modern plate tectonic theory to ancient mountain systems.

This thesis will attempt to show how our present views on the development of the western part of the Appalachians in Newfoundland have evolved since the first investigations and will try to delineate some of the major problems now faced by geologists who wish to understand how plate tectonics can be applied to the Appalachians. Because of the rush of new ideas and new data and a growing awareness of the complexity of the problem, this attempt must leave many loose ends.

The writer started work on the problems of west Newfoundland geology in 1963 under the guidance of H.D. Lilly at the Memorial University of Newfoundland. Between 1965 and 1967 he worked in the area for the Geological Survey of Canada. From 1967 to 1970 he worked with W.R. Church at the University of Western Ontario. A short, but interesting time at the University of Toronto as research associate to J.T. Wilson has been followed by research and teaching at the Memorial University of Newfoundland.

1.8 Investigations up to 1971

The geological importance of Newfoundland was first clearly understood by Sir William Logan who recognized that the excellent shore exposures of the island could provide answers to many of the problems not easily solved in the less well exposed Appalachians of the Canadian Mainland. Logan was so intrigued by the potential of Newfoundland to solve problems of Canadian geology that he sent Richardson to work in west Newfoundland even though Newfoundland was not part of the Canadian Confederation at that time. Newfoundland's first geological links were with the Appalachians.

The links to the Caledonian system of north west Europe and Greenland were recognized much later (Wegener,1924; Bailey, 1927, 1929), but not until the Gander Conference in 1967 (Kay, 1969) was it generally accepted that the Appalachians and the Caledonides are, in fact, part of the same orogen. Newfoundland and Ireland were once much closer together but are now separated by the Atlantic Ocean. The orogenic system is common to North America and Europe and this is of some importance to the history of geology since it has provided a common testing ground for ideas generated in two separate schools of geological thought.

The early history of geological investigation in Newfoundland has recently been reviewed by Baird (1975) and involves such illustrious names as Captain James Cook and Sir Joseph Banks. The basic geological framework, however, was laid by James Richardson during summers of 1857 to 1863. His results were first published by Billings in 1862 but appeared in detail in the "Geology of Canada" (Logan, 1863). Richardson worked almost entirely in west Newfoundland where he constructed a stratigraphic section that has remained the basis of all subsequent investigations (Table I). As a result of Richardson's work in west Newfoundland, Logan was able to correlate these rocks with the Quebec and Taconic Groups and conceived his idea that not only was much of the Quebec Group in Quebec and Newfoundland allochthonous, but, prior to its transportation, it formed part of an ancient continental margin (Stevens, 1974). This aspect of Logan's work is treated more fully later in this thesis.

Following the publication of the "Geology of Canada", the Newfoundland government started a geological survey of its own in an attempt to develop the economy of the island. Alexander Murray, previously Logan's assistant in Quebec and Ontario, was hired in 1864 to direct the Survey. A short biography of Murray is given by Bell (1892). In 1869, James P. Howley became Murray's assistant and eventually succeeded Murray when he retired in 1883. Howley retired in 1909.

The results of the Survey are contained in annual reports to the Newfoundland government which were compiled and published in book form in 1881 and 1918. Murray compiled the first geological map of the island in 1873. It was reissued in 1877. Howley published a map in 1909 with reprintings in 1915 and 1925.

Murray and Howley studied most of the coastal and river sections in west Newfoundland and described them using Richardson's stratigraphic nomenclature. Much of their work concerned the potentially economic rocks of Carboniferous age but also delineated the distribution of older rocks which they referred to the Cambrian and Silurian systems. (It is hard to understand Shuchert and Dunbar's [1934, p.3] criticism of Murray's assignation of Ordovician rocks as Silurian since at the time Murray started work there was no Ordovician system. Murray was merely using stratigraphic nomenclature used at the time by the Geological Survey of the United Kingdom.)

The relevant parts of Murray and Howley's reports are those for 1864, 1865-1866, and 1877. A brief review of the early Newfoundland Survey publications can be found in Nature (A.G., 1876). Even at this early date the significance of geological investigation in Newfoundland for the interpretation of the geology of Scotland appears therefore to have been recognized.

Although Murray and Howley's work did not lead to any basic change in the understanding of the geology of west Newfoundland, it did stimulate several private economic surveys. Most of the reports of these surveys are in the Newfoundland Government files and are listed in Betts (1936) and Butler and Bartlett (1969).

During the early part of the present century, Yale and Princeton universities established field programs in Newfoundland. The main concern of the Yale group, directed by C. Schuchert, was the sedimentary sequences of west Newfoundland. The Princeton group, directed by G. van Ingen, concentrated in Notre Dame Bay and, later, northern Newfoundland and the Bay of the Islands area.

The results of the Yale program are contained in Schuchert and Dunbar's (1934) "The Stratigraphy of Western Newfoundland", though several theses were submitted after this date (Sullivan, 1940; Troelsen, 1947; Smith, 1952; and Weitz, 1953).

The stratigraphic sequence established by Schuchert and Dunbar is reproduced in Table I. According to Schuchert and Dunbar (1934), the Lower Cambrian Labrador Group unconformably overlies Laurentian Gneiss. No Middle Cambrian rocks are present. The Upper Cambrian is represented by the March Point Formation which marks the onset of shallow water carbonate sedimentation that continues from the Canadian (St. George Formation) to the Chazy (Table Head) and the Black River (Long Point).

The lowest Canadian Green Point Series of graptolite-bearing shales and thinly bedded limestones presented difficulties of interpretation since they very much resembled the presumed much younger Humber Arm Series. Schuchert and Dunbar (1934, p. 40) suggested that the Green Point Series was either older than the St. George or a near shore facies of the St. George. They preferred the former interpretation.

A spectacular sequence of limestone breccias above the Table Head was taken to have formed during Middle Ordovician thrusting since in at least one locality the breccias are interbedded with Middle Ordovician graptolite-bearing shales. The faulting was thought to be related to uplift in the east that gave rise to the thick clastic sequence of the Humber Arm Series of Mid and perhaps Late Ordovician age. No diagnostic fossils were reported from the Series except from close to its contact with the Table Head.

The entire Cambro-Ordovician sequence, broken only by disconformities in Middle Cambrian time and at the base of the Table Head, was thought to have been deformed at the end of the Ordovician.

Table I. Stratigraphic Nomenclature used by Schuchert and Dunbar, 1934 and Logan, 1863. (from Schuchert and Dunbar, 1934, p. 16)

Historical Geology of Newfoundland

Period	Subdivision	Logan's divs.	Western	Northeastern (Notre Dame Bay)	Interior	Southeastern
Pleistocene			Glaciation and crustal oscillation.			
Pliocene to Eocene			No sedimentary record. Peneplane of summit of Long Range uplifted and partially destroyed by long erosion, reducing the Gulf of St. Lawrence area to a lowland later submerged by crustal warping.			
Cretaceous to Triassic			No sedimentary record known. Newfoundland probably subjected to continued erosion.			
Permian			Folding and faulting during *Appalachian revolution* followed by long erosion interval.			
Pennsylvanian			Land interval ?Lower Coal Measures, all continental, 3000′ Land interval	?	?	Erosion interval
Mississippian			Windsor series 3450′	No record known	Windsor series of Humber River, Deer and Grand lakes, and Red Indian Lake	?*Windsor disturbance* Erosion interval
Devonian	Up.		Land interval *Acadian disturbance* and basic intrusions	*Acadian disturbance* and basic intrusions	*Acadian disturbance* and basic intrusions	*Acadian disturbance*
	Low.		Clam Bank series 1700′	No record known	No record known	Erosion interval
Silurian			No record known	Silurian in White Bay (2800′+) and Notre Dame Bay (9000′)	No record known	Silurian probably deposited, now eroded away
Ordovician		Logan's divs.	*Taconian disturbance*	*Taconian disturbance*	*Taconian disturbance*	*Taconian disturbance*
	Mohawkian and later — ?	Q much extended	Humber Arm series at least 8000′ Highlands rising to east	Present in Pistolet Bay in far N. Also in Notre Dame Bay with Red Cliff volcanics	? Volcanics Shales with graptolites	All younger formations eroded away
	Mohawkian and later — ?	P	Cow Head thrust breccia Faulting and elevation	Goss Pond volcanics	No record known	
	Mohawkian and later — Black River	O much extended	Long Pt. series 1520′		?Volcanics Probably represented	
	Chazyan — Chazy	N to K	Table Head series 1380′	Snooks Arm volcanics Table Head present as shales	Table Head present as shales with graptolites Volcanics	
	Canadian	I to D	St. George series 1570′–2080′+	Later St. George present as slates with volcanics	Late St. George present with graptolites. Volcanics	Wabana 3000′ Bell I. 6000′ Clarenville
	Canadian	Q in part	Green Pt. series 1700′+	Probably represented	No record known	Possibly represented
Cambrian	Up.		March Pt. series 1180′+	?	?	Johannian 400′–500′
	Mid.		Land interval			Manuels 300′
	Low.	C to A	Labrador series 2600′	?	?	Hanfordian Etcheminian 200′
Proterozoic			Great unconformity Record unknown	Great unconformity Record unknown	Record unknown	Avalon series 15,000′
Archeozoic			?Laurentian granite		Laurentian granite	Laurentian granite

during the Taconic orogeny and to be unconformably overlain by the Clam Bank Series of red beds of Lower Devonian age. The Acadian orogeny, accompanied by the intrusion of the ultramafic and mafic Bay of Islands Complex, further deformed the rocks of west Newfoundland which were then eroded and covered by Mississippian and Pennsylvanian sediments deformed during the Appalachian revolution (Permian age). This geological framework served, with a few exceptions, as a standard frame of reference for all workers until 1963.

Meanwhile, the Princeton geologists Ingerson (1935, 1937), Cooper (1936) and Buddington and Hess (1937) studied the Bay of Islands Igneous Complex. Ingerson, working in the northern part of the Complex, concluded that he was examining layered laccoliths of ultramafic and mafic rocks, most probably of Lower Devonian age. Buddington and Hess, working in essentially the same area felt that the intrusions were lopoliths. Furthermore, they thought that Table Mountain and North Arm Mountain formed parts of a single lopolith disrupted by westwards thrusting. Cooper (1936) reached a similar conclusion while working in the southern part of the complex. He suggested that the Blow me Down and the Lewis Hills massifs were part of a great disrupted lopolith with a thickness of about 7 miles. He suggested that the floor of the lopolith consisted of schists derived from the Humber Arm sediments and recognized that the roof consisted of volcanic and sedimentary rocks. Cooper (1936, p. 8) considered that the southern part of the Complex consisted of a gravity differentiated body with primary rhythmic banding and a secondary, parallel tectonic banding. Furthermore, Cooper recognized that the Bay of Islands Complex was related to the Mount Albert Complex of the Gaspe Peninsula of Quebec.

All workers agreed that the igneous rocks intruded the Humber Arm Series.

Cooper (1937) extended his work to the Hare Bay region of Newfoundland under the auspices of the Newfoundland government. Table II shows his stratigraphic column and correlations. The most striking feature of the Hare Bay area recorded by Cooper is the spectactular thrusts that bring the Hare Bay ultramafic rocks and the Goose Cove Schists over the little metamorphosed Maiden Point and Goose Tickle sediments. Cooper (1937, p. 11) compared the thrusts with the Moine thrust of northwest Scotland. He correlated the ultramafic rocks above the thrust with the Bay of Islands Igneous Complex while the clastic rocks below were thought to be in place and equivalent to the Humber Arm Series of Middle Ordovician and later age.

Betz (1939), also working from Princeton, described the geology of the Canada Bay area, south of Hare Bay, in terms of Schuchert and Dunbar's standard section. His stratigraphic column and correlation are reproduced in Table III.

Between 1949 and 1955 several students from Columbia University, mainly directed by Marshall Kay, worked in west Newfoundland. These included Walthier (1949), Oxley (1953), and Nelson (1955). Of particular note is Walthier's suggestion that the metamorphic rocks east of Corner Brook are thrust over the carbonate rocks of the St. George Group. This suggestion, yet to be reconfirmed in the field, implies the existence of a Moine thrust-like feature in west Newfoundland.

The work of the American universities in western Newfoundland broadly confirmed and considerably refined the earlier results of the

Western Newfoundland	Hare Bay
	7. Ireland Point Volcanics 2,000'
Humber Arm Series 5,000'	6. Maiden Point Sandstone 6,000'
	5. Goose Tickle Slate 2,000'-5,000'
Cow Head Breccia	4. Northwest Arm Formation 0-500'
Long Point Series 1,530'	
Table Head Series--1,380'	3. Hare Island Limestone 1,000'
St. George Series 1,570'-2,080'	2. Southern Arm Limestone 1,500'±
Green Point Series 1,700'	1. Brent Island Limestone 350'±

Table II. Stratigraphic Column and Correlations used by Cooper, 1937.

Age	Betz (1939)
Lower Middle Ordovician	Bide Arm Fm.
Middle Cambrian to Early Ordovician	Chimney Arm F.
Middle Cambrian	Treytown Pond Fm.
Early Middle Cambrian	Cloud Rapids Fm.
Lower Cambrian	Forteau Fm.
Lower Cambrian	Devils Cove Fm.

Table III. Stratigraphic Column used by Betz, 1939.

Canadian and Newfoundland Surveys. Logan's broad stratigraphic synthesis was polished, expanded and placed on a more secure basis.

However, one curious and apparently minor difference of interpretation occurs in the descriptions of the Bonne Bay area given by Logan and a footnote in Schuchert and Dunbar.

Logan (1863, p. 293) insisted that certain rocks, later included by Schuchert and Dunbar in their Humber Arm Series, were the equivalents of the Sillery and Levis Formations of his Quebec Group in Quebec. Logan's view was based mainly on lithic similarity and apparent stratigraphic position. Schuchert and Dunbar disagree (1934, p. 95)

> . . . in this correlation, however, Logan appears to be wrong, since the greenish sandstones of Bonne Bay are not of Lower Ordovician age but are now known to be younger than the Long Point (=Black River) time.

The key to much of the present interpretation of the geology of west Newfoundland is hidden within this apparently minor difference of opinion. To appreciate its significance, it is necessary to review briefly the early history of the Taconic problem in west Newfoundland, Quebec and New England. More detail can be found in Stevens (1974) and Zaslow (1975).

Early workers in the New England states and Quebec recognized three major rock sequences. The oldest rocks, gneisses and granites, formed the basement and the western foreland of the Appalachian system. These were referred to as the Laurentian System. The overlying rocks, sandstones, shales and carbonates of Cambrian and Lower Silurian (Ordovician) age, were subdivided into the Potsdam Group, the Calciferous, Chazy, Trenton, Hudson River, and Utica Formations. The third sequence of rocks, the Quebec and the probably correlative Taconic Groups, consisted mainly of clastic rocks. These were virtually without fossils and of intransigent aspect. They "looked" older than the second group and this was indeed Logan's first hypothesis (Logan, 1863, p. vii). Later field work demonstrated that in fact the Quebec Group rested on the fossiliferous Hudson River Formation. Logan assumed this was a normal sedimentary succession. Fossils were discovered in the Quebec Group and by 1860 paleontological evidence enabled Billings to state that the Quebec Group fossils were older than the Utica and about the same age as the underlying Calciferous and Chazy Formations. Logan's first reaction was to believe the field data and to suggest that colonies (in the sense of Barrande) of older fossils had survived into post Utica times (Logan, 1860, in a letter to Barrande, quoted in Logan, 1863, p. viii). In the same year, after more fossils had been collected, Logan realized that the doctrine of colonies could not explain the exclusively primordal aspect of the fauna. He was forced to conclude that parts, at least, of the Quebec Group were time equivalents of the Calciferous and Chazy Formations. Now the problem was how could the Quebec Group overlie its time equivalents? Logan concluded that the Quebec Group must have been transported. He suggested that a great dislocation at the base of the Quebec Group brought it over the Utica Formation. Logan explained the lithological differences between the two sequences by suggesting that the autochthonous sequence was a shallow water shelf sequence whereas the Quebec Group formed in deep water at a continental margin. The ocean was named the Paleo Atlantic (Stevens, 1974, Fig. 3). It is not clear if this name was ever used by Logan or if it was coined by Dawson (in Harrington, 1883).

Logan, on the basis of Richardson's observations, recognized that the "Great Dislocation" should pass through the Bonne Bay area of west Newfoundland between his divisions N and Q. Logan, in other words, recognized that the Humber Arm Supergroup was transported. Schuchert and Dunbar rejected Logan's correlation and it was a hundred years before Logan's hypothesis was fully substantiated.

Schuchert and Dunbar's failure is difficult to understand since, in the Taconic region, Ruedemann (1909) and Keith (1913) recognized that the Hudson River Group was thrust into its present position. This hypothesis was neither fully accepted or conclusively proven until quite recently (Zen, 1961) and several rival hypotheses existed (Zen, 1967). It is possible, therefore, that Schuchert, who started work in Newfoundland in 1910, did not accept the Taconic Klippe. However, Schuchert (1930, p. 711) shows that he understood the regional significance of Ruedemann's work and its relationship to Logan's work. He appreciated that Logan's Line "may be traced from Kingston, New York, and Lake Champlain to Quebec City, and thence it follows the estuary of the St. Lawrence, undoubtedly continuing to the south of Anticosti." (Schuchert, 1930, p. 711). Furthermore Schuchert realized that the thrusting took place within the Ordovician Period (Schuchert, 1930, p. 718).

In Newfoundland, Schuchert and Dunbar (1934) and Dunbar (1934) recognized the importance of Middle Ordovician thrust faulting and found an anomalous sequence of rocks, the Green Point Series, indistinguishable from the Humber Arm Series (Schuchert and Dunbar, 1934,

p. 38). Even with their wide knowledge of Appalachian geology, and the field evidence (the thrusts are clearly visible at several localities), Schuchert and Dunbar failed to make the logical deduction that the Humber Arm Series was, in large part, transported. Indeed, Schuchert (1930, p. 712) says " . . . the Quebec Group . . . (is) known in situ only in western Vermont and northern Newfoundland.".

Perhaps part of the failure is explained by the scarcity of fossils in the Humber Arm. The fossiliferous Cow Head Breccias were misinterpreted as tectonic breccias and the fossiliferous Green Point Series was assigned an autochthonous position beneath the St. George even though it is never seen in this position.

Perhaps of even greater importance is the marked facies convergence between the transported Humber Arm and the top of the autochthonous sequence. This is explained in a later section and it is sufficient to note here that the richly fossiliferous rocks above the Lower Table Head greatly resemble those of the Humber Arm, and it would seem logical, therefore, to assign a Middle Ordovician or later date to the Series.

In 1941, however, H. Johnson, who had been working for the Newfoundland government, recognized that the anomalous Green Point Series was only the oldest member of a thick sequence of shales, sandstones, carbonates and carbonate breccias, coeval with the St. George and Table Head Formations, that is of Tremadoc to Llanvirn age. Johnson (1941) separated the anomalous rocks from the unfossiliferous main bulk of the Humber Arm. He erected three new groups, the St. Pauls Group, the Western Brook Pond Group, and the Green Point Group. Johnson realized that his three new groups could not be fitted into Schuchert and Dunbar's standard scheme, so he suggested that these rocks had been thrust from a source in the east, over the Long Range crystalline rocks. The suggestion seemed reasonable, especially since Johnson (1941) found that the Long Range itself had been thrust to the west along horizontal thrusts. Johnson thought that the age of the thrusting was Taconic or Caledonian but still regarded the bulk of the Humber Arm to be in place.

Unfortunately, the faunal data on which Johnson's hypothesis rested has never been published, though lists of Johnson's graptolites appear in Ruedemann (1947, p. 59-60). Perhaps, for this reason, Johnson's conclusions did not become widely known or appreciated. Kay (1945, p. 442), however, accepted Johnson's hypothesis, but only for those rocks separated by Johnson from the Humber Arm. As late as 1951, Kay (1951, p. 52) cites west Newfoundland as an area where eugeosynclinal rocks follow on top of miogeosynclinal deposits. He regarded the igneous rocks as in situ intrusions.

A major reinterpretation of the Humber Arm Supergroup had to await a reinterpretation of the Taconic region. Zen (1961) found that in west-central Vermont the Taconic allochthon definitely existed and that its base was not the carbonate/shale contact but was well within the shale sequence. A description of the whole Taconic region can be found in Zen (1967) and a regional discussion in Zen (1972).

In Newfoundland, yet another anomalous sequence of rocks had been discovered by Kindle and Whittington (1958, 1959). The Cow Head Breccias (Schuchert and Dunbar, 1934, p. 73) were not, at the type section, a chaotic thrust breccia but an orderly sequence of shales, limestones and limestone breccias of Middle Cambrian to Middle Ordovician age. The age of the clasts within any breccia bed is the same, as far as can be told, as the age of the interbedded black shale. Kindle and Whittington (1958, p. 341) suggested that the Cow Head Breccias are a type of flysch. They emphasized that there was no known source for many of the fossiliferous boulders since the equivalent carbonates of the shelf sequence are in large part very poorly fossiliferous.

Using the new information from the Taconics and west Newfoundland, Rodgers and Neale (1963) reinterpreted the Humber Arm Group as two large klippen, thereby bringing to fruition Logan's original concept. They drew a detailed stratigraphic and structural analogy between the two Newfoundland klippen and the Taconic Klippe and suggested that the Newfoundland klippen were emplaced by gravity sliding from a source to the east of the Long Range. These authors were the first to include the igneous rocks of the Bay of Islands and Hare Bay in the transported rocks, though they still assumed that these intruded the sediments of the Humber Arm, a relationship apparently confirmed by the detailed mapping of Smith (1958).

The age of sliding was deduced as Middle Ordovician, since the youngest rocks on which the klippen rest are of Middle Ordovician age. The Long Point Formation, of late Middle Ordovician age, was interpreted as a neoautochthonous cover, so that the Humber Arm allochton was emplaced in Middle Ordovician times. Rodgers (1965) later confirmed the neoautochthonous nature of the Long Point. It should be noted, however, that, given the relationships described by Rodgers (1965) it was possible that the emplacement was later than the age of the Long Point since it is possible, if improbable, that the Long Point was transported on top of the Humber Arm allochthon. The likelihood of this possibility was lessened by Stevens (1970) who suggested that there might be a continuous section between the Table Head and the Long Point in the Mainland area of the Port-au-Port Peninsula though the critical part of the section was under the sea.

Rodgers and Neale (1963) concluded that the klippen could not have slid from the Long Range since the Precambrian rocks are surrounded by autochthonous rocks. A much more probable source lay east of White Bay in the Burlington Peninsula area. According to this view, the Humber Arm Supergroup is the unmetamorphosed equivalent of at least part of the Fleur de Lys Supergroup which must, if this is true, have been deformed and metamorphosed during or after the emplacement of the allochthons. An alternative view, also presented by Rodgers and Neale (1963), is that the Fleur de Lys is a Precambrian basement from which the allochthons slid. Much depends on the source of the allochthons and this matter will be discussed in more detail later.

Lilly (1964) urged caution in accepting the klippen hypothesis and commented that several other hypotheses were equally plausible given the information then available. Unfortunately Lilly, who had probably seen more of the rocks of west Newfoundland than any other geologist, never presented his ideas in detail. However, from incomplete manuscripts (Lilly, 1967), compiled by W. Bruckner, it appears that Lilly thought that much of the Humber Arm was in place and older than the Carbonate rocks, although he did allow that some of the upper units could have been thrust from the west.

Rodgers and Neale's (1963) klippen hypothesis stimulated a flurry of new work. Stevens (1965) mapped in the Humber Arm area and succeeded in dividing the Humber Arm rocks into several formations. He found fossils that suggested that the rocks ranged in age from early Cambrian to perhaps Middle Ordovician. Rocks much like the Green Point Series were found in the Tremadocian part of the succession. Spectacular melange zones, mapped as zones of chaotic deformation, were found at the base of the allochthon and at different horizons within it. They were interpreted as marking thrust zones so that the allochthon was constructed of several discrete slices. The melanges were thought to develop in zones of high hydrostatic pressure developed during movement. In such zones friction would be low. This interpretation of melange was at the time unusual since most workers interprated such rocks as sedimentary deposits (Zen, 1961, Bruckner, 1966).

Misled by the coarse grained nature of the lower and upper units of the Humber Arm, Stevens (1965) suggested that the Humber Arm largely formed in a deltaic environment. He did, however, confirm Rodgers and Neale's klippen hypothesis in the Humber Arm type area.

Further evolution of thought on the geological evolution of west Newfoundland awaited developments in the realm of continental drift and plate tectonic theory. Early on, the former unity of the Appalachians and Caledonides was recognized by Wegener (1923) and Bailey (1927, 1929). Schuchert (1928), however, strongly denied any similarity and, as is well known, the hypothesis of Continental Drift passed into obscurity. Wilson (1962) suggested that the Cabot Fault and the Great Glen Fault of Scotland were once connected and analagous to the San Andreas Fault in California. Church (1965) correlated the geology of the British Isles with that of Newfoundland. Perhaps his most significant correlation was that of the metamorphic rocks of the Scottish Highlands and Ireland with similar rocks on the Burlington Peninsula. Wilson published an important paper in 1966 in which he introduced the name "Proto Atlantic". Geologists studying the American Appalachians were reverting to Logan's view that the Appalachians somehow formed at an ancient continental margin (Drake et al, 1959; Dietz, 1963; Dietz and Holden, 1966). This concept was in agreement with the hypothesis of continental growth by the accretion of marginal orogens. These concepts were not popular outside North America for, in many other parts of the world, orogens seem to be intracratonic. Even in North America there were growing suspicions that the Appalachians had in fact an eastern craton and were not open to the Atlantic (Williams, 1964). How can orogens form at continental margins if they are bounded by older basement and some are intracratonic?

Wilson solved this dilemma by invoking ancient continental drift. He suggested that the Appalachian/Caledonian system is the suture zone in which a Proto Atlantic ocean was destroyed. Later continental drift has disrupted the orogen transposing parts of Paleo-Europe and Paleo-North America. For no good reason, Wilson shows the island arcs produced during the closure of the Proto Atlantic as fringing the North American Continent. As far as the writer is aware, it was W. Fritz who first suggested the possibility that the movement of the west Newfoundland allochthons was related to the closure of the Proto Atlantic. This suggestion was made in a private discussion after the writer had given a talk to the Logan Club of the Geological Survey of Canada on the geology of west Newfoundland. Unfortunately at the time he underrated its importance.

The whole matter of trans North Atlantic correlations was discussed in detail at the Gander Conference (Kay, 1969), conceived and organized by Marshal Kay and convened in 1967. During this conference it became clear that there was overwhelming evidence that the Appalachians and the Caledonides were once part of the same orogenic belt and this paved the way for the later reinterpretation of Newfoundland geology in terms of the much better known geology of north west Europe.

At the Gander Conference, Stevens (1967a) reintroduced Murray's use of the term "ophiolite" for the Hare Bay and Bay of Islands Igneous Complexes but with no genetic implications. He also suggested that the Goose Cove Schists under the Hare Bay Complex were the equivalents of the Birchy Schists of the Fleur de Lys Supergroup (Church, 1969). This was thought to be evidence for the pre-Middle Ordovician deformation and metamorphism of the Fleur de Lys Supergroup as well as producing the first direct link between the geology of the Burlington Peninsula and that of west Newfoundland. Stevens (1967b) also demonstrated to the conferees the geology of the Humber Arm type section and a newly discovered section through the base of the allochthon north of The Gravels west of Stephenville.

The realization came in 1968 that the ophiolites did not intrude the sediments on which they rest but were thrust sheets in their own right (Church and Stevens, 1968). This interpretation is self-evident in Hare Bay where Cooper (1937) had mapped the thrusts under the Goose Cove Schists. In the Bay of Islands area, the discovery of abundant detrital chromite and some serpentinite fragments in the Blow me Down Brook Formation under the igneous rocks and in the clastic rocks above the Table Head pointed to the same conclusion. The clastic sediments were, in part, derived from the ophiolites as they were transported. A field trip to Gaspe in 1968 (Stevens, ms. 1969) confirmed a suspicion that Logan's Tourell sandstones were analogous to the Blow me Down Brook Formation and are a flysch deposit derived in part from an ophiolite source terraine. This also implied that the ophiolites were Arenig or older and not Devonian.

The similarity of the Quebec and Newfoundland ophiolite sequences to those of Papua (Davies, 1968), Cyprus (Gass, 1968) and Oman (Reinhardt, 1969) was finally recognized in 1969 (Stevens et al, 1969). Since these ophiolites were described as oceanic crust and mantle sequences, it was logical to suggest that the Appalachian ophiolites had an oceanic origin.

This concept was expanded by Stevens (1969, 1970). After visiting the Gaspesian sections of the Quebec Group with J. Lajoie, C. Hubert, G. Middleton and R. Walker in 1969, it was realized that much of the Humber Arm Supergroup could be interpreted as part of a continental rise prism of deep water turbidites. If this were so, the autochthonous sequence would represent a continental shelf sucession. In 1969, the writer was not aware that this was Logan's original interpretation (Stevens, 1974).

In 1969, then, continental shelf and continental rise sediments had been recognized in west Newfoundland as well as probable oceanic crust and mantle. It was logical to try and incorporate these elements into a tectonic scheme based on Wilson's concept of a Proto Atlantic. This was done in Stevens (1970). This paper made the following suggestions:

1. The geological relationships in west Newfoundland could be explained by assuming that the autochthonous sequence was a Cambro-Ordovician shelf sequence. The transported Humber Arm Supergroup was part of a continental rise prism. The Fleur de Lys Supergroup was the rest of the rise prism. The ophiolites were oceanic crust/mantle sequence that once floored part of Wilson's Proto Atlantic.

2. After initiation in late Proterozoic or Early Cambrian times, the ancient margin of North America remained essentially stable until latest Arenig times.

3. In late Arenig times, the shelf sequence was uplifted to give rise to the Table Head/St. George disconformity. At this same time flysch derived from the east appeared in the Humber Arm Supergroup. Late Arenig times, therefore, marked an important change in the history of the ancient continental margin in North America.

4. After this time the shelf broke up and sank. The rocks above the Table Head/St. George disconformity show a progressive increase in depth of deposition. Rocks much like the Humber Arm formed and led some previous geologists to the belief that all of the Humber Arm Supergroup was in place. These facies changes are a striking example of the workings of Walther's law.

5. The ophiolites were a prime cause of movement of the Humber Arm Supergroup. As they moved westwards they peeled off packets

of the rise sediments. Figure 6 of Stevens (1970) is not too dissimilar to recent diagrams of the structure of trench regions (e.g. Seely et al, 1974, fig. 2).

6. As the ophiolites moved westwards they shed detritus in front of them in the form of a flysch fan. This fan progressively migrated westwards and transgressed onto the now foundered shelf sequence during the Middle Ordovician. The movement of the allochthons was, therefore, a drawn out process, lasting several graptolite zones.

7. It seemed possible that the ophiolites of west Newfoundland once were continuous with those of the Burlington Peninsula so that it was possible that the deformation and metamorphism of the Fleur de Lys Supergroup was related to the ophiolite obduction.

8. Since detritus from the highest, ophiolite, sheet occurs in all of the internally derived flysch sequences it appears probable that the slice complex was progressively assembled and arrived at its final resting place in west Newfoundland in an already assembled condition.

9. In general, the stacking order of the slices reflects their paleogeographic position. The highest slice, the ophiolites, is farthest travelled and the lowest slices, locally parautochthonous shelf carbonates, are the least travelled. This again implies the slices were detached from their substrate in an order inverse to the stacking order.

Church and Stevens (1970, 1971) emphasized the oceanic origin of the Newfoundland ophiolites and suggested that they were emplaced as a result of the collision of the ancient margin of North America with a southeasterly dipping subduction zone. They drew a detailed comparison between the ophiolite stratigraphy and the geophysical layering of modern ocean basins. According to this scheme the ultramafic rocks represent the upper mantle, the overlying gabbros and sheeted dikes represent layer 3 of the oceanic crust and the pillow lavas and sediments layers 2 and 1. The metamorphic rocks under the ophiolites of west Newfoundland were thought to be produced either as a result of frictional heating during obduction or as a result of obduction of hot (1000°C) ophiolite. This latter hypothesis would imply that the ophiolites were formed by sea floor spreading only shortly before obduction. This in turn opened the possibility that the ophiolites formed in a small ocean basin rather than in a major ocean basin such as the present Atlantic.

It was further suggested that some of the volcanic rocks of Notre Dame Bay were once continuous with the Baie Vert and Be ts Cove ophiolites but have an island arc complex built on them. The spectactular sheeted dyke unit of the Be ts Cove ophiolite was first recorded in this paper and, if the conclusions are correct, it is possible to study the Moho on land without deep drilling.

Church (1972) later gave a more substantial account of the ophiolite problem.

Synchronous with the work at the University of Western Ontario, Dewey and Bird published an important series of papers on the same general problem (Dewey, 1969; Bird and Dewey, 1970; Dewey and Bird, 1971). These papers discussed the origin of the Appalachian/Caledonian system in terms of plate tectonics, which then was only recently developed. Indeed, as far as the writer is aware, Dewey's 1969 paper was the first to apply plate tectonics to an ancient orogen. The earlier papers (Dewey, 1969; Bird and Dewey, 1970) differ from the interpretations of Church and Stevens in two main ways. The ophiolites found west of Notre Dame Bay were regarded as intrusive igneous bodies derived as diapirs from a subduction zone. The second point of difference concerned the polarity of subduction. According to Dewey (1969) and Bird and Dewey (1970) subduction was directed in a generally western direction, that is under the North American continent so that the ancient continental margin would have had the character of an Andean mountain range. This is difficult to accept since there are no post Lower Cambrian intrusions in west Newfoundland and terrestrial sedimentation did not commence in west Newfoundland until the late Silurian, early Devonian deposition of the Clam Bank Formation. The problem of polarity of subduction is explained in more detail in a later section.

By late 1971 Dewey and Bird (1971) had accepted the Stevens (1970) and Church and Stevens (1970, 1971) interpretation of the western ophiolites but suggested that they formed in a small ocean basin above a west dipping subduction zone.

Later works (Williams, 1971, 1972; Upadyuay et al, 1971; Williams and Malpas, 1972; Williams and Smyth, 1973; Norman and Strong, 1975; and Riccio, 1976) have substantially supported the oceanic origin of the western ophiolites. It is now also generally accepted that the sedimentary rocks of west Newfoundland represent a telescoped continental margin of Cambro-Ordovician age and that sedimentary and tectonic evolution of the region is somehow related to a cycle of birth and destruction of an Early Paleozoic ocean; that is, a Wilson Cycle.

The second part of this thesis is devoted to a discussion of the second generation of plate tectonic hypothesis based on the geology of west Newfoundland.

CHAPTER 2 - RECENT INVESTIGATIONS

2.A Introduction

It is clear from a study of the many papers recently published concerned with the geology of west Newfoundland that, although there is a certain degree of agreement as to the identity of the basic geological elements involved, there is no consensus as to how the various elements fit together. Serious disagreement exists about the nature of the events that led to the destruction of the Proto Atlantic.

In this chapter, the writer will attempt to analyse some of the more contentious issues that have preoccupied workers in west Newfoundland during the last few years. However, a constant background problem concerns the weight to be placed on data gathered in other parts of the Appalachian/Caledonian system. Can, for example, the radiometric evidence indicating an orogenic event in the Scottish Highlands at about 500 m.y. be used as evidence of the same event in the Fleur de Lys of Newfoundland where no such evidence is available?

2.B The Importance of Newly Discovered Rock Sequences

2.B.1. Introduction

Church and Stevens (1971) tacitly assumed that all of the igneous and metamorphic rocks in the Bay of Islands and Hare Bay regions were part of an ophiolite sequence or obduction-related metamorphic assemblages. This view has been challenged. Williams (1971), Williams and Malpas (1972) and Comeau (1972) suggested that much of the metamorphic rock in the Bay of Islands region can be separated from the ophiolitic sequence and its basal metamorphic rocks. At first these rocks were referred to the Coastal Complex but more recently the term Little Port Complex has been used (Williams and Malpas, 1972).

Similarly Strong (1974) showed that the Skinner Cove Formation (Troelsen, 1947) is probably not the normal top of an ophiolite, but a sequence of alkaline basalts, trachytes and related volcanogenic sediments. The Cape Onion Formation of Pistolet Bay is also alkaline (C. DeLong and B. Jamieson, pers. comm., 1976).

These observations necessitate a revision of the models presented by Church and Stevens (1971) and Bird and Dewey (1970).

2.B.2 The Little Port Complex

The Little Port Complex (Williams and Malpas, 1972) occupies a position high in the transported slice assemblage of the Humber Arm Allochthon but its true relationship with adjacent slices has not yet been firmly established. Equivalent rocks are not known from the Hare Bay Allochthon though similar, but not identical, rocks occur as blocks in the Milan Arm melange. Lithologically the complex is characterized by foliated gabbro and amphibolite associated with less deformed, though frequently shattered sodic granite. Brittle deformation is common throughout the complex. Locally deformed ultramafic rocks are common. A. Nicholas, viewing the writer's thin sections of these ultramafic rocks from north of Trout River in 1975, remarked that he had only once before seen a naturally deformed ultramafic rock that showed evidence of such high strain rates. They were from the Pyrenees. Diabase dykes cut all units of the complex.

Outcrops of the complex are confined mainly to the western coastal exposures, though in the Lookout Hills and Crow Hill areas of Bonne Bay, the complex wraps around the northern end of the ophiolite exposure and continues for about 2 km. along the eastern margin of the ophiolite. Here it is separated from the ophiolite and the basal metamorphic rocks of the ophiolite by a thin broken sequence of shales and sandstones much like those of the Blow me Down Brook Formation. (The red shales unconformably overlie the Little Port gabbros.) Likewise, the complex crops out from beneath shales and sandstones, now melange, in the Lark Harbour Provincial Park in the Bay of Islands area. There is some indication that the ophiolites rest directly on the Little Port Complex in the Lewis Hills (Cooper, 1937, plate 1). In general the complex as a whole looks like a megamelange, with blocks, several kilometers across, set in a shaly serpentinite melange matrix (Comeau, 1972, plate 1). It is not impossible that the Skinner Cove, described below, also forms blocks in this megamelange. The megamelange seems to be sandwiched between the ophiolite above and the Humber Arm sediments below.

A zircon age of about 500 m.y. has been obtained by Mattison (1975) from a sodic granite from within the complex and shales from the melange matrix have yielded Tremadocian graptolites (Kindle and Whittington, 1965).

The Little Port Complex is difficult to interpret mainly because analagous rocks have not been reported from other Lower Paleozoic orogens. Three differing interpretations have been proposed. Comeau (1972) and Williams and Malpas (1972), impressed with the deformed nature of the complex and the abundance of sodic granitic bodies, suggest that the complex is not ophiolitic but represents a remnant of continental crust, possibly of Grenville age, caught up in the spreading episode that gave rise to the Bay of Islands ophiolite. These authors compare the complex to the Twillingate granite of Notre Dame Bay. Dewey (1974), however, suggests that the complex is a fragment of the Fleur de Lys terrain that was stranded in an ocean basin formed as the Fleur de Lys block migrated away from the continental margin during late Cambrian and early Ordovician times. The present writer, however, prefers a suggestion he made in Malpas et al (1973) that the complex is more like the metamorphic basement of certain Pacific Islands such as Yap (Shiraki, 1971). More recently Karig (1974) has interpreted this basement complex as an oceanic accretion melange formed at the leading edge of an obducting oceanic plate. If the Little Port Complex had a similar origin it would explain its structure as a megamelange, the relationship with the overlying sediments, its position high in the slice assemblage, the predominantly mafic-ultramafic composition of the metamorphic rocks and the strong deformation of the complex as a whole. In this interpretation the sodic granites represent partial melts of amphibolites in a subduction zone.

Difficulties of this interpretation include the origin of the mafic dykes that cut the complex. The zircon dates obtained by Mattinson (1975) also seem old for this interpretation since they are as old as the ophiolite itself. Perhaps the zircons are xenocrystic as might be expected if the sodic granites are a product of partial melting.

The main strength of the above model would seem to be that the complex resembles a deformed ophiolite much more than it resembles the Grenville basement or the Fleur de Lys. The associated shales and greywackes can be regarded as an unconformable flysch cover, derived at least in part from an island arc, that is sediments deposited in the trench/arc gap.

2.B.3 The Skinner Cove and Cape Onion Formations

These formations comprise a remarkably fresh and undeformed association of alkali basalt pillow lavas and volcanoclastic sediments. Trachytes occur locally within the Skinner Cove Formation which crops out from under the western outcrops of the Little Port Complex in the Bay of Islands region and forms the northwestern parts of the Hare Bay allochthon. The possibility that all of the alkalic rocks are large blocks within a megamelange has already been mentioned above.

At first the Cape Onion Formation was thought to form the displaced top of the Hare Bay ophiolite (Stevens, 1970) and, as such, the Tremadocian graptolites it yielded from black shales at Cape Onion were thought to date the ophiolite. A similar origin was generally assumed for the Skinner Cove Formation.

Strong (1974), however, recognized that the Skinner Cove comprised a continuous alkaline differentiation sequence from pillowed ankaramites to trachytes. At first Strong (pers. comm., 1973) was so impressed by the fresh undeformed nature of the pillow lavas (they contain undevitrified volcanic glass and completely fresh olivine and titaniferous augite) that he suspected that they might be of Carboniferous age like the alkalic rocks of the Midland Valley of Scotland. Fossils, however, indicate a Late Cambrian to Lower Ordovician age (Strong, 1974) though the evidence is not good. Fahraeus (pers. comm., 1974) indicated that the fossils might be of any Lower Ordovician age.

On the basis of the chemistry and petrology of the Skinner Cove, Strong (1974) suggested that the rocks formed as an "off-axis" volcanic suite, erupted at some distance from the main ridge and analagous to the Upper Pillow Lavas of Cyprus (Gass and Smewing, 1973).

The Cape Onion Formation has been less well studied and as yet little or no chemical data are available. Nevertheless, on the basis of petrology, B. Jamieson and C. DeLong (pers. comm., 1976) suggest that the formation is similar to the Skinner Cove and markedly alkalic. Furthermore B. Jamieson (pers. comm., 1976) suggests that rocks indistinguishable from the Cape Onion grade into the Goose Cove Schists that form the metamorphic floor of the Hare Bay ophiolite. This supports an observation made by the writer that local shear zones cut the Cape Onion Formation and convert the rocks into greenschists and locally amphibolites indistinguishable in the field from rocks of the Goose Cove Schists.

The relationships outlined above suggest to the writer that the alkalic volcanic rocks formed as an "off-axis" volcanic sequence on ocean floor of the North American plate and were incorporated into a megamelange associated with rocks of the Little Port Complex at the leading edge of the obducting oceanic (European?) plate. If this is correct it is to be expected that some of the Little Port Complex has alkali basalt parentage.

It should be noted that the general arrangement of units at the tops of the allochthons is by no means unique. In southern Turkey, for example, Graciansky (1973) describes the downward succession ophiolite, metamorphic complex, alkalic basalt, melange, autochthonous flysch and carbonates from the Lycian nappes of southwest Turkey and the Aegean.

2.6 The Nature of Lower Paleozoic Subduction

Two main schools of thought have developed over the last few years concerning the closure of the Proto Atlantic. Wilson (1966) showed island arc development on the North American side of the Proto Atlantic but with no explanation. This probably stems from an acceptance of Kay's (1951) assumption that the arcs are essentially autochthonous with respect to North America. In the same tradition, Dewey (1969) and Bird and Dewey (1970) show the destruction of the Proto Atlantic via a west dipping subduction zone. Dewey and his coworkers have evolved variations on this theme in which small rear arc and intraarc basins appear and disappear at the western margin of the Proto Atlantic (Dewey, 1974; Bursnall and de Witt, 1975). Kennedy (1975) also favours a similar fragmentation of the ancient continental margin of North America. In general, those favouring west dipping subduction have moved from an early interpretation of the deformation of the margin as an Andean type event to one which might be described as a South West Pacific type event involving migrating island arcs and small ocean basins.

On the other hand, Church and Stevens (1971) suggested that the ophiolites of the Burlington Peninsula and of west Newfoundland once formed a continuous sheet now disrupted by later tectonism and erosion. They suggested that the Proto Atlantic closed via an east dipping subduction zone allowing the obduction of the ophiolite sheet across the continental margin. The writer, working in west Newfoundland, could see no evidence for west dipping subduction. Apart from the Lower Cambrian basaltic rocks marking the birth of the Proto Atlantic, no igneous rocks cut the autochthonous sequence. Two small diabase dykes that cut the Table Head Formation under the Hare Bay allochthon are minor exceptions. The poorly exposed North Brook Granite (Walthier, 1949, p. 28) has proven to be a horst of Grenville basement, a northern continuation of the Indian Head uplift. Furthermore there is no report of volcanic ash in the entire post Lower Cambrian autochthonous sequence. In addition the autochthonous sequence records rather quiet conditions of sedimentation from Lower Cambrian to the D. nitidus zone of the Arenig. After the initial Lower Cambrian transgression there is a late Lower Cambrian regression marked by the development of quartzites. These are followed by shallow water sediments of Later Cambrian and Lower Ordovician age. There is no evidence for dramatic events at the continental margin at this time. This evidence from the autochthon does not negate west dipping subduction far from the continental margin but does seem to contradict obduction of the ophiolite by west dipping subduction and is difficult to reconcile with the fragmentation of the margin during late Cambrian time suggested by several authors. Furthermore, a thick island arc sequence is developed on an ophiolite basement in Notre Dame Bay some 150 km. east of the Bay of Islands area. This might well have developed above an east-dipping subduction zone. On this view the arc would have developed marginal to the old European continent. The west Newfoundland and Burlington Peninsula ophiolites would then have been the trench/arc gap on the European plate.

It is germane to note that this island arc became inactive in Caradocian time, just as the Humber Arm Allochthon stopped moving.

The distribution of potassium in the granites of central and eastern Newfoundland supports, in a very general way, the concept of east dipping subduction (Strong et al, 1974) as does the gross distribution of mineralization (Strong, 1973, 1974a).

Nevertheless, remembering the complexity of subduction patterns in present day active regions such as Indonesia and how rapidly such patterns have changed, it seems wise to keep an open mind at present regarding the pattern of subduction during the closure of the Proto Atlantic. The writer will insist only that during the Cambrian and Ordovician west Newfoundland was not part of an Andean type orogen and that at no time has west Newfoundland been above a subduction zone that produced magma or tectonism.

2D The Deformation and Metamorphism of the Fleur de Lys Supergroup

Although the writer has worked only briefly on the Burlington Peninsula, the best studied outcrop area of the Fleur de Lys Supergroup, the history of these rocks is so important with respect to the evolution of west Newfoundland, that a short account of the various hypotheses regarding its evolution is given here. It should also be noted that the geology of west Newfoundland places certain restraints on hypotheses concerned with the evolution of the Fleur de Lys Supergroup.

Church (1965, 1969) first recognized the similarity of the Fleur de Lys Supergroup and the Moine-Dalradian rocks of the Scottish Highlands and Ireland. Church (1969) further recognized that a two fold division of the Supergroup could be made with the Baie Verte zone of ultramafics being the dividing line. The western division consists mainly of metasediments with mafic intrusions while the eastern division consists of metavolcanic rocks with only subsidiary metasedimentary rocks. The rocks are deformed and metamorphosed (Church, 1969; Phillips et al, 1969; Kennedy, 1975) and cut by granites, some of which are potassium rich. Ophiolites occur in the terrain. These rest on top of the rocks of the western division (Stevens, 1970; Church and Stevens, 1971) but appear to underlie at least the eastern part of the eastern group (Neale et al, 1975). Bursnall and de Witt (1975) concluded that only one sequence of ophiolites is present in the Baie Verte area but that it is equivalent to the Birchy Schist which Church (1969) and all later workers interpret as an integral part of the Fleur de Lys Supergroup.

The only fossil locality on the whole peninsula is in the Snooks Arm Group above the Betts Cove ophiolite but below the Cape St. John group, where Snelgrove (1931) obtained Arenig/Llanvirn graptolites.

Several hypotheses for the evolution of the peninsula have been proposed and it should be stated at the start of this discussion that there is no generally accepted hypothesis.

Most workers would agree that the western, metasedimentary division of the Fleur de Lys is the equivalent of part of the Humber Arm Supergroup and hence coeval in part with the autochthonous sequence of west Newfoundland. This concept was first presented by the writer at the Gander Conference in 1967 and repeated in Stevens (1970). The comparison is based only on general lithological similarity. Stevens (1967a) noted the very remarkable similarity between the Birchy Schist and the Goose Cove Schist of the Hare Bay allochthon. This general similarity led to the assumption that the Fleur de Lys had never been far removed from the ancient continental margin of North America and was, in fact, an integral part of it. Given the non-orogenic sedimentary record of the west Newfoundland autochthonous sequence, the deformation and metamorphism of the Fleur de Lys metasediments must have taken place during and/or after the obduction of the ophiolite sheet. This led Stevens (1974a) to suggest the following scheme for the evolution of the Burlington Peninsula:

1. Sedimentation during Late Proterozoic to early Ordovician as part of the ancient continental rise prism.

2. Late Arenig obduction of the ophiolite sheet over the rise prism, leading to recumbent folding and metamorphism. The ophiolite was regarded as having a cover of island arc volcanic rocks that thickened eastwards. The Birchy Schist, according to this scheme, is like the Goose Cove Schist, and represents the metamorphic base to the ophiolites formed during an early stage of obduction when oceanic lithosphere was moving over oceanic lithosphere. Locally the schist became infolded with the main metasedimentary part of the Fleur de Lys.

3. The situation of a thick sheet of oceanic lithosphere resting on a continental rise prism intruded by mafic material is inherently unstable with respect to gravity. After a while, as the disturbed geothermal gradient gradually returned to a more normal configuration, vertical adjustment of the crust took place, as suggested by Ramberg's (1967) centrifugal models. Parts of the more silicic material melted on its upwards journey to give rise to the potassic granites, quartz-feldspar porphyries and silicic extrusive rocks, some of which include abundant xenoliths of ophiolite. Some of the ultramafic sheet sank to give the synclinal keel of the Baie Verte zone.

Unfortunately, this scheme fails to account for the reported occurrence of metamorphic detritus apparently derived from the Fleur de Lys found in sediments of the Baie Verte Group (Kidd, 1974).

An alternative approach is taken by Dewey and his coworkers and Kennedy who recognize the difficulty of deforming the Fleur de Lys above a west dipping subduction zone close to the ancient margin of North America. They escape this difficulty by rifting part of the continental rise prism away from the margin during the Late Cambrian/Early Ordovician (Dewey, 1974, fig. 7) or Middle Cambrian (Kennedy, 1975, fig. 5). Dewey (1974, p. 947) prefers to move away the whole of the Fleur de Lys terrain whereas Kennedy (1975, p. 58) wants to remove only part of the eastern division. Both authors regard the silicic intrusive and extrusive rocks of the eastern division as subduction-related island arc volcanic rocks.

The schemes outlined above were evolved, in part at least, to explain the evidence for the deformation and metamorphism of the Fleur de Lys equivalents, the Dalradian sequence of Ireland and Scotland at about 500 m.y., without tectonically affecting the continental shelf sequence or introducing clastic rocks onto the shelf. Physical separation makes this possible. The evidence for the late Cambrian/early Ordovician tectonism is partly radiometric and partly stratigraphic. The only evidence for this early deformation in Newfoundland is the occurrence of metamorphic detritus in Arenig and presumed Arenig rocks. In Kennedy's scheme (1975, fig. 5) even this advantage is nullified since he shows the carbonate succession being deformed in the late phase of his late Cambrian-Tremadocian episode. There is no evidence for this deformation in west Newfoundland either in the carbonate sequence or in the Humber Arm Supergroup that was presumably even closer to the orogen than the carbonate sequence.

None of the above hypotheses explains how it is possible to dismember a continental rise prism and form a small ocean basin without disturbing sedimentation on the rise, now the Humber Arm Supergroup, or on the shelf, now the autochthonous sequence. Neither is it explained how these back arc basins can form without the injection of a single dyke into the Humber Arm Supergroup, that all workers agree was, in Lower Cambrian times, contiguous with the Fleur de Lys metasediments. If it is proven that the Fleur de Lys was deformed during Late Cambrian/Tremadocian times, this must mean it was well removed from the ancient continental margin of North America. If this is so the only time it could have been removed was during the well documented phase of rifting in the Lower Cambrian. This must mean that the supposed correlation between the Humber Arm and the western Fleur de Lys is entirely illusory and that the bulk of Fleur de Lys is of Proterozoic age since it would have been removed from a source of sediment in early Paleozoic times.

If the Fleur de Lys was removed from the ancient continental margin of North America it must have been restored during a phase of east dipping subduction if the arguments against west dipping subduction given above are valid. This hypothesis might not be easily tested in Newfoundland because of the small outcrop width of the Fleur de Lys. In Scotland, however, the outcrop of the Dalradian is probably wide enough to detect any systematic variation in composition of the older granitic rocks. It is interesting that as early as

1912, Barrow noted an increase to the south east in the potassium content of the older granitic rocks in Scotland.

An entirely different approach is taken by Bursnall and de Witt (1975). These authors assume that the sediments of the Humber Arm Supergroup and the western division of the Fleur de Lys Supergroup are almost entirely equivalent, as did Stevens (1970), so that the tectonism of the Fleur de Lys may be as young as Llanvirnian. They dismiss any evidence of early tectonism of the Fleur de Lys. They next assume that the Birchy Schist is an integral part of the Fleur de Lys stratigraphy because it is interbanded with semipelitic schists. On the other hand the Birchy Schist is correlated with the ophiolitic Advocate Complex so that this complex, and probably other members of the ophiolite complex, should be included with the Fleur de Lys Supergroup. They conclude, therefore, that a single sequence of ophiolites exists in the area but that these were generated contemporaneously with late Fleur de Lys sedimentation and volcanism and thus must predate tectonism of the Fleur de Lys.

It seems to the present writer that the critical parts of the Bursnall and de Witt hypothesis concern the origin of the Birchy Schist. The Birchy Schist was previously correlated with the Goose Cove Schist of the Hare Bay Allochthon (Stevens, 1967). The Goose Cove Schists seem to have formed by deformation and metamorphism of a volcanic and sedimentary sequence during the obduction of the Hare Bay ophiolite (Church and Stevens, 1971). This suggestion has been confirmed by Williams and Smyth (1973). The Goose Cove Schist, and hence, by correlation, the Birchy Schist is a tectonic-stratigraphic unit developed under the ophiolite from transported volcanic and sedimentary rocks. It can be recognized under the Hare Bay, Bay of Islands, Baie Verte, Mings Bight ophiolites and under the ultramafic rocks at Fleur de Lys village. The present writer considers that apparent interbedding of the Fleur de Lys metasediments and the Birchy Schists will prove to be a tectonic interfingering. If the Jamieson-DeLong hypothesis mentioned above is correct, the Birchy Schists should have, in part, an alkali basalt parentage.

The occurrence of amphibolite and garnet amphibolite at the contact of the Fleur de Lys metasediments and the ultramafic rock of the Advocate Group at the Advocate Pit, Baie Verte, strongly suggests that the Advocate Group is an obducted ophiolite (L. Riccio, pers. comm., 1974).

In summary, then, there are three main groups of hypotheses concerning the origin of the Fleur de Lys Supergroup and associated rocks. The first considers the Supergroup to be part of the old continental margin of North America deformed and metamorphosed as a result of subduction beneath an ophiolite/island arc sequence and then later deformed and intruded as the margin regained gravitation stability. The second group of hypotheses assumes that the Supergroup formed part of the old continental margin until late Cambrian/early Ordovician times when it was rifted away, tectonized and then back-tracked to collide with the margin in late Arenig/early Llanvirn times. The third hypothesis assumes that most of the western Fleur de Lys is older than the Baie Verte ophiolites which are essentially in place. The tectonism post dates ophiolite formation.

2.E The Emplacement of the Humber Arm Allochthon

2.E.1. Introduction

In this section an attempt will be made to incorporate the assembly and transportation of the Humber Arm Allochthon into a general model for the evolution of west Newfoundland. The problem of the transport of large masses of relatively incompetent, yet little tectonized rock over large distances is one that has long intrigued geologists. Usually some sort of gravitational sliding is invoked since gravity acts on all parts of the transported body so that minimal deformation is to be expected. The body is not pushed or pulled, but slides. Nevertheless where large lateral movements are required the gravity slide hypothesis meets real difficulties since it is hard to envisage the long slopes needed for such movements (LeMoine, 1973).

Migrating zones of uplift are sometimes postulated to solve this dilemma. The transported rocks are thought to have been propelled by a series of blocks, sometimes termed composite wedges (Merla, 1957), uplifted serially in the direction of transport. A variant of this hypothesis is that the uplift migrates like a wave, the transported rocks being propelled like a surf rider on the front of the wave. No convincing explanation for the behaviour of the composite wedges or waves has ever been given.

Rodgers and Neale (1963) first suggested that the Humber Arm Allochthon was emplaced by gravity sliding. In part, their hypothesis was based on analogy with the supposed mechanism of emplacement of the Taconic Klippe that was thought to have slid off the adjacent Green Mountains (Zen, 1961). Analogy was drawn with the Appenines (Wise and Bird, 1964). Nobody has seriously challenged the Rodgers and Neale gravity sliding hypothesis yet it has severe difficulties.

Later workers (Stevens, 1970) recognized the importance of the thick upper ophiolite sheet in controlling the assembly of the allochthon. Stevens suggested that during the westward movement of the ophiolites, successive, more westerly slices were peeled from their substrate at the continental margin and incorporated into the base of the allochthon. The higher the slice in the slice assemblage, the further it has been transported (Stevens, 1970, fig. 5, lower). Although the early thrusting that emplaced the ophiolite onto the continental margin was held to be compressional in nature, the later phases were believed to be controlled by gravity. This style of movement was thought to be a varient of Bucher's "peel thrusting" (Bucher, 1955) and the term "gravity slide peel thrusting" was coined to describe this type of movement. As far as the writer is aware nobody else has ever used this term though all later workers (Williams, 1971; Williams and Malpas, 1972; and Dewey, 1974) have accepted the principle that the stacking order of the allochthon reflects the paleogeography before assembly, a sort of tectonic Walther's Law. Still, the slope problem is not solved since gravity is held to be the main motive force.

The upper parts of the allochthon have moved at least 100 km. and maybe as much as 200 km. If sliding took place on a slope of only 5 degrees a difference in elevation between source and destination much have been at least 9 km. and much of this must have been submarine (Stevens, 1970). Clearly there is a slope problem. Yet, how else is it possible to collect, into a single allochthon, so many disparate rock types formed in environments as different as intertidal and deep ocean basin without drastically deforming or metamorphosing most of the components?

As more geophysical and geological data have been collected in subducting ocean trenches, it has become clear that in some trenches, at least, the inner trench slope consists of a stacked series of thrust slices. According to a recent hypothesis (Seely et al, 1974), the inner trench slope thrust complex grows by the addition of slices at its base. The thrust slices are derived from the subducting to obducting plate but the slice assemblage does not significantly move with respect to the obducting plate. Slices are brought to the allochthon and stuck on the bottom. In a superficial way at least, the suggested mode of assembly of the Humber Arm Allochthon (Stevens, 1970, fig. 5, lower) resembles the structural evolution of a subducting trench. Was, in fact, the Humber Arm Allochthon assembled and emplaced in this way?

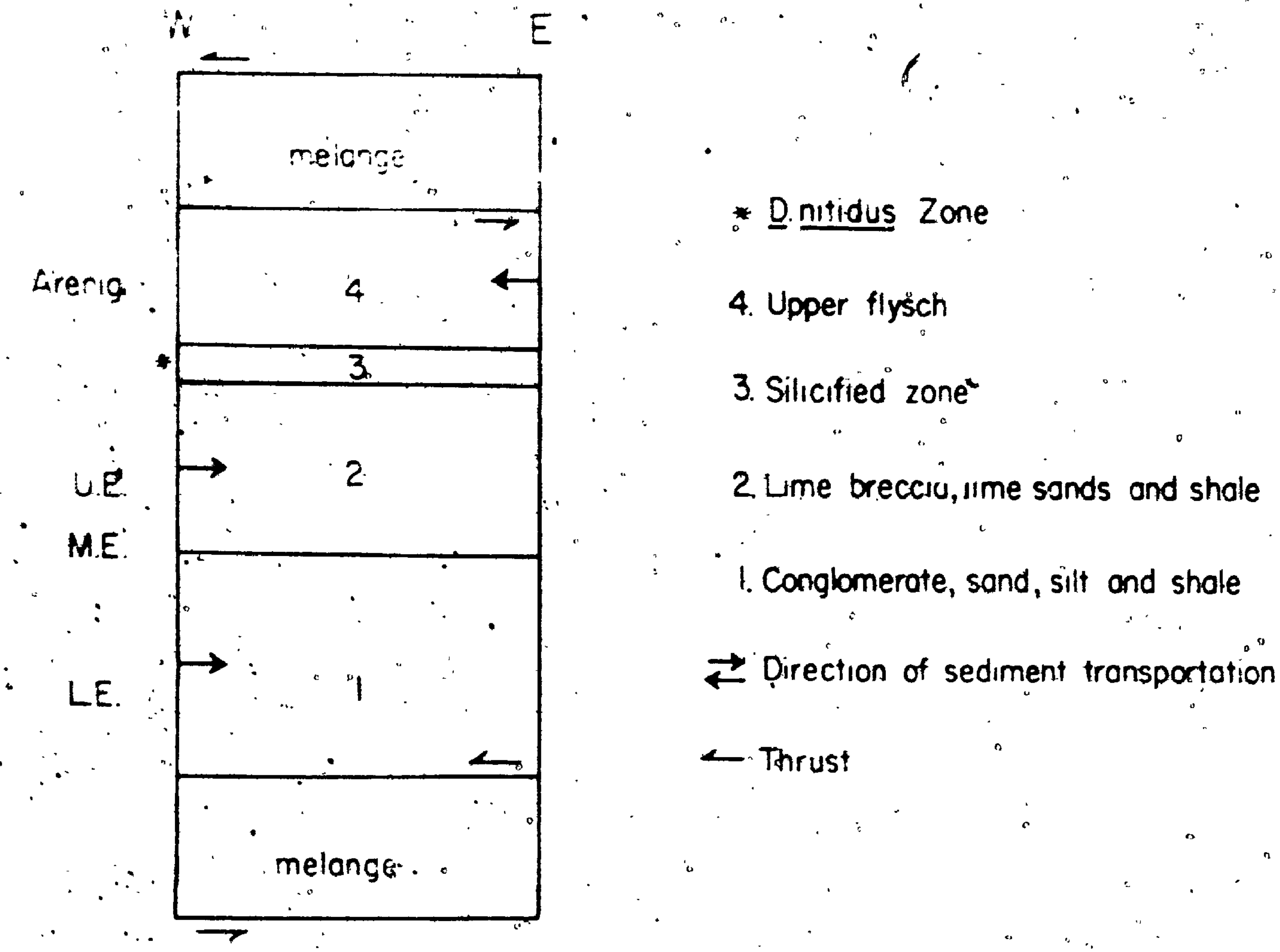
2.1.2 The Humber Arm Allochthon

The architecture of the Humber Arm Allochthon is now fairly well known. It is divisible into a lower series of slices made up of sedimentary rocks and an upper slice series made up of igneous and metamorphic rocks. The very lowest slices are locally slivers of shallow water carbonate rock which are the least transported. In other places the lowest rocks are green and black shales with thick green beds of chert. These are of deep water aspect and are the youngest rocks known to be transported. The bulk of the transported rock, however, occurs in somewhat larger slices, 5 of which can be recognized in the Humber Arm type area. Figure 1 shows a generalized succession within each slice. The bulk of the sediments (1,2) are debris flows, turbidites and shales of (?) Lower Cambrian to early Arenig age. The older rocks (1) are predominantly quartzofeldspathic while the younger rocks are calcareous. Units 1 and 2 originated as part of a continental rise prism and received their sediment from a western source.

During D. nitidus zone sedimentation, the fine turbidites were widely silicified, and locally, bedded radiolarian chert and manganiferous carbonate rocks were deposited with black graptolite bearing shale. These are followed by an influx of clastic rocks from the east, the Blow me Down Brook Formation. These massively bedded turbidites were derived cannibalistically from older rocks of the Humber Arm Supergroup with additional input from the ophiolites and intrusive and extrusive silicic rocks. There is some evidence that a gneissic source contributed detritus to the flysch. The flysch is the last sedimentation before the rocks were incorporated into the base of the growing slice assemblage.

If the record is being read correctly, each of the sedimentary slices seems to have had the following history. 1) Cambrian and early Ordovician turbidite sedimentation as part of a continental rise prism. 2) A bathyal lull, silicification and starved sedimentation. 3) Massive influx of sediment from tectonic lands to the east. 4) Incorporation of the sediments into the base of the growing slice assemblage and transportation. This sequence is compatible with slice assembly at the inner trench slope.

Figure 1. Generalized Section Through a Single Slice of the Humber Arm Allochthon.


W
E
melange
4
3
2
1
melange
Arenig
U.E.
M.E.
L.E.
* D. nitidus Zone
4. Upper flysch
3. Silicified zone*
2. Lime breccia, lime sands and shale
1. Conglomerate, sand, silt and shale
Direction of sediment transportation
Thrust

2.1.3 The Upper Igneous and Metamorphic Slices

As already described above the upper slices consist of an ophiolite with a basal metamorphic rind overlying an assemblage of foliated gabbros, amphibolites, and sodic granites. These overlie an alkalic volcanic assemblage, though it is possible that the two last units are components of a megamelange. Although not critical to the present argument it will be assumed in this discussion that these lower slices formed as an accretion melange as described by Karig (1974) and have since been overrun by the ophiolite.

2.1.4 Events on the Continental Shelf

The geological record of the autochthonous sequence is the easiest to read. After relatively stable shallow water sedimentation that lasted from Lower Cambrian to Mid Arenig times, the shelf broke up and sank. The sinking seems to have been somewhat diachronous, earlier in the east than the west (Stevens, 1970) and local horsts seem to have formed against a background of general subsidence. The subsidence is recorded by the Table Head Formation and younger rocks (Stevens, 1970) and seems to have started, after a short period of uplift, at about the same time as the easterly derived flysch appeared in the Humber Arm succession.

The Middle Table Head locally contains radiolarian bearing-lime turbidates and is locally silicified. The Upper Table Head is a condensed sequence of black graptolite bearing shales of Llanvirn age, and is followed by an easterly-derived flysch of Llanvirn/Llandeilian age that coarsens upward. It is similar in composition to the Blow me Down Brook Formation flysch except that it contains less detritus derived from silicic igneous rocks. The flysch is followed by emplacement of the allochthon.

Immediately after the emplacement of the allochthon, it was covered by the shallow water, well sorted, Long Point Formation during the late Llandeilian. This immediate covering of the allochthon with mature shallow water sediments suggests the possibility that the allochthon came to rest in water as deep as the allochthon is thick, that is about 5 km., even if some subsidence may have taken place as a result of post-emplacement isostatic sinking. The implication is that the continental crust sank to oceanic depths prior to the emplacement of the allochthon.

The history deduced for the autochthon under the Humber Arm Allochthon seems to be generally similar to that recorded in individual slices of the Humber Arm Supergroup. That is, stable sedimentation as part of a continental margin, rapid sinking, perhaps to oceanic depths, influx of easterly derived clastic sediment and then overriding by the allochthon.

2.L.5 Application of the Trench Model

For a trench model to be applicable to the assembly and emplacement of the Humber Arm Allochthon, it must be assumed that a subduction zone dipped away from the continent during the process. It does not matter if the subduction was closing a major ocean basin or a rear arc basin or if the Fleur de Lys was part of the margin or at some distance. Evidence for the assumed polarity of subduction has been outlined above.

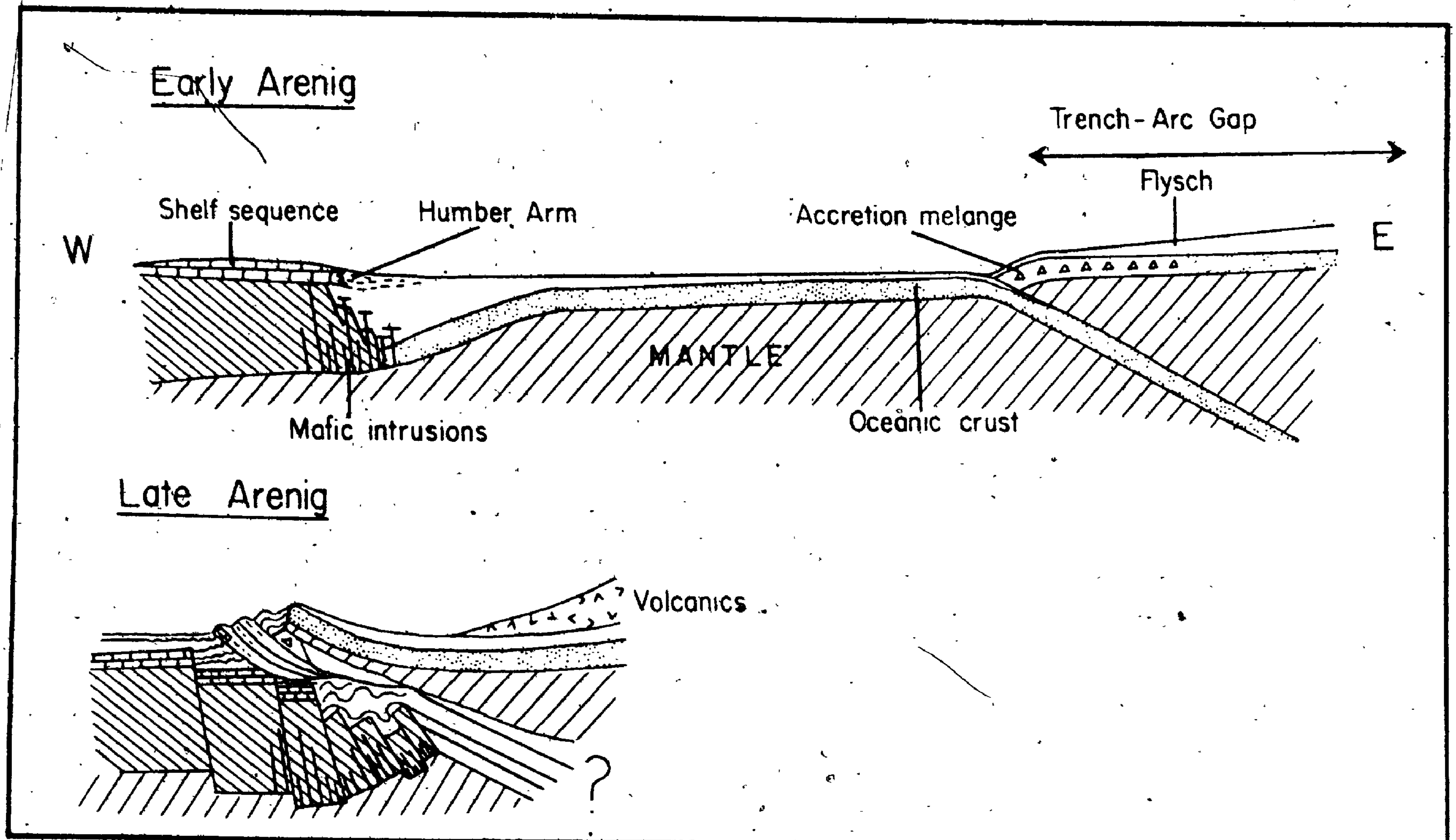
If the polarity of subduction is accepted, the inner trench slope thrust zone would have accreted under a cover of ophiolite and modified ophiolite, a trench arc gap. Each slice would have been derived from progressively closer to the continent as the continental rise prism impinged on the trench. Such a situation seems to exist in the region northwest of Australia where the Australian continental block has run into the trench in front of the Flores island arc (Beck, 1972).

The sedimentary record to be expected in a trench environment has been indicated by Seely et al (1974). Within each thrust slice, an upwards succession of abyssal plain to trench deposits is to be expected. In the case when a continental rise prism impinges on a trench, we may expect a succession, continental rise turbidites, abyssal plain sediments, trench sediments within each thrust slice. The sedimentary record of the Humber Arm Supergroup (fig. 1) can easily be accommodated in this model.

The development of melange between each slice can be explained as a result of deformation under high hydrostatic pressure induced as each new slice is underthrust into the base of the slice pile. There seems to be no reason why thrusting could not have affected the basement, as seems to have happened in Timor (Hamilton, 1973) where thrust wedges of the Australian basement are now being eroded to provide detritus to the Timor Trench.

The postulated sequence of events is shown in figure 2. It may be objected that it is impossible to subduct continental crust under oceanic lithosphere because of the high density contrast, but it should be

Figure 2. Possible Evolution of West Newfoundland During Part of the Lower Paleozoic.


Early Arenig
Trench-Arc Gap
Flysch
W
E
Shelf sequence
Humber Arm
Accretion melange
MANTLE
Mafic intrusions
Oceanic crust
Late Arenig
Volcanics
?

remembered that the Grenville basement close to the old continental margin is extensively intruded by Lower Cambrian diabase (Williams and Stevens, 1969), up to 60% intrusions. There is evidence that this intrusive material converted to eclogite (Church, 1969) in the Fleur de Lys terrain. This would have increased its density.

If a model such as that outlined above is accepted, then gravity sliding need not be invoked as a means of emplacing and assembling the Humber Arm Allochthon. The model might have general application where sediments are stacked under ophiolites with the least-moved towards the base.

CHAPTER 3 - CONCLUSIONS

The present investigation has taken place during an unprecedented revolution in earth science. The full implications of this revolution for the geological evolution of west Newfoundland are still not completely resolved, but it seems fair to say that the broad outlines are now understood and are as presented in this thesis. It seems clear that the Lower Paleozoic evolution of west Newfoundland involved the construction and destruction of an ocean basin even though it is not yet clear what type of ocean basin it was. The Lower Paleozoic rocks of western Newfoundland formed at the margin of this ocean basin and include some rocks that formed the lithosphere of the ocean basin. Closure of the ocean basin started in the Lower Ordovocian, resultinqin destruction of the ancient continental margin and its westwards transport, perhaps as an inner trench slope thrust complex. The process was completed by Caradocian times when stability returned to west Newfoundland.

Major problems yet to be resolved include the relationship between west Newfoundland, the Burlington Peninsula and Notre Dame Bay during the Lower Paleozoic and the mechanism whereby the ancient continental margin was translated back onto the continent. Solution to these problems would have more than local importance.

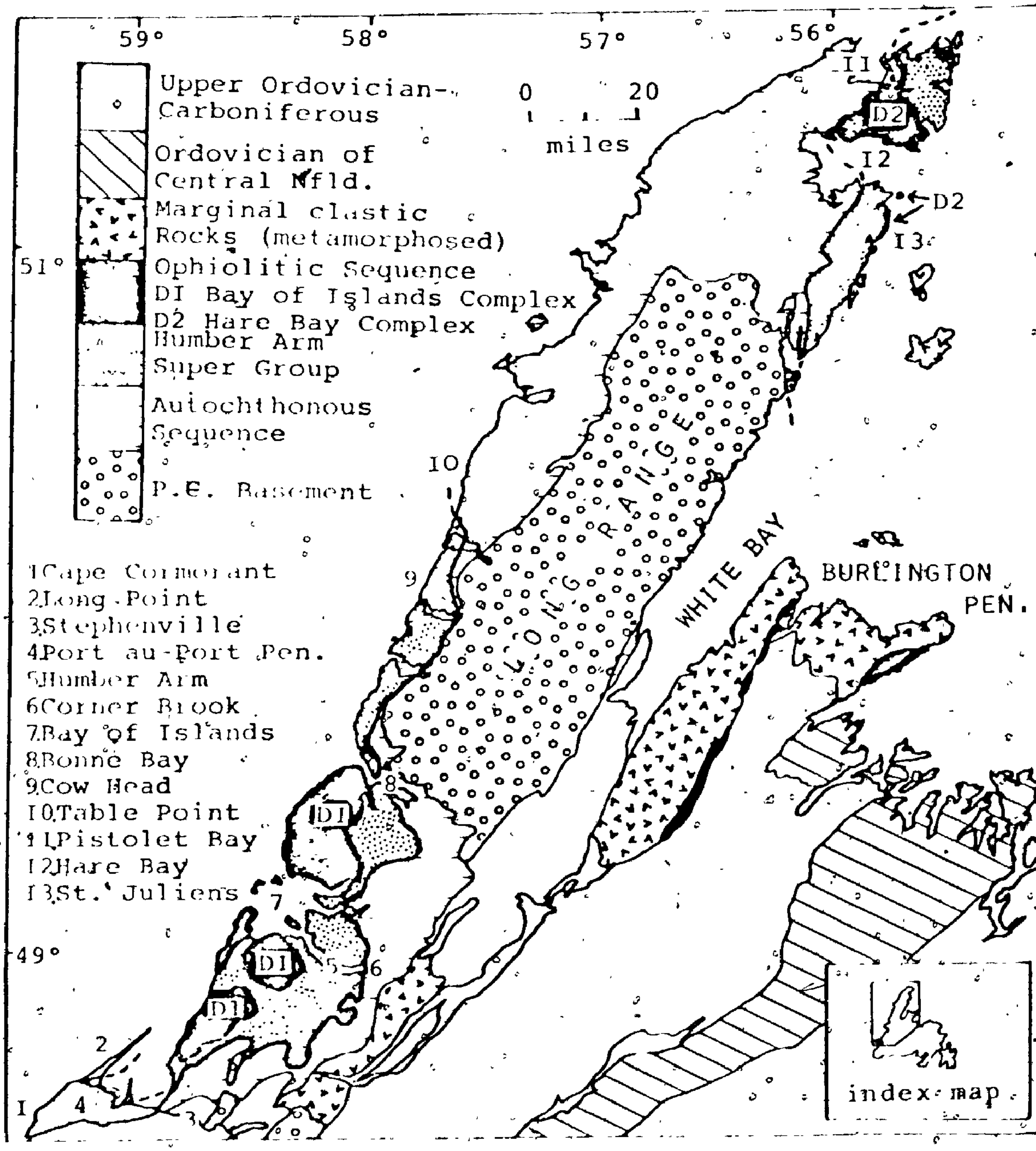


Fig. 3. Generalized geological map of west Newfoundland.

APPENDIX 1 - PALEONTOLOGICAL DATA AND ITS GEOLOGICAL SIGNIFICANCE

A. Introduction

Much of the geological interpretation given in the main body of this thesis and in Appendix 2 depends on paleontological data. This appendix is designed to be a record of the fossils collected by the writer and his assistants and, in some cases, in cooperation with other geologists during several field seasons in west Newfoundland. For each collection, a geographic description is given as well as the name of the determining paleontologist and a geological interpretation of the fossil data. Only samples that yield significant information are recorded. The collections are presently located at the Geological Survey of Canada in Ottawa unless otherwise stated. The writer is grateful to D. Skevington for data on graptolite correlation used in this appendix. The graptolite zones and correlations used by Skevington (1969) are used for the Tremadoc Series. For later Ordovician zones and correlations the scheme proposed by Williams et al (1972) is used.

B. Fossils from the Autochthon

B.1 Fossils from beneath the Humber Arm Allochthon

B.1.1 G.S.C.# 77768

Locality. 2 km. west of Three Rock Cove, Port-au-Port Peninsula

Identified by. B.D. Erdtmann

Stratigraphic Horizon. High in the Mainland sequence (Stevens, 1970).

Glyptograptus euglyphus Lapworth
Diplograptus cf. *D. multidens* var. *diminutus* Ruedemann
Glossograptus aff. *G. hincksii* Hopkinson
branch fragment of *Dicellograptus* sp.
Climacograptus cf. *C. innotatus* var.
Pseudoclimacograptus sp. (aff. *P. scharenbergi* Lapworth)

Age. D. multidens Zone (Caradocian)

Geological Significance. These fossils show that the Mainland is significantly younger than the Table Head and support the field evidence that it is not transported despite its great similarity to younger parts of the Humber Arm Supergroup. The Mainland sequence is an autochthonous flysch succession.

It is also interesting to note that these rocks are of the same age as the basal Long Point, confirming the suggestion that the allochthon was covered by the Long Point immediately after its emplacement (Stevens, 1970). The fossils are from just above the coarser part of the Mainland sequence and record the approximate time of arrival of the allochthon to the east.

B.1.2 G.S.C. #79182, 79183, 79186

Locality. Cape Cormorant, Port-au-Port Peninsula

Identified by. B.D. Erdtmann.

Stratigraphic Horizon. #79182, lowest black shale in the section; #79183, black shale interbedded with limestone breccia; #79186, highest black shale beneath the Mainland greywacke sequence.

#79182
Diplograptus cf. D. decoratus Harris and Thomas
Glossograptus hincksii var. fimbriatus (Hopkinson)
cf. Glytograptus sp.
cf. Diplograptus decoratus Harris and Thomas

#79183
Amplexograptus differtus Harris and Thomas
Phyllograptus angustifolius Hall
cf. Diplograptus decoratus Harris and Thomas

#79186
Diplograptus cf. D. decoratus Harris and Thomas
Phyllograptus cf. P. anna Hall
Glossograptus cf. G. hincksii (Hopkinson)

Glyptograptus cf. G. austrodentatus Harris and Keble
Diplograptus decoratus var. amplexograptoideus Ross and Berry
cf. Didymograptus euodus Lapworth

Age. These collections all seem to be transitional between the zones of D. murchisoni and G. teretiusculus

Geological Significance. The limestone breccias and shales of this section were once correlated with the Cow Head Breccia (Schuchert and Dunbar, 1934). These collections show that the Cape Cormorant rocks are younger, supporting the field data that show that they rest with disconformity on the Table Head. Furthermore the collections show that about 100 meters of rock were deposited very quickly. This is in contrast to the slow accumulation of the Cow Head Breccias (Stevens, 1970).

S.P.S. G.S.C. 9144

Locality: West Bay, Port au Port Peninsula. Shore about 1 km. west of Piccadilly Provincial Park

Identified by: R.B. Erdtmann

Stratigraphic horizon: Gold greywackes above the Table Head Formation.

Amplexograptus confertus (Lapworth)
cf. Leptograptus sp. or Didymograptus subtenuis (Hall)
Glossograptus cf. G. ciliatus Emmons
Glossograptus cf. G. hincksii (Hopkinson)

Age. This collection seems to range between the zones of D. murchisoni and G. teretiusculus.

Geological Significance. The collection was made from the top of the greywacke sequence close to the overriding lowest slice of the Humber Arm Allochthon. Its age seems to be about two graptolite zones older than collection ...08 which marks the arrival of the allochthon about 30 km. to the west. This either means that the allochthon was moving about two centimeters a year or that much sediment was removed during the passage of the allochthon over the West Bay locality. The later hypothesis is preferred since it is probable that turbidites derived from the allochthon could have flowed 20 km.

B.2 The Autochthon beneath the Hare Bay Allochthon

B.2.1 G.S.C. # 83364

Locality: 5 km. south of Goose Tickle Point

Identified by: R.D. Erdtmann

Stratigraphic horizon: Goose Tickle Formation

Janograptus terranovensis n. sp.
Dictyonema sp. indet.
Didymograptus cf. D. robustus Ekstrom
Glossograptus fimbriatus Hopkinson (Elles and Wood)
Cryptograptus schaeferi Lapworth
Amplexograptus cf. A. confertus (Lapworth)
Glyptograptus cf. G. intersitus Harris and Thomas
Climacograptus cf. C. angulatus subsp. micidus Berry

Age: Low in the D. murchisoni Zone (D. Skevington, pers. comm., 1976)

Geological Significance: This collection is from close to the top of the Goose Tickle type section and records the age of emplacement of the Humber Arm Allochthon. This is in accord with conodonts collected by the writer from the Middle Table Head beneath the Goose Tickle and identified by Fahraeus (1970). These now suggest to him that the Middle Table Head in eastern Hare Bay correlates with the D. Purundo Zone. This is about a zone older than the Table Head Type Section (Fahraeus, pers. comm., 1976).

It should be noted, however, that this collection dates only the emplacement of the Northwest Arm part of the allochthon which seems to be part of an olistostrome. It is possible that the higher slices were emplaced at a later date.

C. Fossils from the Allochthons

C.1 Fossils from the Humber Arm Allochthon

C.1.1 G.S.C. # 66026

Locality. McIvers, north shore of the Humber Arm

Identified by. W.H. Fritz

Stratigraphic Horizon. Irishtown Formation.

? Austinvillia sp.
Pagetides sp.

Age. Lower Cambrian, probably late Lower Cambrian.

Geological Significance. This collection comes from a limestone clast in a coarse turbidite from near the top of the Irishtown Formation. If it can be assumed that the clast was incorporated into the turbidite soon after the original deposition of the limestone, this collection dates most of the Irishtown and the underlying Summerside Formation as Lower Cambrian or older.

C.1.2 G.S.C. # 74853

Locality. Cooks Brook, south shore of the Humber Arm.

Identified by. W.H. Fritz

Stratigraphic Horizon. Cooks Brook Formation.

? Phoidagnostus sp.

Age. Probably late Middle Cambrian

Geological Significance. This collection is from a clast.

in a limestone breccia close to the base of the Cooks Brook Formation. It helps establish the Middle Cambrian of this part of the Cooks Brook.

C.F.3 G.S.C.# 82089, 82090, 82091.

Locality. Bound Head, north shore of Humber Arm.

Identified by. W.H. Fritz

Stratigraphic Horizon. Cooks Brook Formation.

Bathyuriscus sp.
Hypagnostus parvifrons (Linnarsson)
Utaspis sp.

Age. Late Middle Cambrian Bolaspidella zone.

Geological Significance. This collection, from clasts in a limestone breccia within the Cooks Brook Formation, establishes that the Cooks Brook is at least in part of Middle Cambrian age.

C.F.4 G.S.C.# none available

Locality. Black Head, Bay of Islands

Identified by. L.M. Cumming

Stratigraphic Horizon. Top of the Cooks Brook Formation

Dictyonema sp. cf. D. cyathiforme Bulman
Dictyonema sp. cf. D. rusticum Bulman
Dictyonema sp. cf. D. lapworthi Bulman

Age. Mid Tremadocian

Geological Significance. This collection dates the upper parts of the Cooks Brook Formation and seems coeval with the Green Point Formation.

C.F.5 Locality. Junction of Great Northern Peninsula road and Rocky Harbour road, Rocky Harbour

Identified by. D. Skevington

Stratigraphic Horizon. Top of the Middle Arm Point Formation.

?Clonograptus sp.
Goniograptus perflexilis Ruedemann
Tetragraptus bigsbyi (J. Hall)
T. pendens Elles
T. serra (Brongniart)
Phyllograptus ilicifolius J. Hall
P. ?anna J. Hall
Didymograptus extensus (J. Hall)
D. gracilis Tornquist
D. nitidus (J. Hall)
D. protobifidus Elles
D. cf. tornquisti Ruedemann or D. cf. perditus T.S. Hall
?D. ellesae Ruedemann
Isograptus victoriae lunatus Harris

Age. D. nitidus Zone

Geological Significance. This collection is from a slightly silicified green and black shale horizon associated with green bedded chert only 5 meters beneath its contact with the greywackes of the Blow me Down Brook Formation. It dates, approximately, the first influx of sediment from an eastern source.

Note. This collection will be sent to the Geological Survey at Ottawa.

C.1.6. Locality. Tea Cove, Port-au-Port Peninsula

Identified by. D. Skevington

Stratigraphic Horizon. Blow me Down Brook Formation

Isograptus victoriae maximus Harris

Age. I. gibberulus Zone

Geological Significance. This is the only known fossil locality in the Blow me Down Brook Formation. It confirms a mid Arenig age for at least part of the formation. Previously (Stevens, 1970) a late Arenig age had been preferred for this formation.

Note. This collection will be sent to the Geological Survey at Ottawa.

C.L.7 G.S.C.# 79170

Locality. West Bay, Port-au-Port Peninsula. Shore beneath store 1 km. west of Piccadilly Provincial Park.

Identified by. B.D. Erdtmann

Stratigraphic Horizon. A parautochthonous slice of Middle Table Head lithology.

Tetragraptus quadribrachiatus (Hall)
cf. Paraglossograptus etheridgei (Harris)
Pterograptus cf. P. incertus Harris and Thomas
branch fragment of Thamnograptus capillaris (Emmons)
Amplexograptus confertus (Lapworth)
Isograptus forcipiformis (Ruedemann) var. latus
Glossograptus hincksii (Hopkinson)
Lasiograptus cf. B. costatus (Lapworth)
Desmograptus sp. (fragment)
Dendrograptus sp.
cf. Hallograptus mucronatus (Hall)
Cryptograptus cf. C. antennarius (Hall)
Cryptograptus schaferi Lapworth
Cryptograptus tricornis (Carruthers)
Reteograptus cf. R. tentaculatus (Hall)
Diplograptus decoratus Harris and Thomas
Climacograptus riddellensis Harris
Amplexograptus differtus Harris and Thomas
Didymograptus sp. cf. D. euodus Lapworth
Glossograptus cf. G. fimbriatus (Hopkinson)
Cardiograptus crawfordi Harris
Dictyonema sp.

Age. This fauna possibly contains elements of three zones, high D. bifidus, D. Murchisoni and low G. teretiusculus. The collection was made over a thickness of about five meters. Each slab contains a homogeneous graptolite assemblage, that is to say, zone assemblages are not mixed on any one slab.

Geological Significance. This collection is from rocks lithologically similar to the Middle Table Head, though somewhat more silicified and associated with green chert not found in the Table Head. It is thrust over autochthonous Table Head and is a good example of relatively young rock forming the lowest slice of the allochthon. It is also evident that this collection is from a condensed succession since elements of three zones are present in only five meters of rock. This is in accord with the inference, made on geological grounds, of a bathyal lull in sedimentation prior to the onset of easterly derived flysch sedimentation (Stevens, 1970).

C.2 Fossils from the Hare Bay Allochthon

C.2.1 G.S.C.# 83365

Locality. Goose Tickle Point, Hare Bay

Identified by. B.D. Erdtmann

Stratigraphic Horizon. Northwest Arm Formation

Staurograptus dichotomus cf. var. apertus Ruedemann
Bryograptus cf. B. patens Matthew
Dictyonema sp. (sensu D. clarki Bulman, D. cyathiforme [Lapworth])

Age. Mid Tremadocian

Geological Significance. Shows, for the first time, the Tremadocian age of the Northwest Arm Formation.

C.2.2 G.S.C.# 69397 and 69393

Locality. South shore of Pistolet Bay, 2 km southwest of the mouth of the brook near the Loon Motel

Identified by. B.D. Erdtmann (69397) and L.M. Cumming (69393)

Stratigraphic Horizon. Basal melange of Hare Bay allochthon.

#69397 Glyptograptus sp. indet.

#69393 "many branched Anisograptids"

Age. #69397 Probably Lower Llanvirnian

#69393 Probably Tremadocian

Geological Significance. Collection #69397 is from a block surrounded by shale that yielded #69393. This is an interesting case where an apparent clast is younger than its matrix.

C.2.3 G.S.C.# none available

Locality. Cape Onion, Ship Cove Road

Identified by. B.D. Erdtmann

Stratigraphic Horizon. High in the Cape Onion volcanic sequence (Stevens, 1970).

Dictyonema flabelliforme cf. var. flabelliforme (Eichwald)
Dictyonema flabelliforme cf. var. anglicum Bulman
Dictyonema flabelliforme cf. var. parabola? Bulman
Staurograptus sp. (fragments of S. dichotomus? Emmons)
Anisograptus sp. (fragments of A. norvegicus? Bulman or of A. isolatus? Bulman)

Age. Mid Tremadocian

Geological Significance. Stevens (1970) suggested that the Cape Onion volcanic rocks were the detached top of the Hare Bay ophiolitic sequence. It seems, however, that the volcanic rocks are more akin to the Skinner Cove formation and not ophiolite.

Note. These fossils were collected with H. Williams. They were actually found by C. Wheaton, assistant to H. Williams.

C.2.4 G.S.C.# 69402

Locality. L'anse aux Meadows in cliff behind Viking Site

Identified by. L.M. Cumming

Stratigraphic Horizon. Maiden Point Formation

Zoophycos sp.

Geological Significance. This is the only record of life found, so far, in the Maiden Point and its equivalent, the Summerside Formation. Apparently, it has no bathymetric significance.

APPENDIX 2

PUBLICATIONS AND MANUSCRIPTS ARRANGED IN CHRONOLOGICAL ORDER

Reprinted from:

Maritime Sediments

Volume 1, Number 4, 1965

p. 13

The General Nature of the Humber Arm Group in the Humber Arm Area: West Newfoundland

by R. K. STEVENS

Department of Geology
Memorial University of Newfoundland

The Humber Arm Series is a Cambro-Ordovician succession of clastic and igneous rocks which underlie much of the western Newfoundland coastlands between Port au Port and Daniel's Harbour.

In the Humber Arm area these rocks fall into four broad units - a lower sandstone-shale unit, a carbonate shale unit, an upper sandstone and shale unit, and the youngest unit, an igneous complex.

The oldest rock is a succession of red and green argillaceous sandstones and shale overlain by dark shales with interbedded orthoquartzites, conglomerates and greywackes. Fluxoturbidite and slumped units are locally common. The general character of these rocks suggest a deltaic environment of deposition.

Lime breccias of the Cow Head type mark the base of carbonate-shale unit. The older carbonates are mainly platey, current-bedded limestones interbedded with black shale. The younger part of the unit is platey, sandy dolomite with interbedded green and black shale.

A thin sequence of flysch-like rocks marks the transition of the carbonate shale unit into a series of dark shales, greywackes, and massive arkosic sandstones. This appears to indicate a return to deltaic conditions of deposition.

Volcanic rocks at the base of the igneous complex are locally interbedded with arkosic sandstones.

The whole series seems to represent a facies intermediate between the eugeosynclinal Ordovician rocks of Central Newfoundland and the Cambro-Ordovician shelf deposits of west Newfoundland.

The present position of the Humber Arm Series on top of the shelf deposits of west Newfoundland is best explained by Rodger's and Neale's klippe hypothesis. However their supposition that the series is a deep water deposit does not seem to be valid according to the present study.

Reprinted from:

Geological Survey of Canada

Report of Activities

Part A: May to October, 1966

Paper 67-1, Part A

p. 186-188

113. GREAT NORTHERN PENINSULA (PARTS OF 2L, M, 12I, P)

R.K. Stevens

Geological study of the Great Northern Peninsula for publication at 1 inch to 4 miles occupied 6 weeks of the 1966 season. This represented a continuation of a 1965 study initiated by J.W. Gillis who has published a small scale map of the region[1]. The present study concentrated on the region between Hare Bay and Canada Bay, but also included a short visit to Belle Isle, which had not received previous geological investigation.

In the Hare Bay - Canada Bay region, four Palaeozoic stratigraphic sequences were recognized: a pre-Upper Ordovician platform sequence; a Middle Ordovician flysch sequence; a pre-Upper Ordovician geosynclinal sequence, and a Carboniferous molasse sequence.

The platform sequence consists of fossiliferous Lower Cambrian shales and oolitic limestones of the Forteau Formation[2], overlain by a succession of massive carbonates of Middle Cambrian to Middle Ordovician age. The sequence and facies of the platform rocks resemble the standard section along the west coast of Newfoundland[2] except that massive carbonate deposition may have started slightly earlier in the Canada Bay region.

Massive carbonate deposition ceased during Middle Ordovician (Wilderness) time and was followed by an influx of calcareous shale, greywacke, and conglomerate, interpreted as flysch derived from an advancing gravity slide mass. The contact between the slide mass and the flysch sequence is marked by zones of chaotic structure made up of blocks, derived from both the allochthone and autochthone, in a shaly matrix.

The gravity slide mass constitutes a [illegible] sequence of graywacke, slate, volcanic rocks, [illegible], and [illegible] which have been [illegible] as the Maiden Point sandstone [illegible] and the [illegible] formation. The stratigraphic [illegible] within the slide mass is not yet well understood.

A recent description has been published of the Carboniferous conglomerate, sandstone, and shale sequence.

All known structures in the [illegible] and decrease in intensity from east to west. The autochthonous rocks along the east side of the peninsula have undergone at least [illegible] and [illegible] phases of deformation. The [illegible] rocks show the effects of at least [illegible] and the [illegible] deformation. Major structures associated with the [illegible] events have not been recognized. Correlation of the [illegible] phases in the autochthonous and the allochthonous [illegible] not yet [illegible].

The [illegible] structure are [illegible] all phases [illegible] that affect the autochthonous rocks [illegible] that the region was not subjected to [illegible] folding [illegible] the emplacement of the slide mass.

[illegible] basement [illegible] and [illegible] associated with the [illegible] are [illegible] in [illegible] and shales [illegible] Carboniferous [illegible] formation [illegible] carbonates.

of probable Middle Cambrian age. A northeasterly trending cleavage cuts the basic intrusions and sediments. High angle faults with similar northeasterly trends are abundant.

[illegible], "Great Northern Peninsula," Newfoundland, in Report of Activities, May to Oct., 1965, Geol. Surv. Can., Paper 66-1, pp. 176-181 (1966).

Schuchert, C., and Dunbar, C. O., The stratigraphy of western Newfoundland, Geol. Soc. America Mem. 1 (1934).

Rodgers, J., and Neale, E. R. W., Possible "Taconic" klippen in western Newfoundland, Am. J. Sci., vol. 261, pp. 713-730 (1963).

Cooper, J. R., Geology and mineral deposits of the Hare Bay area, northern Newfoundland, Newfoundland Dept. Nat. Res., Geol. Sec., Bull. 9 (1937).

[illegible], The [illegible] of sudden facies changes in the [illegible] Bay area, northern Newfoundland, unpub. Ph.D. thesis, Univ. of [illegible].

Betz, F., Geology and mineral deposits of the Canada Bay area, northern Newfoundland, Newfoundland Geol. Surv., Bull. 16 (1939).

Baird, D. M., Carboniferous rocks of the Conche-Groais Islands area, Newfoundland, Can. J. Earth Sci., vol. 3, pp. 247-257 (1966).

Reprinted from

Geological Survey of Canada

Paper 6[illegible]-41

Canadian Upper Mantle Report 196[illegible]

(1) The Taconic Klippen of Western Newfoundland (R. K. Stevens, University of Western Ontario)

Two Taconic klippen, each approximately 100 miles long and 20 miles wide, consisting of Cambro-Ordovician sedimentary rocks and ophiolites, rest on a Cambro-Ordovician platform of miogeosynclinal sequence in western Newfoundland. The klippen are composed of a variety of sedimentary rocks, including coarse lime breccias, deltaic deposits and flysch, such that the assemblage cannot be classified as strictly miogeosynclinal or eugeosynclinal. The ophiolites represent a major pre-tectonic phase of basic igneous activity.

Although the allochthonous rocks are believed to have been transported westwards from central Newfoundland by gravity sliding (Rodgers and Neale, 1963), no satisfactory source area has been identified.

Zones of chaotic structure, resembling certain facies of Alpine wildflysch were generated during the Taconic sliding. There is evidence to suggest, however, that the wildflysch associated with the ophiolites was formed as a result of pre-Taconic sliding of the ophiolites prior to the final emplacement of the klippen. At least some of the ophiolites appear to have had a complex history of movement within the geosyncline.

Rodgers, J. and Neale, E. R. W.
1963. Possible Taconic klippen in western Newfoundland. Am. J. Sci., vol. 261, pp. 713-730.

Reprinted from

Field Trip Guide, Gander Conference,

Geology along the North Atlantic

August 1967,

Humber Arm Area and Stephenville - Port-au-Port Peninsula

63p.

[illegible]

FIELD TRIP [illegible] - Humber Arm Area, Corner Brook

Sunday, September [illegible] and Thursday, September [illegible], 197[illegible]. Low tides at 5.15 p.m. and 8.[illegible] a.m. respectively

Leader: Robert K. Stevens, University of Western Ontario, London

The Bay of Islands [illegible] of the autochthonous Cambro-Ordovician sequence that was [illegible], that is succeeded by an allochthon of [illegible] volcanic rocks [illegible] the ultrabasic [illegible] of the Bay of Islands [illegible]. [illegible] in the allochthonous sequence [illegible] quartzite, Irishtown shale with sandy interbedded [illegible]. The [illegible] Humber Arm [illegible] to the allochthon has [illegible] rocks including large boulders. Toward the mouth of the estuary, the Humber Arm contains [illegible] as well as sedimentary rocks.

The trip will be along the southern shore of the Humber Arm and Bay of Islands west of Corner Brook, including stops in the type area of the Humber Arm Group. Relevant literature is cited in Stockner, [illegible], "Stratigraphy and structure of west central Newfoundland", Geol. Assoc. Canada Guidebook 197[illegible], p. 137-155.

Mileage is only approximate.

(0.0) Tourist information booth at junction of Trans Canada Highway and West Valley Road, south of Corner Brook.

Stop 1 Go north along the highway to a road cut on the west, exposing deformed black shale with blocks or lenses of quartzite, and infrequently, limestone. The melange could represent the basal zone of the klippe exposed to the west. Autochthonous limestone outcrops in the hills to the east.

[illegible] West Valley [illegible] to the west [illegible] Street.

Stop 2 1.7 Bank of Montreal in Corner Brook. Walk northward to hill behind the bank. Quartzite, conglomerate and black slate of the Irishtown Formation. Conglomerate contains igneous, metamorphic and sedimentary clasts. The strata dip and young eastward and lie on the west limb of a large syncline whose core is exposed in the railroad yard below.

1.7 Turn south, left, on Lumber Road, continuing to west Corner Brook, turning west on Curling Road; take second road to the south, left, to top of Crow Hill.

Stop 3 3.5 Crow Hill. The [illegible] capped by greenish greywacke and slate of the [illegible] Formation, [illegible] normally underlie the Irishtown, but at this place, [illegible] thrust to the east during deformation that [illegible] dates the emplacement of the klippe. The thrust surface is shown on the [illegible] face of the hill. Several cleavages are developed including a [illegible] reticulate cleavage of possible primary origin. The north face shows [illegible] deformational features; the bluffs south of the car park show folds [illegible] (Down [illegible]).
Descend Crow Hill and rejoin Curling Road, drive west to service station above Giles Point.

Stop 4 [illegible] Giles Point. Take path to the shore.
[illegible] of the [illegible] Formation [illegible] of the Irishtown [illegible] several types of limestone breccia are [illegible] with interbedded shale [illegible] limestone [illegible] Middle Ordovician [illegible]
Return to road and drive westward to [illegible] Cove.

Stop 5 [illegible] Frenchman's Cove, preferably low tide. Walk eastward along the shore to exposures of [illegible] cliff and off shore(?) sections show a melange of [illegible] with blocks and chips of greywacke, shale, carbonate and volcanic [illegible] blocks of shale and carbonate beds [illegible]. The matrix is often not strongly deformed and contains [illegible] and unidentified cone shaped fossils. Three mechanisms have been [illegible]

1. The whole [illegible] flow or olistostrome
2. [illegible] that it represents a regolith on a land that was later over[illegible] thrust sheet.
3. It could represent [illegible] breccia, an ancient zone of high water pressure [illegible] part of the thrust sheet, a locus of movement during the emplacement of the allochthon. The melange, on this view, is a movement zone [illegible] upper part of the thrust sheet with its ultrabasic and basic intrusives [illegible] the lower part.
4. [illegible] has suggested [illegible]

Return to the main road and drive westward past arkose and greywacke of the Blow-me-down [illegible]

Stop [illegible] The Bay of Islands [illegible] possible for the hills south of the road and north across the bay [illegible] argentine with rosettes of aragonite. Drive westward [illegible] at foot of Blow-me-down Mountain, .4 mile beyond [illegible]

Stop 7 28. Sedimentary and [illegible] rocks of the upper Humber Arm Group. A zone of breccia [illegible]
[illegible] structure."
Drive westward [illegible] Little Port through poorly exposed basic volcanic rocks and [illegible] of the Bay of Islands Complex.
Stop [illegible] Little Port [illegible] and a variety of volcanic phenomena;
return to [illegible]

CAREER CONFERENCE [illegible]

FIELD TRIP GUIDE [illegible] Stephenville – Port au Port Peninsula

Monday, September 4 and Friday, September 8. Low tides – 6.00 p.m. and 8.35 a.m. respectively

Leader: Robert K. Stevens, University of Western Ontario, London.

The area [illegible] displays the excellent sections of Cambrian and Ordovician carbonate [illegible] and Table Head formations, succeeded by graptolite-bearing shale and limestone boulder conglomerate. This autochthonous sequence is structurally succeeded by an allochthonous [illegible] Ordovician rocks of the Humber Arm group, [illegible] by basic and ultrabasic rocks of the Bay of Islands Complex forming [illegible] mountains extending northward to Bonne Bay. The Long Point limestone on the extreme northern tip of [illegible] west of the Port au Port Peninsula has been thought to [illegible] overlie the allochthon. The Long Point seems of [illegible] late Caradocian.

The guide is prepared on the assumption that the trip is made when tide is [illegible] the [illegible] route requires several hours. This will not be possible at the time of the trip, so the middle part of the section will be omitted.

0.0 Stephenville Post Office corner [illegible] junction with Road 47 to the west.

1.5 [illegible] are exposed here, the ridge to the west, Table [illegible] Ordovician [illegible] limestone.

4.1 Bridge over [illegible], lower Carboniferous Windsorian gypsum exposed back to the [illegible]

5.9 [illegible] (6.3) [illegible] turn right to fork at 7.0, bear left, and left [illegible] in airbase property to [illegible]

[illegible]

[illegible] The [illegible] of the [illegible] Port au Port area, west of Stephenville [illegible]

[illegible] from the Port au Port [illegible] and Table Head [illegible] of the Humber Arm [illegible] and Table Head carbonates [illegible] phenomena associated with [illegible] The northern part of the [illegible] part of the section can be reached [illegible]

[illegible] from the [illegible] Newfoundland, Journ. [illegible] Stephenville map-area, [illegible] and Dunbar, C.O., [illegible] Mem. 1, 173 p. [illegible] Table Head formation, [illegible]

[illegible] the [illegible] cliffs [illegible] of the northeast-dipping [illegible]

[illegible] Formation, which [illegible] Table Head formation [illegible] shallow water deposits [illegible] 3 feet across [illegible] The beds are lower Ordovician

2. About two thirds of a mile northeast of The Travels, the St. George is conformably overlain by limestone of the Table Head Formation, the contact is a disconformity on the Port au Port Peninsula to the west. The lowest 72[illegible] feet of the Table Head is wavy bedded, mottled grey limestone of shallow water deposition. Trilobites are scattered throughout the limestone, the Arenigian-Llanvirnian boundary falls at or just below the base of the succeeding unit, the limestone forms the cliff northeastward to Black Cove.

3. Black Cove, about 1.5 miles northeast of The Travels and .3 mile south of the Tanks, Stop 1A. The lower part of the Table Head is faulted against 35 feet of Middle Table Head interbedded dark shale and limestones. North of the cove is [illegible] feet of Middle Table Head dark shales. Trilobites, brachiopods and graptolites are found in the limestones, and graptolites in the shales, the latter are regarded as lower Llanvirnian by some, as upper Llanvirnian by others. A zone of intraformational deformation occurs near the top of the dark shale unit.

4. The shales are overlain by a [illegible] graded calcarenite unit, separated by a thin shale from a mass of chaotic limestone breccia in the upper Table Head, which strikes nearly parallel with the shore for 1[illegible] feet, beyond the tanks. The breccia has one or two massive beds aggregating a thickness of about 1[illegible] feet. Most of the blocks were derived from Table Head limestone though some resemble the rocks of the St. George Formation, some blocks are themselves of breccia. There is a general tendency for the larger blocks to [illegible] the base, though large blocks of calcarenite occur near the top. [illegible] of greenish impure limestone occur [illegible] the tanks, and was soft when the breccia was laid. The matrix of the breccia is calcareous, but becomes argillaceous near the top. The shale bed just south of the tanks may lie between two breccia beds, or be local shale [illegible]. A large shaly mass in the cliff north of the tanks is probably a block.

As the breccia is thicker and coarser on the Port au Port Peninsula, it was probably derived from the [illegible]. The upper [illegible] of the breccia is conformably overlain by a few feet of green [illegible] shale and calcarenite having convolute and current bedding, graptolites near the top of the bed are like those at Black Cove.

5. North of the tanks, Stop 1A, a [illegible] of flysch, some [illegible] feet thick, overlies the carbonate breccia sequence. The contact is gradational, exposed [illegible] south of the wooden slipway about 2.5 miles northeast of The Travels. The flysch consists of greenish brown to black shale with scattered interbedded fine grained greywacke that show ripple drift current bedding and convolute bedding, [illegible] deposition from turbidity currents. Information from other areas suggests that the source lay to the east and was the advancing [illegible] [illegible] occur in the flysch, and often have [illegible] preferred orientation in the greywacke.

6. At the base of the first headland north of the slipway, [illegible] is overlain by a breccia zone, regarded as the base of the thrust sheet, [illegible] of chert and carbonate in a shaly [illegible] matrix. Allochthonous [illegible] rests on the breccia. For several hundred yards to the north, [illegible] of thrust slices and breccia zones [illegible] exposed. Some of the slices are [illegible] truly allochthonous [illegible] [illegible] fauna at other places), while [illegible] stripped off the basement [illegible] chert yield [illegible] regarded as a complex [illegible] The structural [illegible] it is correlated with [illegible]

7. From the [illegible] (about [illegible] northeast of The Travels), the all[illegible] include [illegible] breccia with [illegible] shales with interbedded [illegible] to

coarse-grained conglomerate containing material derived from plutonic, volcanic and sedimentary terranes. Several horizons show very large load casts. The sequence is correlated with rocks of the Humber Arm type section, believed to be of lower Ordovician age.

The structure of this part of the section is interpreted as a gently recumbent syncline that closes to the north. The overturned, gently-dipping lower limb is exposed in the cliffs just north of the fisherman's hut, it is tectonically thinned. The core is exposed in the west-facing cliffs north of the hut as well as in the cove to the north of the cliffs. Disharmonic folding and thrusting is associated with the axial zone of the fold. The normal, steeply-dipping limb of the fold is exposed between Black Point and the cove to the south. Facing criteria are abundant on the normal limb but uncommon on the inverted limb.

To reach return transportation, the party will retrace the route to the slipway about 2.5 miles northeast of the Gravels. A path through the woods meet the Port au Mal road about .5 mile north of the junction with the Radar Site road, which is just northeast of that to the Tanks. If the tides are unfavorable, cars will drive to the Tanks, Stop 1A, from which point it is practical to examine that part of the shore, subsequently, a trip can be made along the path to the slipway.

The cars will return [illegible]
6.7 Junction at [illegible] [illegible] distance ahead to right turn into Aguathuna Quarry [illegible] [illegible] dolomite, extending to 9.4.
Stop [illegible] The quarry [illegible] [illegible] Table Head Limestone on the St. George, and [illegible]
Return to [illegible] [illegible] along the coastal road.
10.3 Felix Cove, 13.[illegible] Campbell's Cove.
15.[illegible] [illegible] roadside.
16.2 Cliffs of [illegible] Abrahams Cove, leave coast [illegible]
[illegible] [illegible] Port au Port Bay.
Stop [illegible] Exposures [illegible] Humber Arm [illegible] Provincial Park [illegible] strongly folded [illegible] and greywacke [illegible] by wildflysch and parautochthonous cherts and [illegible] limestones.
26.1 Road to Air Force station on left, continue straight
28.8 [illegible] road junction, turn right [illegible] cliffs of Lower Devonian Clam Bank reddish shale along the shore on the left to sharp right turn at 33.5
34.4. Sharp turn left, the road follows [illegible] the west slope of a cuesta of Long Point Limestone to the settlement at Black Duck [illegible]
Stop [illegible] First readily accessible exposures of the Long Point Limestone, with abundant fossils conglomerate of [illegible], faces, cephalopods, brachiopods, gastropods, etc., of Trentonian age (probably Rocklandian through Shorehamian) (Kay). Return to Stephenville, or to omitted stops.

[illegible] Precambrian basic and ultrabasic rocks outcrop in a belt across the road east of Stephenville. From 0.5 on the log, turn right on road
47.- In about 6 miles, cross a railroad, and continue [illegible] The Precambrian Indian Head Complex is exposed in the next three miles.

Reprinted from:

Abstracts for the Gander Conference

August 24-30, 1967

Sponsored by Columbia University

New York, New York

(An exact reproduction of a slide used in this talk is included.)

THE THRUST SHEETS OF WESTERN NEWFOUNDLAND

Robert K. Stevens (University of Western Ontario, London, Ont.)

The Humber Arm Group underlies two seperate belts in western Newfoundland each about three thousand square miles in area. One belt is centered about the Bay of Islands, the other about Hare Bay to the north.

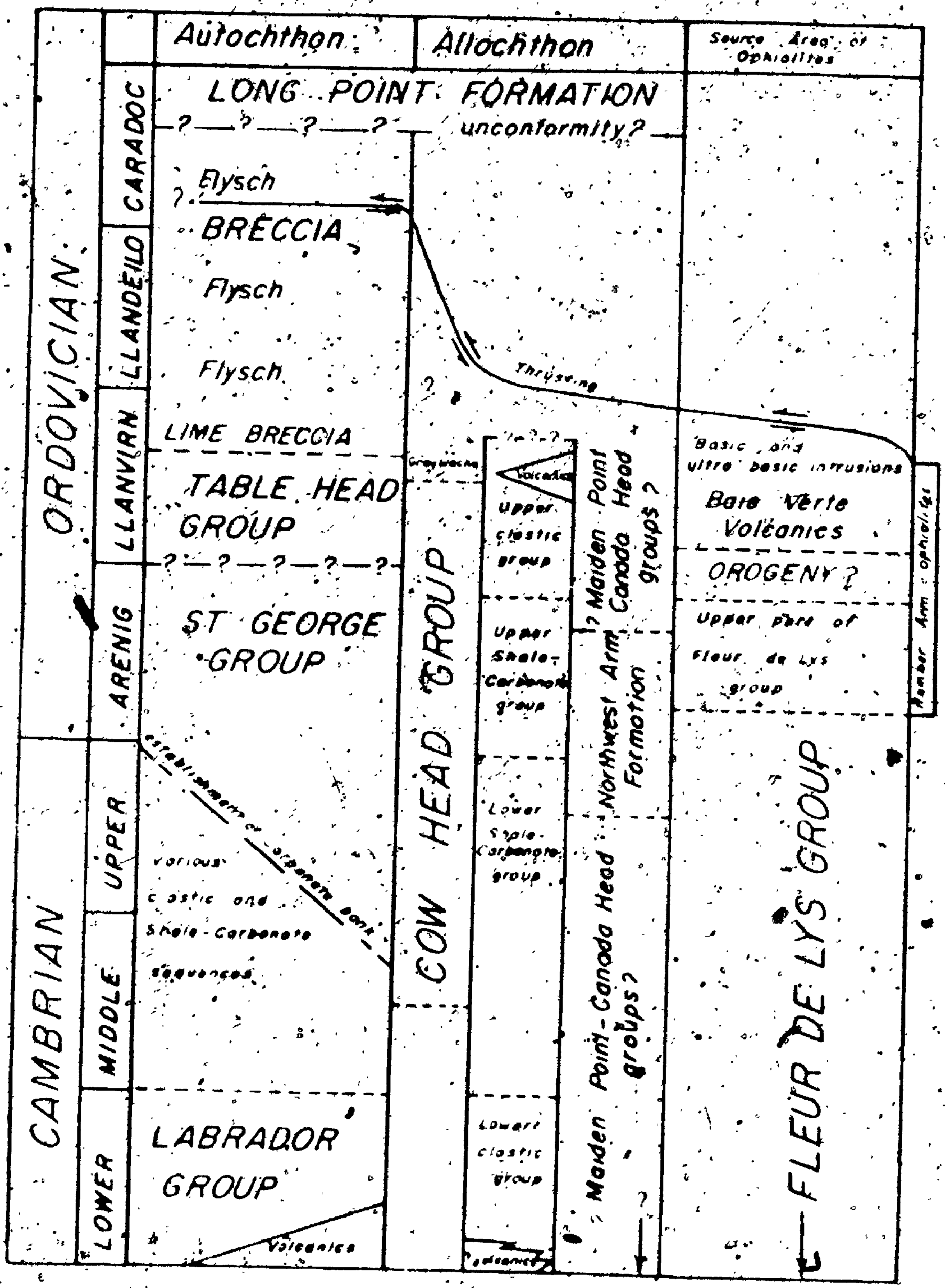
Four years ago Rodgers and Neale challenged the almost unaminous traditional view that the Humber Arm Group was an autochthonous Middle Ordovician and later sequence. They speculated that the two belts of Humber Arm rocks were klippen emplaced as Middle Ordovician ("Taconic") submarine gravity slides. Recent work has largely confirmed this concept.

The emplacement of the klippen is recorded by a sequence of flysch and wildflysch (melange) and the movement was clearly submarine.

Stratigraphic successions within the klippen are complex and several different facies are represented including very coarse conglomerates of various compositions and large ophiolitic complexes. Correlation between the two transported sequences is incomplete.

Deformation occurred before, during and after the emplacement of the thrust sheets. Some of the ophiolites have had a particularly complex history and they are regarded as the load responsible for much of the sliding.

The klippen were probably derived from the western part of the Newfoundland Early Paleozoic Mobile belt and form a potentially important record of its pre-"Taconic" evolution. There is some evidence for pre-Middle Ordovician orogeny in the same area.


Autochthon
Allochthon
Source Area of Ophiolites
ORDOVICIAN
CAMBRIAN
CARADOC
LLANDEILO
LLANVIRN
ARENIG
UPPER
MIDDLE
LOWER
LONG POINT FORMATION
unconformity?
Flysch
BRECCIA
Flysch
Flysch
Thrusting
LIME BRECCIA
TABLE HEAD GROUP
ST GEORGE GROUP
establishment of carbonate bank
various clastic and Shale-Carbonate sequences
LABRADOR GROUP
Volcanics
COW HEAD GROUP
Greywacke
Volcanics
Upper clastic group
Upper Shale-Carbonate group
Lower Shale-Carbonate group
Lower clastic group
Volcanics
Maiden Point Canada Head groups?
Northwest Arm Formation
Maiden Point-Canada Head groups?
Basic and ultra basic intrusions
Baie Verte Volcanics
OROGENY?
Upper part of Fleur de Lys group
FLEUR DE LYS GROUP
Advocate Complex ophiolites

2 OF/DE 4

Reprinted from:

Geological Survey of Canada

Report of Activities

Part A: May to October, 1967

Paper 68-1, Part A

p. 8-10

5. TACONIC KLIPPEN OF WESTERN NEWFOUNDLAND (2 L, M)

R.K. Stevens

A study of the two major Taconic Klippen[1] of western Newfoundland was undertaken during the 1967 field season. A geological map of the northern klippe (Hare Bay klippe) is being prepared for publication on a scale of 1 inch to 2 miles.

Rocks of the Hare Bay klippe[2,3,4] comprise three sequences:

(1) The Northwest Arm Formation[3,5] consisting of Tremadocian and Arenigian (?) black and green shales with some impure carbonate and arenite beds and blocks.

(2) The Canada Head[6] and Maiden Point[5] Groups consist of greywacke, shale and volcanic rocks. The age of these rocks is problematic; some resemble Cambrian rocks elsewhere in Newfoundland whereas others appear to be Arenig or later in age.

(3) The Goose Cove schists[5] and related rocks which are interpreted as an ophiolitic complex of Llanvirnian and earlier age.

The Northwest Arm Formation occurs as a melange between the autochthon and the allochthonous Canada Head and Maiden Point Groups. The ophiolites form the highest structural slice and consist of a basal greenschist unit showing polyphase deformation and low grade metamorphism, overprinted by thermal metamorphism bordering ultrabasic intrusions. The roof of the intrusions consists of an assemblage of pillow lavas, black shale and chert with a structural and metamorphic history less complex than that of the greenschists.

Several different sedimentary sequences are recognized in the southern klippe[7,8] (the Humber Arm klippe), which may be described in terms of the type section along Humber Arm[7]. New fossil discoveries have, for the most part, confirmed previous age assignments [7,8].

An upper clastic unit, represented at Humber Arm and at Port-au-Port Peninsula, is best interpreted as a fan which spread from the east across the various sequences of the Humber Arm klippe before emplacement during Arenig and Llanvirn times.

Relationships at the base of the Humber Arm klippe form a consistent pattern. The autochthonous carbonate sequence gives way to an internally derived flysch sequence of Llanvirnian to Caradocian age (an external facies of the clastic fan described above). Lime breccias intercalated near the base of the flysch, mark a westwards migration of the carbonate shelf edge but should be distinguished from the older Cow Head breccias of similar facies. The upper part of the flysch, where preserved, contains sedimentary breccia derived from the klippe. The top of the flysch, however, is usually incorporated into the basal melange of the klippe developed by the mingling of soft autochthonous and allochthonous rocks under high water-pressure in the movement zones.

Phacoidal cleavage is extensively developed in the melange zones of both klippen and its relationship to the regional cleavage suggests that the melange was dewatered during or immediately after its formation. The melange zones can be distinguished from mudflows which are not dewatered until the development of the regional cleavage.

Folds within the melange zones and in rocks immediately adjacent to them, are commonly recumbent and isoclinal. The fold axes generally lie at right angles to the inferred direction of movement of the klippen and parallel the long axes of 'blocks' in the melange and the lens-shaped segments resulting from the phacoidal cleavage.

Final emplacement of the klippen is dated by newly discovered fossil localities as early Caradocian.

An almost unbroken transition between the autochthon and negautochthon exists along the western shore of Port-au-Port Peninsula and this marks the original western edge of the Humber Arm klippe.

A preliminary survey of Lower Cambrian shales in northern Newfoundland was conducted at the suggestion of A.G. Darnley of the Geological Survey using a scintillation gamma ratemeter. The purpose was to determine whether some shales are rich in potassium similar to some Lower Cambrian shale of the Fucoid Beds of northwest Scotland. One sample from the Forteau Formation[9], found to be anomalously radioactive, assayed 7% K_2O by gamma-ray spectrometer. Potassium feldspar was detected by X-ray diffractometer.

---

[1]Rodgers, J. and Neale, E.R.W.: Possible "Taconic" Klippen in western Newfoundland; Am. J. Sci., vol. 261, pp. 713-730 (1963).

[2]Gillis, J.W.: Great Northern Peninsula, Newfoundland; in Report of Activities, May to October, 1965; Geol. Surv. Can., Paper 66-1, pp. 179-181 (1966).

[3]Tuke, M.F.: The significance of sudden facies changes in the Pistolet Bay area, northern Newfoundland; unpubl. Ph.d. thesis, Univ. of Ottawa (1966).

[4]Stevens, R.K.: Great Northern Peninsula; in Report of Activities, May to October, 1965; Geol. Surv. Can., Paper 67-1, Part A, pp. 186-188.

[5]Cooper, J.R., Geology and mineral deposits of the Hare Bay area, northern Newfoundland; Nfld. Dept. Nat. Res., Geol. Soc.; Bull. 9 (1937).

[6]Betz, F.: Geology and mineral deposits of the Canada Bay area, northern Newfoundland; Newfoundland Geol. Surv.; Bull. 16 (1939).

[7]Stevens, R.K.: The geology of the Humber Arm area, western Newfoundland; unpubl. M.Sc. thesis, Memorial Univ. Nfld.

[8]Bruckner, W.D.: Stratigraphy and structure of west-central Newfoundland; in Guidebook, Geology of parts of Atlantic Provinces; Geol. Assoc. Can. and Mineral. Assoc. Can., pp. 137-155 (1966).

[9]Schuchert, C. and Dunbar, O.: The stratigraphy of western Newfoundland; Geol. Soc. Am., Mem. 1 (1934).

Reprinted from:

Program of the 1968 Annual Meetings

of the Geological Society of America,

Mexico City, Mexico

p. 53-54

(with W.R. Church)

The "Taconic" (Caradoc) klippen of western Newfoundland are composite thrust sheets. Thick ophiolite units structurally overlie allochthonous Cambro-Ordovician clastic sediments which include Arenig flysch with fragments of serpentine and grains of chromite. The foreland or miogeosyncline on which the klippen lie is bounded to the east by the Cabot fault zone which marks the transition from crust of Canadian Shield type to that of Appalachian type. East of the fault occurs a vertical belt of rock, composed of a thick apparently unrepeated succession of high-grade metamorphic rock separated by a screen of ultramafic rock from an easterly younging ophiolitic sequence. Sediments associated with the ophiolites contain clasts of volcanic rock, grains of chromite, and material from the nearby Burlington granodiorite. The allochthonous ophiolites of Western Newfoundland may have been derived from a similar although perhaps slightly older sequence. However, no source exists for the lower units of allochthonous sedimentary rock, which represent a facies at least 30 miles wide intermediate between that of the eugeosyncline and the miogeosyncline. The segment of crust on which the allochthonous sediments were laid down seems to have been lost along the line of the Cabot fault zone; perhaps as a result of downward movements (Verschluckung) in association with thrusting and rotation during the Acadian orogeny.

Reprinted from:

Canadian Journal of Earth Science,

Volume 6, Number 5, 1969,

p. 1145-1157

(with H. Williams)

Geology of Belle Isle—northern extremity of the deformed Appalachian miogeosynclinal belt

HAROLD WILLIAMS
Department of Geology, Memorial University, St. John's, Newfoundland

AND

R. K. STEVENS
Department of Geology, University of Western Ontario, London, Ontario

Received April 10, 1969
Accepted for publication June 13, 1969

Belle Isle, situated between northern Newfoundland and the southeast coast of Labrador, consists of an uplifted block of Precambrian plutonic rocks intruded by northeast-trending diabase dikes and uncomformably overlain by Lower Cambrian and earlier (?) sedimentary and volcanic rocks. The Precambrian rocks lie along strike and are similar to Grenville gneisses of the Long Range Complex of western Newfoundland. In the southwest part of Belle Isle, the cover rocks are gently dipping basaltic flows and agglomerates that are succeeded conformably by arkosic sandstones and fossiliferous upper Lower Cambrian shales. In the northeast, the basement rocks are overlain by steeply dipping boulder conglomerates and arkosic sandstones, followed conformably by white quartzites.

Diabase dikes are inseparable from overlying flows, but do not penetrate higher sedimentary strata of the southwestern Lower Cambrian succession. Toward the northeast, plutonic boulder conglomerates and quartzites are cut by the dikes.

The distribution of supracrustal rocks around the periphery of the island, combined with local steeply inclined surfaces of unconformity between basement and cover rocks, indicate a major anticlinal structure produced by Paleozoic deformation. The study also shows that at Belle Isle the established Lower Cambrian succession of southeast Labrador and western Newfoundland is locally underlain by basalts and conglomerates and quartzites that thicken southeastward and northeastward.

Introduction

Belle Isle is situated 18 miles (28.8 km) north of the northern tip of the Island of Newfoundland and about the same distance from the southern coast of Labrador, where it forms the northern extremity of the exposed part of the deformed Appalachian miogeosynclinal belt (Fig. 1). The island trends northeast, parallel to Paleozoic structures, and is 10½ miles (16.9 km) long by 3½ miles (5.6 km) wide. Its surface is a rolling, hummocky terrain that is virtually devoid of vegetation, and maximum elevations reach 800 ft (244 m). The shoreline is almost everywhere steeply cliffed, with the edge of the surface generally from 250 to 500 ft (76 to 152 m) above sea level. A general view of the barren upland surface of the island is illustrated in Fig. 3.

The island consists of a Precambrian crystalline core, cut by a northeast-trending swarm of diabase dikes and locally bordered by a discontinuous envelope of deformed early Paleozoic rocks. It is of particular geologic interest as its deformed Paleozoic rocks are a mere 20 miles (32 km) east of the stable Canadian Shield of Labrador and its established Cambrian stratigraphic section is underlain by several hundred feet of mafic volcanic rocks, rather atypical of the miogeosynclinal succession found along the western side of the Appalachian System to the south.

Although visited many years ago by Selwyn (1890), the geology of the island has only recently been known through a brief visit by Stevens in 1966 and a coastal survey by Williams in 1968. Selwyn recorded the presence of crystalline rocks, and at the southwest end of the island, recognized unmetamorphosed overlying strata, which he assigned to the Huronian. Recent interest stemmed from the work of Gillis (1966), Tuke (1968), and Stevens (1967; 1968) in nearby northern Newfoundland, all of whom were concerned with problems of transported Paleozoic sequences in that area. The nature of the rocks of Belle Isle, whether in place or transported, relates to these problems and occasioned Stevens' visit in 1966. He found that Cambrian sedimentary strata were present and that they conformably overlie mafic volcanic rocks which, in turn, are fed by diabase dikes that are ubiquitous throughout the crystalline Precambrian terrane. Williams' interest initially concerned the occurrence of mafic volcanic rocks below dated Cambrian strata. Similar, but undated, volcanic rocks occur in widely separated areas of northern Newfoundland and southeast Labrador (Clifford 1965) where they are presently being investigated (Williams, manuscript in preparation). The relationships reported by Stevens (1967) were confirmed by Williams' coastal survey in 1968, which also showed that toward the northeast part of the island, plutonic boulder conglomerates directly overlie a steeply east-tilted surface of Precambrian basement rocks. The conglomerates, along with thick overlying quartzites, are cut by diabase dikes.

Geologic Setting

Belle Isle (Fig. 1) is included in the Appalachian System, as its crystalline basement rocks are overlain by Lower Cambrian strata that have been affected by Paleozoic deformation. Lower Cambrian rocks are common along the deformed west flank of the Appalachian System, but are generally absent upon the undeformed interior platform to the west. With respect to western insular Newfoundland, Belle Isle occupies a position comparable to the Grenville inliers of the Long Range and Indian Head Range Complexes (Williams 1967, Fig. 1). Similar Precambrian inliers occur all the way along the western flank of the Appalachian System, where they include such well known physiographic features as the Green Mountains and Berkshire Highlands of Vermont and Massachusetts and the Blue Ridge Mountains of Virginia. Volcanic rocks that occur at the base of the Lower Cambrian section at Belle Isle are uncommon among the dominantly miogeosynclinal rocks in this western part of the system, but a somewhat analogous situation is present in the Blue Ridge Province of the Southern Appalachians, of Virginia. There, mafic dikes cut crystalline basement rocks and feed overlying flows of the Catoctin Formation, in turn conformably overlain by Lower Cambrian Chilhowee quartzites (Reed 1955).

Folding and faulting that affected the cover rocks at Belle Isle also involved the Precambrian basement. Steeply dipping surfaces of unconformity between the basement and cover rocks are evident along the northeast coastline of the island, and toward the south the basement has been affected by high-angle faults and involved in local thrust faulting. The intensity of deformation in the cover rocks appears to increase northeastward across the island. Cleavage, where evident, dips steeply east, indicating that folds face toward the west. Locally the cover rocks are overturned toward the west, and they are cut by westward directed thrusts or high-angle reverse faults. This pattern of deformation, indicating a westward directed force acting toward the platformal or foreland area, is characteristic of the entire Appalachian miogeosynclinal belt.

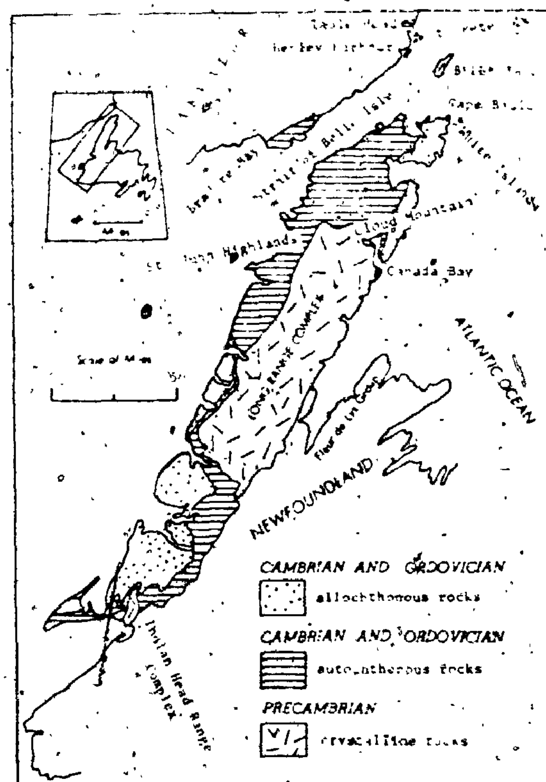


FIG. 1. Map showing position of Belle Isle relative to the Island of Newfoundland and Labrador and its position with respect to the Precambrian Long Range and Indian Head Range Complexes.

General Geology

General Features

The stratigraphic successions represented at Belle Isle are everywhere clear as the contact relationships are well exposed in coastal areas. Lithic units above the basement gneisses in the southwest are basal volcanic rocks, arkosic sandstones, and Lower Cambrian fossiliferous shales, respectively. Locally at White Point (Fig. 2), limestones and white sandstones of varied lithology and unknown age are in fault contact with fossiliferous limy shales that are at the top of nearby successions. All of these rocks are assigned to the Cambrian System, but lower units of the succession, e.g., basal volcanic rocks, could conceivably be of late Precambrian age, though there is nothing to suggest a major hiatus or disconformity within the sequence. The arkosic sandstones and fossiliferous limy shales that overlie the volcanic rocks can be directly correlated with the Bradore and Forteau Formations (Schuchert and Dunbar 1934), respectively, in nearby southeast Labrador and western Newfoundland. New formational names are proposed in this paper for the volcanic rocks (Lighthouse Cove Formation) and for the fault-bounded limestones at White Point (White Point Formation).

The stratigraphic succession above the basement rocks in the northeast is basal boulder conglomerates and arkosic sandstones, overlain by thick white quartzites. All are assigned to the Bateau Formation, which may be either Early Cambrian or Late Precambrian in age.

The diabase dikes, which cut the gneisses, merge with and are inseparable from the flows of the Lighthouse Cove Formation at the base of the Cambrian sequence in the southwest. However, nowhere do they cut the overlying sandstones and fossiliferous shales of the Bradore and Forteau Formations. Toward the northeast the sedimentary rocks of the Bateau Formation are cut by the dikes.

The contrasts between the sequences at opposite ends of the island are rather marked, particularly as they are separated by only 10 miles (16 km). Neither is there any reason to suspect that the two sequences have been brought into their present positions by major crustal movements. A clue to the stratigraphic relationships and correlation between the two sequences is furnished by the local section at Greenham Bight, located in the middle of the island and having characteristics typical of both the northeastern and southwestern sections. The section at Greenham Bight is for the most part similar to sections in the northeast, with basal boulder conglomerate directly overlying the basement gneisses and in turn overlain by several hundred feet of siltstone, shale and quartzose sandstone. The top of the section, however, has several tens of feet of green mafic volcanic rocks, and the underlying sedimentary rocks are cut by diabase dikes that are elsewhere inseparable from basalts of the Lighthouse Cove Formation. Volcanic rocks are absent in much thicker sections farther northeast, but like the Greenham Bight section, the thick sedimentary sections are cut by diabase dikes. Assuming that the diabase dike intrusion and mafic volcanism represent a single event that occurred contemporaneously throughout the island, then the sedimentary rocks of the northeast sections can be interpreted to represent a northeast- and eastward-thickening prism, deposited before diabase dike intrusion and volcanism. According to this interpretation the supracrustal rocks in the northeast are older than those in the southwest. A possible correlation for the rock units is summarized in Table I.

The unconformity at the base of the Bateau Formation on the east side of the island dips moderately to steeply east and the strata all along this side of the island, including the volcanic rocks near the southwest end at Barbers Cove, are east facing and east dipping. Around the southern end of the island the unconformity beneath the Lighthouse Cove Formation is inclined toward the southwest and attitudes between Blandfords Cove and Scotswood Cove trace an arcuate pattern convex towards the southwest. The attitudes of beds among the faulted rocks along the southwest side of the island between Blandfords Cove and White Point are more irregular, but farther north at Lark Harbour the Lighthouse Cove volcanics are followed westward by the Forteau Formation, indicating a westward-facing sequence on this western side of the island. This distribution of Cambrian rocks around the periphery of the island, combined with the attitudes of the beds and the attitudes of the basal unconformities where exposed, all suggest that the island forms a large domical or anticlinal structure with relatively steep flanks and a gentle southwesterly plunge. This overall pattern is modified, particularly to the southwest, by later faults. Northeast-trending

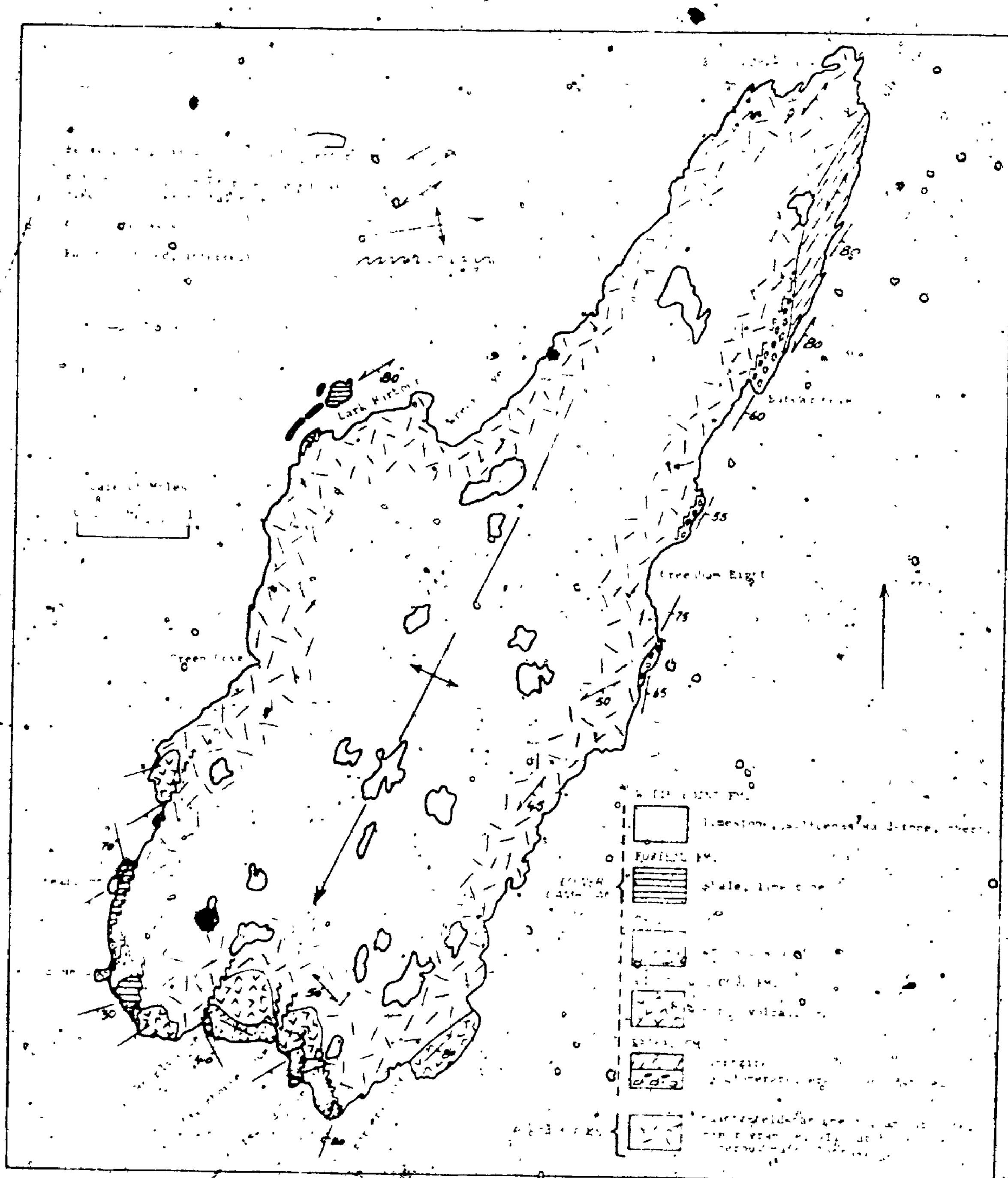
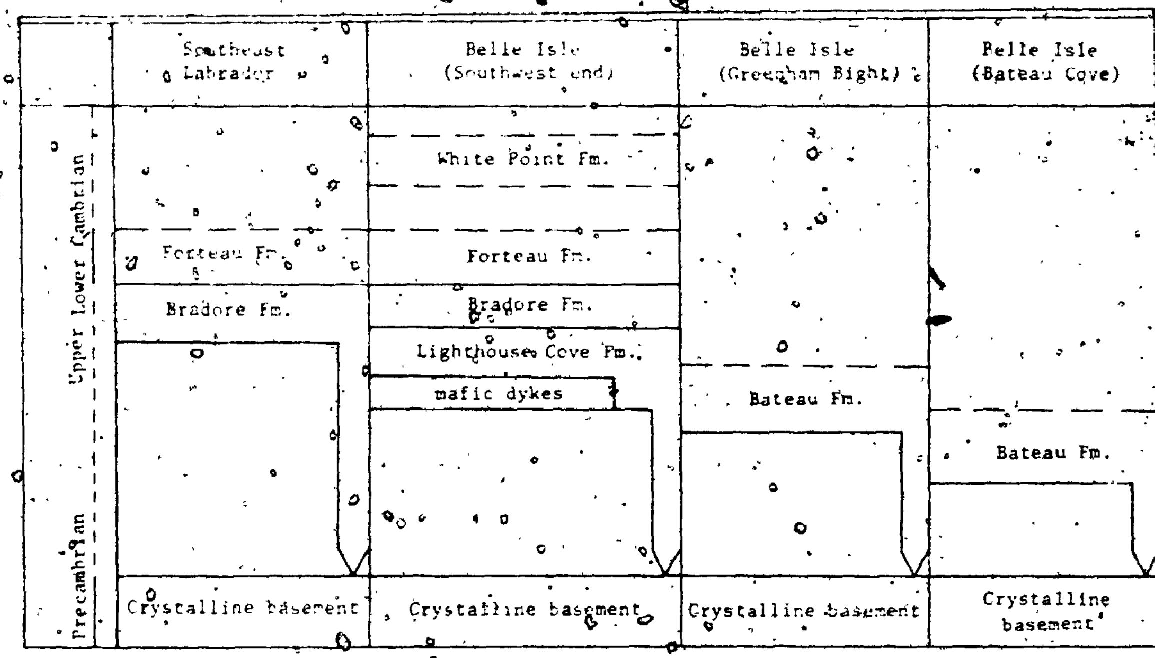


FIG. 2. Geologic map of coastal areas of Belle Isle.

high-angle faults are evident at Scotwood Cove, Lighthouse Cove, Blandfords Cove, and westward to Round Head and White Point. The Lighthouse Cove–Bradore contact is offset by the faults at Lighthouse Cove and Scotswood Cove and the sense of displacement suggests that the faults have a right-lateral strike-slip component. Other faults in this area are probably normal faults or west-directed high-angle reverse faults.

TABLE I

Possible correlation of rock units in southeast Labrador and Belle Isle



The basement rocks at Belle Isle are complexly folded quartzo-feldspathic gneisses that are gray to pink, with local intercalations of dark green amphibolite. These rocks are cut by small granitic dikes and pegmatites that are also Precambrian. The gray and pink crystalline rocks are sharply contrasted with dark diabase intrusions that have the form of dikes where observed on the upland surface of the island. The dikes trend N 30° E, parallel to the long dimension of the island, and dip steeply (about 80 degrees) to either the southeast or northwest. They are chiefly from 50 to 300 ft (15 to 91 m) wide, though locally some are narrower than this, and alternate with similar widths of intervening basement gneisses. In places at tide level, the mafic intrusions form a ramifying irregular network among which only small screens of basement gneisses remain. The diabase intrusions constitute about 50% of all exposed bedrock, but they have not been separated from the basement gneisses on Fig. 2. Alternating dikes and intervening gneisses are evident in Fig. 3, and complexly folded gneisses cut by a mafic dike are illustrated in Fig. 4.

Description of Formations

Bateau Formation

Plutonic boulder conglomerates, quartzites, arkosic sandstones, siltstones, slates, and minor volcanic rocks comprise the layered sequence that directly overlies basement gneisses along the northern east shore of Belle Isle. These rocks are referred to the Bateau Formation with its type section at Bateau Cove (Fig. 2). The succession ranges from approximately 250 ft (≈ 76 m) thick at Greenham Bight in the south to an estimated maximum of 800 ft (244 m) near the type area. Plutonic boulder conglomerates at the base thicken northeastward. A steeply east-dipping surface of unconformity is exposed south of Greenham Bight and in the cliffs at Bateau Cove. Elsewhere the contact is modified by faults parallel to the boundary, or else the crystalline rocks are separated from the overlying beds by diabase dike intrusions. A penetrative cleavage is evident in the less competent beds of the formation that dips steeply eastward at higher angles than bedding. Diabase dikes cutting the sedimentary rocks are also sheared indicating that they too have been involved in the deformation.

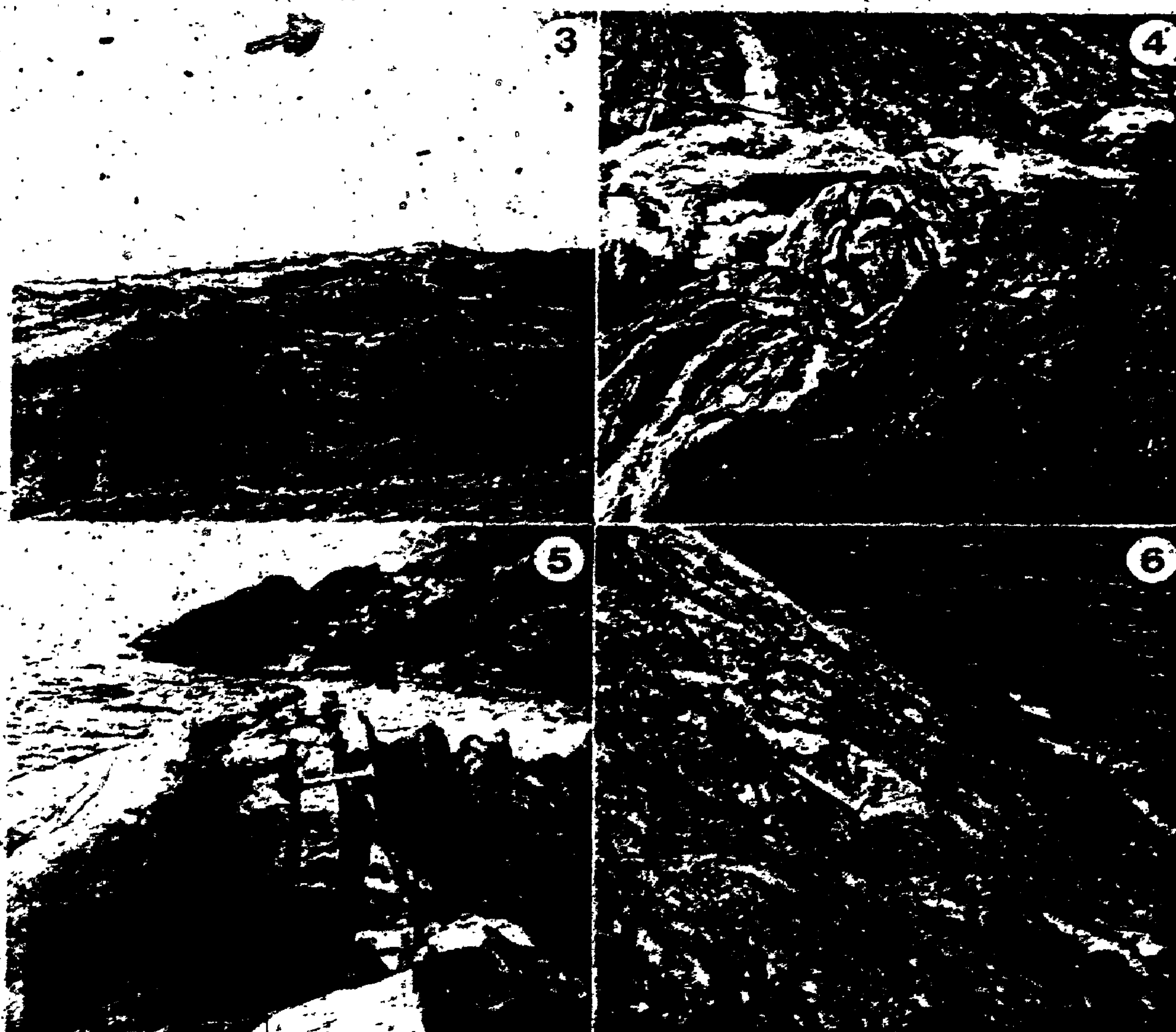


FIG. 3. Upland surface of Belle Isle showing northeast-trending diabase dikes (dark, ridges) that alternate with bands of quartzofeldspathic basement gneisses (light, depressions).

FIG. 4. Intricately folded gneisses cut by a diabase dike, Belle Isle. (Geol. Surv. Can. Photo 145477).

FIG. 5. Sheared diabase dikes cutting quartzites of the Bateau Formation, near Bateau Cove, Belle Isle. (Geol. Surv. Can. Photo 145490.)

FIG. 6. Plutonic boulder conglomerate at base of Bateau Formation, Greenham Bight, Belle Isle. (Geol. Surv. Can. Photo 145481.)

At the type section, the Bateau Formation consists of approximately 300 ft (91 m) of pale, purplish conglomerate with interlayered sandstones overlain by about 500 ft (~ 152 m) of white quartzite. The conglomerates have well rounded fragments from a few inches to more than 2 ft (.6 m) in diameter, consisting of a variety of granitic gneisses, granite, chert, and quartzite. Interlayered sandstones are purplish, arkosic, and crossbedded, ranging from 1 ft (.3 m) to several feet thick. Along the north shore Bateau Cove the beds dip steeply east and are parted by nearly vertical, sheared, diabase dikes from 20 to about 100 ft (6 – 30 m) thick. One half mile (.8 km) north of Bateau Cove the purplish conglomerates are conformably overlain by hard, white quartzites that are similarly cut by diabase dike intrusions (Fig. 5), measuring 10 to 30 ft (3–9 m) thick. These quartzites are evenly bedded and locally display grading in beds about 1 to 2 ft (~ .3–.6 m) thick. The rocks are composed mainly of quartz except for the coarser basal parts of some beds that contain granite, chert, and feldspar fragments. The contact between the Bateau conglomerates and basement gneisses is faulted along most of its length, and toward the north near Eagle Cove, quartzites and basement rocks are separated by diabase dikes without intervening conglomerates.

At the southern exposed limit of the Bateau Formation south of Greenham Bight the sequence of units is more variable, although the exposed section is not more than 250 ft (76 m) thick. There the basal boulder conglomerate is very coarse, but only 10 ft (3 m) thick (Fig. 6), and is followed in ascending order by 30 ft (9 m) of dark gray slate, pyritic siltstone, and quartzose sandstone; 100 ft (31 m) of gray siltstone and slate with cleavage parallel to bedding and locally displaying kink bands; and 50 ft (15 m) of siltstone and slate with thin sandy beds. The latter is overlain by a 5-ft (1½ m) green conglomerate bed that is sheared, and is composed mainly of discoidal quartz fragments from 1 inch to 8 inches (2½–20 cm) in diameter and local sandstone and siltstone fragments up to 2 ft (.6 m) long. This conglomerate is overlain by about 50 ft (~ 15 m) of sheared, epidote-rich, green volcanic rocks, which appear to have fragmental textures locally. The sequence of beds changes along strike, and at the northern Greenham Bight exposures it includes 50 ft (15 m) of slaty quartzite containing 1- to 4-ft (.3 to 1.2 m) beds of crossbedded quartzite. Similar to the type section, the sequence of units at Greenham Bight is parted by at least two diabase dikes, each approximately 50 ft (15 m) thick.

The lithologies represented in the Bateau Formation are in some respects similar to the Bradore Formation, except for the thick quartzites of the type area which are not represented either within or above the Bradore Formation. The age of the Bateau Formation is unknown, but it is cut by dikes similar to those that fed flows of the Lighthouse Cove Formation to the south. This suggests that the Bateau Formation is older and is either of Early Cambrian or late Precambrian age. Tuke (1968) has noted the occurrence of about 2300 ft (~ 700 m) of white quartzites exposed on the White Islands southeast of Cape Bauld (Fig. 1). These probably represent a southward continuation of the Bateau Formation.

Lighthouse Cove Formation

The name Lighthouse Cove Formation is proposed for the volcanic rocks that overlie basement gneisses and underlie arkosic sandstones of the Bradore Formation. The type locality is Lighthouse Cove, where the volcanics are approximately 300 ft (~ 90 m) thick and both upper and lower contacts are well exposed. Similar volcanic rocks occur as far north as Lark Harbour where they are faulted against gneisses to the east, and the rocks occur as far eastward as Barbers Cove. One mile (1.5 km) north of White Point, about 400 ft (~ 120 m) of basaltic flows dip gently southward and are in sharp planar contact with pink and gray basement gneisses (Fig. 7). Probably 1000 ft (310 m) of steeply-dipping flows and agglomerates are exposed at Barbers Cove. There the basement gneisses are cut by numerous diabase dikes, which meet and join upward and merge with overlying dark basalt flows.

Volcanic rocks of the Lighthouse Cove Formation are black to dark green and purple to reddish brown basalts and pyroclastic rocks. Dark green flows are most abundant and are present in all of the outcrop areas. These rocks are fine to medium grained and locally amygdaloidal with calcite, quartz, chlorite, and epidote amygdules. Some of the flows, particularly at Barbers Cove, display a poorly developed columnar jointing and are several tens of feet thick. Green and purple agglomerates occur interlayered with the flows at Barbers Cove and near the lighthouse at the south tip of the island. The agglomerates consist of fragments 2 to 6 inches (5 to 15 cm) in diameter of green or purple basalt with calcite amygdules. All are set in an altered green matrix. Layering within the volcanic rocks is well displayed at Barbers Cove. Several distinct purple or green flows and agglomerate horizons can be distinguished, and the sequence includes a 1- to 2-ft

7

8

9

10

FIG. 7. Tilted unconformity between basalts of the Lighthouse Cove Formation (dark) and underlying leucocratic gneisses, 1 mile (1.6 km) north of White Point, Belle Isle. (Geol. Surv. Can. Photo 145494.)

FIG. 8. Horizontal basalt flow overlying flat-lying Bradore sandstones, Table Head, southeast Labrador. (Geol. Surv. Can. Photo 145498.)

FIG. 9. Horizontal columnar basalt flow overlying Precambrian gneisses, eastern island among St. Peter Islands, southeast Labrador. (Geol. Surv. Can. Photo 145499.)

FIG. 10. Moderately dipping Bradore sandstones, south end of Belle Isle. (Geol. Surv. Can. Photo 145483.)

(.3–.6 m) bed of arkosic sandstone typical of the overlying Bradore Formation.

Volcanic rocks like those of the Lighthouse Cove Formation, though much thinner, occur in northern Newfoundland at Cloud Mountain of Canada Bay and at three localities on the southeast coast of Labrador, i.e., Table Head (Fig. 8), Henley Harbour, and St. Peter Islands (Fig. 9). None of these rocks is dated stratigraphically, but in most places they are underlain by arkosic sandstone and conglomerate typical of the Bradore Formation. The volcanic rocks appear to thicken southeastward from approximately 12 ft (~3.1 m) at Table Head, to many tens of feet at St. Peter Islands, to several hundreds of feet at Belle Isle. Sedimentary rocks underlying the volcanic rocks in Labrador thin in the same direction from approximately 50 ft (~ 15 m) at Table Head to less than 2 ft (.6 m) at the eastern exposures of St. Peter Islands, and of course are absent below the Lighthouse Cove Formation of Belle Isle. Clifford (1965) originally regarded the Newfoundland and Labrador volcanic rocks as Lower Cambrian, first because they conformably overlie sediments correlated lithologically with the Bradore Formation, and secondly because the flows at Cloud Mountain were fed by dikes that are abundant throughout the Precambrian Long Range Complex, but do not cut Cambrian or younger cover rocks surrounding the Precambrian rocks. More recently Clifford (1968) reinterpreted the age of the volcanic rocks as Early Carboniferous, thus accommodating an isotopic date of 334 m.y. determined on a co-magmatic dike at Cloud Mountain (Wanless *et al.* 1966). He further suggested that the volcanism and associated diabase-dike intrusion were related to a tensional stress system created by the suggested rotation of Newfoundland in late Devonian time (Black 1964). In view of the relationships at Belle Isle, the latter age for the volcanic rocks is untenable, and there is little doubt but that the volcanic rocks in the widely separated localities of northern Newfoundland and southeast Labrador are approximately the same age as the Lighthouse Cove Formation. Recent geophysical studies of the volcanic rocks on opposite sides of the Strait of Bell Isle reveal similar rock magnetic properties, suggesting similar age (H. R. Deutsch, personal communication, 1969).

Bradore Formation

The sandstone unit that overlies the Lighthouse Cove Formation is assigned to the Bradore Formation and is correlated lithologically with similar rocks of the type area in Bradore Bay of southeastern Labrador. On Belle Isle the sandstones outcrop along the southwest coastline from Scotswood Cove to Round Head (Fig. 10), with another occurrence ½ mile (.8 km) north of White Point. Presumably the sandstones occur on the sea floor at Lark Harbour, as volcanic rocks of the Lighthouse Cove Formation occur to the east and tiny shales of the Forteau Formation to the west of the harbour. The Bradore Formation is from 300 to 400 ft (91 to 122 m) thick at Belle Isle, which is intermediate between its thickness of 220 to 230 ft (67 to 70 m) in the type area to the west and its reported thickness of 585 ft (178 m) (Cloud Mountain Formation, Betz, 1939) to the south at Canada Bay.

The Lighthouse Cove – Bradore Formation boundary is sharp and easily defined and is without significant interlayering of volcanic rocks and sandstones in the contact zone. Between Blandfords Cove and Lighthouse Cove the base of the Bradore is marked by 10 ft (3.1 m) of purplish fissile argillite, probably tuffaceous, that lies conformably above the volcanic rocks. East of Lighthouse Cove, 5 ft (1.5 m) of sheared conglomerate with flattened fragments of purplish basalt occurs at the base. Still farther east, a small fault-bounded section displays a conformable sequence from green agglomerates to gray quartzose sandstones, with the overlying sandstones including a discontinuous 3-ft (.9 m) thick purple to green amygdaloidal lava flow about 20 ft (~ 6 m) above the basal contact. This is the only known occurrence of volcanic rocks within the Bradore Formation at Belle Isle.

The Bradore Formation consists of gray to pink, pale purple to deep purple, and brownish to red arkosic sandstones with local pebble conglomerates and siltstones. The rocks are composed mainly of quartz and feldspar grains, with magnetite visible locally and sparse metamorphic rock fragments. Purplish beds contain volcanic rock fragments in places, but these are rare and confined to certain specific levels, suggesting that the sediments were derived mainly from a crystalline terrane. The sandstones have large-scale crossbedding in places and locally display mega-ripple marks. At Lighthouse Cove, the orientation of crossbedding suggests currents flowed from the north toward the south and southwest.

Purplish sandstone beds occur interlayered with gray sandstones in most parts of the section, but the top of the formation is everywhere marked by a distinct purplish bed that is approximately 5 ft (~ 1.5 m) thick at the southern extremity of the island, thickening westward to 10 ft (3.1 m) at Scotswood Cove and Blandsford Cove and about 30 ft (~ 9 m).

near Round Head. Locally, near the southern tip of the island this upper purplish bed is overlain by 2 ft (.6 m) of coarse brownish weathering sandstone. The latter has a 4-inch (10 cm) bed of hematitic iron ore and also contains fragments of the iron ore up to 6 inches (15 cm) in diameter. This coarse sandstone also has large (up to 1-ft (.3 m) diameter) discoidal fragments of purple amygdaloidal basalt.

The Bradore Formation is unfossiliferous, except for vertical worm tubes *Scolithus linearis*, (Schuchert and Dunbar 1934), present in the type area of southeastern Labrador. Its early Cambrian age, however, is unquestioned as it is conformably overlain by Lower Cambrian strata, and at least locally, by upper Lower Cambrian strata. At Henley Harbour and Table Head in Labrador, typical Bradore sandstones are overlain by columnar basalts, probably equivalent to the Lighthouse Cove Formation (Fig. 8). This suggests that basal parts of the Bradore Formation in Labrador may be equivalent to upper measures of the Lighthouse Cove Formation of Belle Isle (Table I).

Forteau Formation

Gray shales and limy shales that overlie the purplish Bradore sandstones are assigned to the Forteau Formation (Schuchert and Dunbar 1934) and are correlated with similar rocks in the type area of southeastern Labrador. At Belle Isle, the Forteau Formation outcrops intermittently from the southern tip of the island westward to Round Head and White Point, and extends as far north as Lark Harbour, where it constitutes the off-shore islands. This formation is the least competent of the units in the southwestern sequence; consequently it is the most deformed. The beds occur in a small syncline overturned to the west at the southern tip of the island and are locally tightly folded at White Point. To the north at Lark Harbour, the rocks have a prominent southeast-dipping cleavage.

The base of the Forteau Formation is well exposed at Round Head, Blandfords Cove, Scotswood Cove, and at the southern tip of the island. Basal, buff to brownish weathering dolomite and dolomitic limestone, a few inches to several feet thick, conformably overlies the Bradore sandstones. Lenses of buff-weathering dolomite occur within the uppermost purplish Bradore sandstones at Round Head, indicating no major depositional break between the Bradore and Forteau Formations. About 100 ft (~ 31 m) of shales are exposed at Blandfords Cove and Round Head, and probably 150 ft (~ 46 m) of folded Forteau strata at White Point. The top of the formation is not exposed.

The Forteau Formation consists of buff-weathering finely bedded gray shale and argillite with interlayers of limy shales in upper parts of the section and several feet of buff and brownish weathering dolomite and dolomitic limestone at the base. The argillite beds range from less than ¼ inch (< .6 cm) to several inches in thickness and alternate with zones containing limy nodules. The nodules weather to leave a characteristic pitted surface.

Fragmented trilobites and trilobite fragments occur sparingly in the formation at most places. Two large fragmented trilobites collected at Blandfords Cove were identified by W. H. Fritz of the Geological Survey of Canada as either *Olenellus* sp. or *Paedeumias* sp., indicating a late Early Cambrian age. At Blandfords Cove the undersides of bedding surfaces display curved sole markings up to 1½ ft (47 cm) long that possibly represent organism tracks. Achaeocyathid reefs, so characteristic of the Forteau Formation elsewhere, were not noted on Belle Isle.

White Point Formation

Approximately 100 ft (~ 31 m) of sedimentary strata occurring at White Point are referred to the White Point Formation. The rocks are hard siliceous sandstones, siltstones, and cherts, with interbeds of gray fragmental limestone. All are light gray to white weathering so that they contrast conspicuously with nearby rocks. Individual beds are from 4 inches to 2 ft (.1–.6 m) thick and in places buff-weathering gray shale lenses occur among the white weathering layers. Many of the fine-grained siliceous rocks are fragmental with the fragments and matrix distinguishable only on a weathered surface. Stylolites occur in a few places.

The White Point Formation is faulted against the Forteau Formation to the east so that its stratigraphic position and age are unknown. The rocks resemble Cambrian beds exposed above the Forteau Formation in western Newfoundland and are therefore most likely late

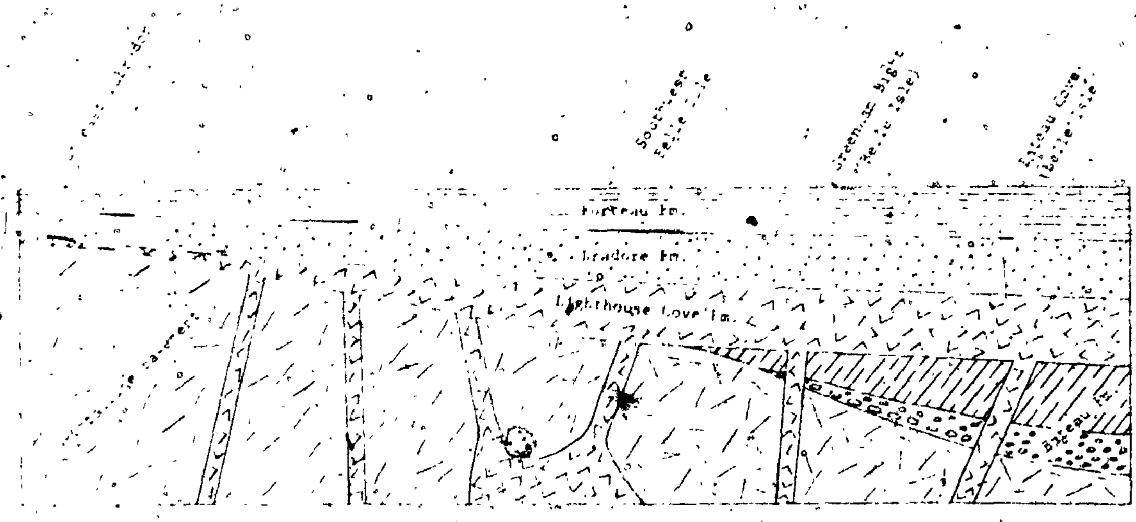


FIG. 11. Schematic illustration and interpretation of stratigraphic relationships from southeast Labrador to Belle Isle.

Early Cambrian or Middle Cambrian. An attempt to recover conodonts from these rocks proved unsuccessful.

Conclusions and Discussions

The stratigraphic relationships at Belle Isle indicate that the established Lower Cambrian succession is there underlain by a prominent mafic volcanic unit and, toward the northeast, by a thick conglomerate and quartzite unit. Eastward from Labrador, the Bradore Formation thickens from 230 ft (70 m) at its type locality to approximately 400 ft (~ 122 m) at Belle Isle and to about 600 ft (~ 183 m) at its exposures in Canada Bay. Similarly the volcanic unit, locally underlain by Bradore-type sandstones in southeast Labrador, thickens eastward from a few feet or a few tens of feet at Henley Harbour and Table Head to about 400 ft (~ 122 m) at Belle Isle. The eastern extent of the volcanics is unknown and the present exposures in Labrador probably closely coincide with their western depositional limit. The conglomerate quartzite unit or Bateau Formation, thickens northeastward from 250 ft (76 m) in east central Belle Isle to more than 800 ft (~ 244 m) in the northeast. Its western depositional edge must transect the northeast part of the island, and possible correlation of these rocks with the quartzites on the White Islands to the south suggests that they thicken southeastward across the structural trend.

These stratigraphic relationships and thickness distributions indicate that the Bradore Formation thickens southeastward and that it is underlain by increasingly thicker and older units eastward across Belle Isle (Fig. 11).

The conglomerates and quartzites of the Bateau Formation are of shallow water accumulation, as indicated by the alternation of coarse boulder conglomerate and arkosic sandstones at the base of the succession and cross-bedding in overlying quartzites. Structural and lithologic features of the Lighthouse Cove volcanic rocks indicate that the ensuing volcanism was largely terrestrial rather than marine. The volcanic rocks exhibit columnar jointing, a local abundance of amygdules, and in the southeast end of the island they include an arkosic sandstone interbed. In addition, the flows, although thin, have a considerable lateral extent. These features, combined with the complete lack of pillows and other marine depositional features, suggest that the mafic volcanic rocks are mainly plateau basalts or flood basalts, rather than eugeosynclinal spilitic lavas so common in central Newfoundland. The flows, presently exposed only in the Strait of Belle Isle area, may have been once much more widespread and subsequently removed by erosion. This inference is supported by the extent of co-magmatic diabase dikes that cut crystalline basement rocks throughout western Newfoundland wherever the latter are exposed.

The Bradore sandstones were derived from a crystalline source that must have lain outside the areas of earlier volcanism, for the sandstones contain very little volcanic debris. Large-scale crossbedding within the sandstones suggests fluvial transport and ripple-marked bedding surfaces attest to deposition in a shallow-water environment. The provenance areas of the Bradore sandstones are unknown. Schuchert and Dunbar (1934) suggested derivation from the northwest, observations by Stevens suggest transport from the southwest, and a few observations at Lighthouse Cove of Belle Isle suggest that source areas lay to the north and northeast. Whether these scanty data are compatible or in contradiction remains to be seen. An interesting sidelight to any future provenance and paleocurrent study in this area would be the comparison of gross patterns established on opposite sides of the Strait of Belle Isle so as to provide information on the proposed hypothesis of the rotation of Newfoundland relative to mainland Labrador (Black 1964).

None of the established Lower Cambrian or older units in the Strait of Belle Isle area can be clearly recognized farther southeast in the more deformed and metamorphosed terrain of central Newfoundland. It is possible, however, that correlatives of the Bateau Formation are represented in the highly deformed and metamorphosed plutonic boulder conglomerates and thick arenaceous units of the Fleur de Lys Group (Williams 1967; Neale and Kennedy 1967). Garnetiferous amphibolites that crosscut the Fleur de Lys schists may represent the metamorphic equivalents of the diabase dikes cutting the Bateau Formation in its type locality.

Seismic refraction studies in the Strait of Belle Isle area indicate that a significant change in the crustal structure coincides very nearly with the position of Belle Isle (Sheridan and Drake 1968). To the southwest and west, the seismic results indicate a crystalline basement overlain by undeformed cover rocks. Northeast of the island, the crystalline rocks are interpreted by Sheridan and Drake (1968) to be overlain by deformed supracrustal strata, and seismic velocities between 6.59 and 7.19 km/s indicate deep-seated basic rocks and an intermediate crustal layer not recognized to the southwest and west. The boundary between the dense intermediate layer and overlying crystalline rocks dips northeast, and if projected to the surface, directly coincides with Belle Isle. Clearly this crustal change must be related to the diabase intrusions so abundant throughout Belle Isle and their source rocks at depth. The position of Belle Isle also coincides with a change in regional Bouguer gravity anomalies, from negative values typical of the Canadian Shield to the west to positive values typical of the Appalachian deformed belt to the east (Bouguer Gravity Anomaly Map of Canada, 1967).

Diabase dike swarms are interpreted by most authors to indicate a tensional stress environment at the time of their emplacement. The number of mafic intrusions exposed on Belle Isle suggests that the crystalline basement must have broken and partly foundered within a rising basic magma. This igneous activity may relate to geosynclinal development and a foundering or sinking of the crystalline crust. In the central parts of the Appalachian System in Newfoundland mafic volcanism was also very prominent in the developmental stages of the geosyncline. This eruptive activity in different parts of the system possibly relates to crustal downwarp or foundering and collapse, a probable prelude to geosynclinal development.

Acknowledgments

The authors wish to acknowledge the cheerful assistance and expert boatmanship of Carl Wheaton, Gander Bay, Newfoundland, who acted as field assistant for the 1968 coastal survey in the rather treacherous waters of the Strait of Belle Isle. Thanks are also extended to W. H. Fritz and T. T. Uyeno of the Geological Survey of Canada for trilobite identifications and endeavors to recover conodonts; to E. R. W. Neale of Memorial University for critical reading of the manuscript; and to the National Research Council of Canada for making this work possible under Grant No. A-5548.

BETZ, F. JR. 1939. Geology and mineral deposits of the Canada Bay area, northern Newfoundland. Nfld. Geol. Surv., Bull. 16, 53 pp.

BLACK, R. F. 1964. Palaeomagnetic support of the theory of rotation of the western part of the Island of Newfoundland. Nature, 202, No. 4936, pp. 945–948.

BOUGUER GRAVITY ANOMALY MAP OF CANADA. 1967. Observatories Br., Dept. Energy, Mines and Resources Ottawa

CLIFFORD, P. M. 1965. Palaeozoic flood basalts in northern Newfoundland and Labrador. Can. J. Earth Sci., 2, pp. 183–187.

——— 1968. Flood basalts and dike swarms. Can. J. Earth Sci., 5, pp. 93–96.

GILLIS, J. W. 1966. Great Northern Peninsula (Parts of 12I, P, and of 2L, M). *In* Report of Activities, May to October 1965. (S. E. Jenness, *Ed.*). Geol. Surv. Can., Paper 66-1, pp. 178–181.

NEALE, E. R. W. and KENNEDY, M. J. 1967. Relationship of the Fleur de Lys Group to younger groups of the Burlington Peninsula, Newfoundland. *In* Geology of the Atlantic Region. E. R. W. Neale and Harold Williams, *Eds*.). Geol. Assoc. Can., Spec. Paper No. 4, pp. 139–169.

REED, J. C. JR. 1955. Catoctin Formation near Luray, Virginia. Bull. Geol. Soc. Amer., 66, pp. 871–896.

SCHUCHERT, C. and DUNBAR, C. O. 1934. Stratigraphy of Western Newfoundland. Geol. Soc. Amer., Mem. 1, 123 pp.

SELWYN, A. R. 1890. Geological Survey of Canada, Ann. Rept. for 1888–1889. 4. new series, pp. 1A–66A.

SHERIDAN, R. E. and DRAKE, C. L. 1968. Seaward extension of the Canadian Appalachians. Can. J. Earth Sci., 5, pp. 337–373.

STEVENS, R. K. 1967. Great Northern Peninsula (Parts of 2L, M, 12I, P). *In* Report of Activities, May to October 1966. (S. E. Jenness, *Ed.*). Geol. Surv. Can., Paper 67-1, part A. pp. 186–188.

——— 1968. Taconic klippen of western Newfoundland. *In* Report of Activities, May to October 1967. Geol. Surv. Can., Paper 68-1, part A, pp. 8–11.

TUKE, M. F. 1968. Autochthonous and allochthonous rocks in the Pistolet Bay area in northernmost Newfoundland. Can. J. Earth Sci., 5, pp. 501–513.

WANLESS, R. K., STEVENS, R. D., LACHANCE, G. R., and RIMSAITS, J. Y. H. 1966. Age determinations and geological studies. K–Ar isotopic ages, Report 6. Geol. Surv. Can., Paper 65-17, p. 96.

WILLIAMS, HAROLD. 1967. Island of Newfoundland. Geol. Surv. Can., Map 1231A.

Reprinted from:

Program for Geological Society of America,
Annual General Meeting,
Atlantic City, New Jersey
p. 215-216
(with W.R. Church and P. St. Julien)

AGE OF ULTRAMAFIC ROCKS IN THE NORTH-WESTERN APPALACHIANS

Stevens, R. K., W. R. Church, University of Western Ontario, London, Ontario, Canada; and St. Julien, P., Laval University, Quebec City, Quebec, Canada

Ultramafic rocks occur in two associations in the north-western Appalachians: an external belt associated with allochthonous Cambro-Ordovician sediments and an internal belt associated with moderately metamorphosed clastic and less altered volcanic rocks. Intrusive and stratigraphic relationships suggest that the primary intrusive age of both belts is Lower Ordovician and, consequently, their emplacement was unrelated to the Middle or Late Ordovician phases of the Taconic Orogeny. Secondary re-intrusion of the ultramafic rocks, however, is related to the Taconic and Acadian Orogenies.

The large amount of ultramafic detritus in the Lower and Middle Ordovician sediments of Quebec and Newfoundland indicates that the ultramafic rocks exposed at present are mere remnants of a much larger sheet, perhaps comparable to those of the Circum-Pacific belt or the Oman.

The ultramafic rocks of the external belt are allochthonous and may represent detached portions of the internal belt, which in the Thetford area at least are probably allochthonous. Secondary re-intrusion of the ultramafic bodies of the internal belt seems to have destroyed any definitive evidence of their early intrusive and structural history.

Reprinted from:

Privately circulated, unpublished manuscript,
University of Western Ontario, London, Ontario.
14 p.

A Note on the Quebec Group Allochthon on the Gaspé Peninsula and "Logan's Line"

R.K. Stevens, The University of Western Ontario, London, Ontario

Abstract

The Quebec Group, along the Gaspé North Shore, is allochthonous on the Cloridorme Formation and forms part of a large allochthon that extends from the eastern extremity of the Gaspé Peninsula to south west of Quebec City. The slide contact is Logan's Line, marked by the development of melange of sedimentary and tectonic origins. The allochthon perhaps emplaced by sliding, was accompanied by extensive flysch sedimentation of late Arenig to Caradoc age. Parautochthonous slices of the Cloridorme are intercalated under the allochthon. The original site of deposition of the Quebec Group is not known.

Resume

Le groupe de Québec, le long de la côte nord de la Gaspésie, est un bloc de charriage superposé à la formation de Cloridorme et form une partie d'un grand allochthone de type taconique qui s'étend de l'extrémité est de la Gaspésie jusqu'au sud-ouest de la ville de Quebec. Le contact de glissement se trouve le long de la zone de failles de Logan et est marqué par le developpement de mélanges d'origine tectonique ou sedimentaire. Le bloc de charriage a été mis en place par glissement gravitationnel et fut accompagné par une vaste accumulation de flysch entre l'Arenig supérieur et le Carodoc. Des écailles parautochthones du Cloridorme sont intercalées sous le bloc de charriage. Le site d'origine du groupe de Québec n'est pas connu.

This note presents additional data to amplify and confirm some of the observations and deductions presented by Riva (1968) in his paper on the graptolite faunas of the Gaspe North Shore. Riva's most significant conclusion is that the Quebec Group is allochthonous on the Cloridorme Formation. The writer endorses this conclusion, which he had previously suggested as a possibility to Riva during a private discussion in May 1968. The data presented by Riva (1968), and in this note, show that there is no valid reason for placing "Logan's Line", the contact between the allochthon and the autochthon (Clark, 1951; Zen, 1968), north of the Gaspé Peninsula, in the Gulf of St. Lawrence.

The allochthonous interpretation is the classical one proposed by Logan (1860) in a letter to Barrande explaining the anomalous relationship between the Quebec Group and the Hudson River or Utica Formation "..... from the east end of the [Orleans] island it [the fault] keeps under the waters of the St. Lawrence to within eighty miles of the extremity of Gaspé. Here again it leaves a strip of the Hudson River or Utica Formation on the coast." (Logan, 1860, p. 475). The critical exposures, on which Logan based his conclusions in the Gaspé area, are described in reports of the Geological Survey, (Logan, 1863, p. 267-270). Logan, however, did not realise that the fault is a folded, low angle slide, so that his fault (Logan, 1863) differs in detail from the thrust shown in figure 1 of Riva (1968).

The remainder of this note, based on field observations ... [illegible]

[illegible]

- 3 -

Mélange zones and the Basal Contact of the Allochthon

The Quebec Group is usually intensely deformed and blocky adjacent to the contact with the underlying Cloridorme Formation. The shales and interbedded arenaceous and carbonate rocks of the Quebec Group are reduced to a chaotic mixture of contorted shale with detached blocks and packets of more competent rocks. These chaotic zones are best described as "Mélange" (Greenly, 1919, p. 65), and are characterized by a phacoidal cleavage with long axes parallel to the inferred transport direction of the allochthon. This particular melange seems to have developed from rocks of the Quebec Group at the base of the allochthon, as a result of deformation during sliding. The mélange zones are locally several hundred feet thick and pass gradually upwards into less deformed rocks. It should be noted, however, that the contact exposed at Jersey Cove shows a minimal development of mélange and resembles a dry overthrust.

Locally parts of the Cloridorme Formation are stripped from the autochthon and incorporated into the basal melange; the graptolites described by Riva (1968, p. 1381), from thrust slices west of Marsoui, are from blocks in the basal mélange, derived from the parautochthonous slice of the Cloridorme exposed near the pier at Marsoui.

The local overturning of the uppermost few feet of the Cloridorme under the mélange is a drag effect under the allochthon and represents the first stage of the incorporation of the Cloridorme into the mélange. The Cloridorme succession is normal for a thickness of several hundred yards under the first few overturned feet.

Two primary types of mélange and one intermediate type are no...

recognized associated with the Quebec Group allochthon. St-Julien (1968) described the first primary type of mélange, associated with the south-western part of the Quebec Group allochthon, south-west of Quebec City and called them "argiles-a-blocs". The "argile-a-blocs" are characterized by a shale matrix of the same age as the interbedded autochthonous rocks, the "argiles-a-blocs" are part of the bedded autochthonous sequence though individual beds are up to 500 feet thick. Many blocks were derived from the Quebec Group allochthon but some are of the same age as the interbedded rocks. This type of mélange was generated by slumps, slides and flows from the front of the advancing allochthon (Zen, 1961, p. 313; St-Julien, 1968) and is a type of proximal flysch or fluxoturbidite. The term "mélange" can justifiably be applied to these rocks since some of the "type" mélanges described by Greenly (1919) are also slides and slumps (Shackleton, 1954). Examples of this type of mélange are also known from the Taconic area (Zen, 1961) and from the Hare Bay area, northern Newfoundland (Tuke, 1968).

The second type of mélange is that described in this note from the north-east end of the Quebec Group allochthon. These are characterized by a shale matrix of approximately the same age as the contained blocks. The matrix and blocks are either both derived from the Quebec Group, as in most of the mélange developed at the base of the allochthon, or derived from the Cloridorme Formation, as in the mélange developed west of Marsoui. These mélanges are generated by the tectonic mixing of bedded rocks with high ductility contrast by simple shear during sliding. The ductility contrast between the shales and the interbedded arenaceous [illegible] rocks [illegible] by high hydrostatic [illegible] induced almost fluid behaviour in the shales and less well cemented beds. The association of high fluid pressure, overthrust faulting and sliding with mélanges formation in the movement zones, is not generally appreciated. Other examples of this association are known from west and north Newfoundland (Stevens, 1965, 1968).

Intermediate types of mélange develop when the first type of melange, generated in front of the allochthon, is overrun and incorporated into a mélange of the second type. St-Julien (1968) has described this type from south-west of Quebec City. Another type of mélange, not yet known from the northern Appalachians, develops if the allochthon itself breaks down to a chaotic mass during sliding.

Enos (1965) and Riva (1968) have shown that parts of the Cloridorme Formation are also allochthonous. Enos recognized one lithologically distinct slice within the main mass of the Cloridorme. Riva, however, recognized several slices, each with a characteristic graptolite fauna. The writer suggests that these slices within the Cloridorme are parautochthonous scales, peeled from their substrate by the passage of the allochthon and piled up under the Quebec Group. This interpretation implies that the highest slice in the structural succession of parautochthonous slices was the first to be peeled off and, for reasons given later, consist of older rock than slices peeled afterwards. The parautochthonous interpretation explains Riva's observation that Cloridorme rocks with a Normanskill fauna are thrust over Cloridorme rocks with a younger Canajoharie and Utica fauna.

The relationships at the base of the allochthon at [illegible] are best explained by the presence of parautochthonous [illegible] the Utica shale [illegible] shown by Riva in his figure 2, are parautochthonous slices resting on grey wackes of similar age. The shales are probably only slightly moved and are overlain by greenish chert, the contact being much disturbed and clearly a thrust. The chert forms the base of another parautochthonous slice containing Normanskill graptolites, a situation comparable to that in west Newfoundland, where similar, but slightly older, cherts seem to have acted as impermeable seals allowing the build up of high hydrostatic pressure which facilitates peeling off.

The Significance of Cloridorme Formation

Enos (1965) recognized that the Cloridorme Formation is an excellent example of a flysch sequence and part of an Ordovician flysch belt that extends from Newfoundland into the southern Appalachians. He suggested that the Cloridorme flysch was deposited as a result of some phase of Middle Ordovician orogenesis; it is here proposed that this phase of "orogenesis" was the emplacement of the Quebec Group allochthon.

Much of the detritus recognized in the Cloridorme was derived from the Quebec Group which now rests on top of the Cloridorme and covered it completely at one time. The flysch must have been derived from the allochthon before its emplacement on top of the Cloridorme so that the allochthon slid into a basin in which a clastic wedge of flysch [illegible] derived from [illegible] itself [illegible] being [illegible] possibly [illegible], facies of the flysch [illegible] the [illegible] of the [illegible] derived [illegible] of the allochthon [illegible] flysch show however that the top of the [illegible] allochthon was above sea level and exposed to erosion. It is possible that the allochthon was emplaced as a moving island. Reefs growing on the migrating island could have been the source of the chromite and serpentine bearing calcarious rocks described from the Cloridrome by Enos.

The Chloridorme Formation along the shore between Rivere-a-Claude and Marsoui gradually coarsens upwards to the contact with the Quebec Group, perhaps reflecting a transition from more distal to proximal turbidites as the source slid into the basin.

Since the allochthon was moving into a basin, gravity was probably the motive force rather than a push from behind. Gravity sliding has also been invoked as the transportation mechanism of the Taconic allochthon (Rodgers and Zen in Zen, 1961) and the Newfoundland allochthons (Rodgers and Neale, 1963). The direction of transport, based on minor structures in the basal mélange, seems to have been from the south or south-east, but the original area of deposition of the allochthonous rocks is a major problem yet to be solved. The facies of the Quebec Group, like that of the Taconic and Newfoundland allochthons, is intermediate between eugeosynclinal and miogeosynclinal; the stratigraphic similarity of the Hare Bay, Humber Arm, Quebec Group and Taconic allochthons is striking. In some parts of the Newfoundland and Quebec allochthons, formation names from the Taconic allochthon could be used almost as defined in the type area.

Flysch within the Quebec Group

The Pillar Sandstones and associated rocks (Logan, 1863, McGerrigle,

1954) comprise a clastic sequence, mainly flysch, of late Arenig and perhaps slightly later age. McGerrigle (1954, p. 27-30) describes the distribution of these rocks. The Pillar Sandstone itself, exposed at Tourelle, is a proximal flysch that yields graptolites (McGerrigle, 1954, p. 29) of late Arenig age. The sequence provides crucial information about the late Arenig history of the Quebec Group. The Pillar Sandstones rest, with a gradational contact, on Lower Ordovician shales like those of the Cape Rosiers Formation but are tectonically overridden by similar shales in the vicinity of Ruisseau-Castor. Mélange is extensively developed at the tectonic contact and at other places within the allochthon, so that it seems probable that the allochthon is made up of a complex series of nested slices. The whole complex has subsequently slid over the Cloridorme Formation on the basal mélange.

The facies of the Pillar Sandstone and associated rocks is virtually identical to that of the Cloridorme Formation immediately east of Marsoui. Nevertheless, fossils prove that the two sequences are of substantially different ages. The similarity no doubt led to the erroneous inclusion of the Cloridorme between Marsoui and Riviere-a-Claude in the Quebec Group (see for example Q.D.M. Map No. 1000). The Taconic problem, both in New England and Newfoundland, was largely the result of an analogous miscorrelation of allochthonous and autochthonous flysch sequences.

The detrital constituents of the Pillar Sandstone and the Cloridorme are similar and were derived from several different sources. Quartz and feldspar from a silicic plutonic terrain are prevalent, but silicic, basaltic and andesitic volcanic rocks as well as granophyres, ophiolites and sediments of the Quebec Group are also represented. This assemblage must have been derived from a more internal part of the geosyncline, not from the foreland, so that the Pillar Sandstones represents the oldest and most internal part of the clastic flysch fan so far recognised on the Gaspé Peninsula.

The prominent ophiolitic debris, chromite and serpentine, show that ophiolitic complexes, such as that at Mt. Albert, were actively eroded as early as late Arenig times. The isotopic age of 495 m.y. (Lowdon et al., 1962) from aureole rocks of the Mt. Albert intrusion is consistent with this deduction. Similarly, the Bay of Islands Igneous Complex in west Newfoundland is now dated as Lower Ordovician and it also yielded chromite and serpentine to allochthonous late Arenig flysch of the Humber Arm allochthon (Stevens, 1970, in press.).

Fragments of the Quebec Group in the Pillar Sandstones were probably derived from the overriding slices while the plutonic and volcanic detritus provides a glimpse of Arenig cordillera rising in the geosyncline.

Age of Sliding

The age of sliding of a gravity slide muass should be considered in terms of the start of sliding and final emplacement. The emplacement of a gravity slide mass is not a sudden, short event, a considerable period of time may elapse between the start of sliding and the final emplacement of the allochthon. The Pillar Sandstone and the overriding shales show that the more internal parts of the Quebec Group had started to slide in late Arenig times. The allochthon did not finish sliding until the deposition of the youngest autochthonous rocks of zone 13 are in Berry's terms (Berry,

1960) or early Utica in Riva's (1968) interpretation. In any case, the final emplacement is Caradocian and broadly contemporaneous with the Taconic Klippe (Zen, 1967) and the allochthons in the Quebec City area (St-Julien, 1968).

The Problem of the Source Area of the Allochthon

A major problem of Gaspé geology is the location of the original site of deposition of the allochthonous rocks. The problem of the source area is not unique to the Quebec Group allochthon but is just as acute in west Newfoundland (Church and Stevens, 1968).

Before the problem can be solved in Gaspé, several obscure geological relationships must be clarified in the field. Are, for example, the Mt. Albert ophiolitic complex and the associated Shickshock Group the autochthonous or parautochthonous, north-eastern extension, of the Quebec-Vermont geanticline, or are they allochthonous like the similar Hare Bay and Bay of Islands ophiolites of northern and western Newfoundland? If the Mt. Albert ophiolites prove to be autochthonous, it will be difficult to find space enough to accomodate the original site of deposition of the Quebec Group sediments. If, however, the ophiolites are parautochthonous, that is, thrust over the sediments of the Quebec Group to the north-west but rooted to south-east, the root zone of the Quebec Group sediments must be hidden under the ophiolites and considerable crustal shortening would be implied. This parautochthonous interpretation encounters less difficulties than any other interpretation so far conceived. If the ophiolites [illegible] to be allochthonous, however, both the Quebec Group and the ophiolite [illegible] must originally have lain to the south or south-east of their present position.

Three interesting groups of pre-Silurian rock appear from under a cover of Silurian and later rocks to the south and east of the main outcrops of the Quebec Group south of the axis of the Gaspé synclinorium. These are the Maquereau Group, the Mictaw Group and the Corner-of-the-Beach and Murphy Creek Formations.

The Maquereau Group (Ayrton, 1967) is a weakly metamorphosed sequence of rocks that much resembles the Sillery rocks of the Quebec Group (Logan, 1863, p. 272). They are thought to be overlain by the Mictaw Group (Ayrton, 1967) of late Middle Ordovician age which contains abundant clasts from the Maquereau Group, but the contact with the Maquereau is everywhere faulted. The Corner-of-the-Beach and Murphy Creek Formations (Alcock, 1935; Kindle, 1942) comprise a sequence of shales and limestones of Cambrian age. Their relationship with other rocks are not known.

At least three possibilities exist to explain the relationship between these sequences and the Quebec Group allochthon.

1. If the allochthon was derived from facies belt under consideration, the Maquereau Group and the Corner-of-the Beach and Murphy Creek Formations could represent rocks equivalent to the allochthonous rocks that did not slide. The Mictaw Group would then be a neoauthochthonous cover, deposited unconformably, on the subsided geanticline from which the allochthon slid.

The second possibility is based on the flysch-like facies of the Mictaw, the resemblance of the Maquereau to the Sillery, and the similarity of the Corner-of-the-Beach and Murphy's Creek to autochthonous Cambrian rocks of the Newfoundland and New England miogeosyncline. It is possible that the Mictaw Group tectonically underlies the Maquereau Group which then might be the south-eastern part of the Quebec Group allochthon, exposed on the south-eastern limb of the Gaspé synclinorium. In this interpretation, the Mictaw is a flysch, derived from the Maquereau during its emplacement and the Corner-of-the-Beach and Murphy Creek Formations, part of the autochthonous miogeosyncline sequence now mostly buried by the Quebec Group allochthon and later Siluro-Devonian rocks.

A third possibility is suggested by an analogy with west Newfoundland where the allochthons are thought to root along the Cabot Fault between the miogeosyncline and the eugosyncline (Church and Stevens, 1968). In Gaspe, the equivalent zone may exist between the Maquereay Group and the Cambrian shales and carbonate rocks.

The above speculations demonstrate the sort of problems that need to be solved before the source area of the Quebec Group allochthon can be located.

In conclusion, the data presented by St-Julien (1968), Riva (1968) and this note, show that the Quebec Group forms a large allochthon of the Taconic type on the Gaspé Peninsula. The allochthon is made up of a complex series of nested slices and was emplaced by gravity sliding during late Arenig to Caradoc times. A clastic flysch fan, derived partly from the allochthon and partly from cordillera rising in the geosyncline, spread out diachronously in front of the allochthon, and parts of the fan are now preserved in the allochthon, in parautochthonous slices, and as part of the Quebec Group between allochthonous slices. The problem of the original site of deposition of the Quebec Group remains.

REFERENCES

Alcock, F. J., 1935, Geology of the Chaleur Bay region. Canada Geol. Survey, Mem. 183, 146p.

Ayrton, W. G., 1967, Chandler-Port Daniel Area. Que. Dept. Nat. Res., Rept. 120, 91p.

Berry, W. B. N., 1960, Graptolite faunas of the Marathon Region, West Texas. Univ. Texas Publs., 6005, 179p.

Clark, T. H., 1951, New light on Logan's Line. Roy. Soc Canada Trans., v. 45, ser. 3, sect. 4, p. 11-22.

Church, W. R. and Stevens, R. K., 1968, Crustal Evolution of the Western Margin of the Newfoundland Appalachians, (abstract). Geol. Soc. America ann. mtg., Mexico City, p. 53-54.

Enos, P., 1964, Cloridome Formation, Middle Ordovician flysch, northern Gaspe Peninsula, Quebec. Ph.D. thesis, Yale Univ., 68p.

Greenly, E., 1919, The Geology of Angelsey. Great Britain geol. Surv. Mem., 980p.

Kindle, C. H., 1942, A Lower(?) Cambrian Fauna from Eastern Gaspe, Quebec. Amer. J. Sci., v. 240, p. 633-641.

[illegible] Age Determinations and Geological Studies. Geol. Surv. Canada, Paper 62-17.

Logan, W. E., 1860, Remarks on the Fauna of the Quebec Group of Rocks and the Primordial Zone of Canada, addressed to Mr. Joachim Barrande. Canadian Naturalist and Geologist, v. 5, p. 472-477.

__________, 1863, Geology of Canada. Geol. Surv. Canada, Rept. Prog. 1833, 983p.

McGerrigle, H. W., 1954, The Tourrelle and Courcelette Areas. Que. Dept. Nat. Res., Rept. 62.

Riva, J., 1968, Graptolite Faunas from the Middle Ordovician of the Gaspe North Shore. Naturaliste can., 95, p. 1379-1400.

Rodgers, J., and Neale, E. R. W., 1963, Possible "Taconic" Klippen in Western Newfoundland. Amer. J. Sci., v. 261, p. 713-730.

Shackleton, R. M., 1954, The Structure and Succession of Anglesey and [illegible]

Stevens, R. K., 1965, Geology of the Humber Arm Area, West Newfoundland. M.Sc. Thesis, Memorial Univ. of Newfoundland, p.121.

__________, 1968, Taconic Klippen of Western Newfoundland, in Report of Activities, May to October, 1967, Geol. Surv. Canada, Paper 68-1, p. 8-9.

St-Julien, P., 1968. Les "Argilles-a-Blocs" du Sud-ouest des Appalaches due Quebec. Naturaliste can., v. 95, p. 1345-1356.

Tuke, M. F., 1968, Autochthonous and Allochthonous Rocks in the Pistolet Bay area in northermost Newfoundland. Canad. J. Earth Sci., v. 5, p. 501-513.

Zen, E., 1961, Stratigraphy and Structure at the North End of the Taconic Range in West-Central Vermont. Geol. Soc. Amer. Bull., v. 72, p. 293-333.

______, 1967, Time and Space Relationships of the Taconic Allochthon and Autochthon. Geol. Soc. Amer. Special Paper No. 97, 107p.

______, 1968, Middle Ordovician Gravity Slides along "Logan's Line". Geol. Soc. Amer. Northeastern Section Abstracts for 3rd Ann. Mtg., p. 64-65.

Reprinted from:

The Geological Association of Canada,
Special Paper Number 7, 1970,
"Flysch Sedimentology in North America",
edited by J. Lajoie
p. 165-177

THE GEOLOGICAL ASSOCIATION OF CANADA, SPECIAL PAPER NUMBER 7, 1970

CAMBRO-ORDOVICIAN FLYSCH SEDIMENTATION AND TECTONICS IN WEST NEWFOUNDLAND AND THEIR POSSIBLE BEARING ON A PROTO-ATLANTIC OCEAN

R. K. Stevens
Erindale College, University of Toronto

ABSTRACT

A succession of Ordovician flysch derived from the east overlies Cambro-Ordovician carbonate rocks in west Newfoundland. The flysch is overridden by two allochthons mainly made up of flysch sequences also of Cambro-Ordovician age. The transported flysch consists of an older assemblage resembling sediments of a continental rise of the Atlantic type and a younger assemblage derived from tectonic lands possibly bordering a former closing ocean. Parts of the old ocean crust might be preserved as ophiolites in the upper slices of the allochthons. The tectonic activity associated with the emplacement of the allochthons also led to the deposition of the allochthonous flysch which transgressed westwards onto the craton.

RÉSUMÉ

Les carbonates cambro-ordoviciens de la partie ouest de Terre-Neuve sont recouverts par une séquence de flysch ordovicien au-dessus de laquelle on trouve deux séquences allochtones de type flysch. Les allochtones sont séparés par deux ensembles sédimentaires dont l'un, apparemment, des sédiments du glacis continental et l'autre dérivé possiblement de terres en bordure d'un océan qui se referme. Des lambeaux de cette croûte océanique sont peut-être préservés dans les parties supérieures des allochtones (ophiolites). L'activité tectonique associée au mouvement des allochtones a produit une séquence de flysch transgressive vers l'ouest.

INTRODUCTION

West Newfoundland constitutes the western unit of Williams' (1964) tripartite division of the Newfoundland lower Paleozoic orogene and forms the western, relatively stable, margin. Until recently the sediments of west Newfoundland were thought to comprise a single sequence of Cambrian to Silurian ages (Schuchert and Dunbar, 1934) showing a change from miogeosynclinal to eugeosynclinal environment (Smith, 1958). Johnson (1941), Kay (1951) and Rodgers and Neale (1963), however, have proposed that much of the upper part of the section is not in place but has been transported from a sedimentary basin farther east. Rodgers and Neale (1963), in particular, emphasized the regional extent and importance of the allochthons which they compared with the Taconic Klippe.

An autochthonous Cambro-Ordovician sequence, and three transported but coeval sequences are now recognized in west Newfoundland. Two of the transported sequences are made up of flysch which also caps the autochthonous sequence. This paper attempts to interpret these sequences in terms of Dietz's (1963) model of a continental terrace wedge-continental rise prism couple combined with Wilson's (1966) concept of a proto-Atlantic ocean that closed during Ordovician time.

It should be remembered, however, that the geology of west Newfoundland is imperfectly known so this analysis of sedimentation and tectonics must be regarded as a preliminary attempt subject to modification or perhaps obsolescence as new data become available.

STRATIGRAPHY

Nomenclature

The autochthonous sequence is overlain by two disconnected transported rock masses, the Humber Arm and Hare Bay allochthons (Figures 1 and 2). Each allochthon is made up of several sedimentary sequences and capped by an ophiolite complex. It is proposed that the transported sedimentary rocks and minor interbedded volcanic rocks be referred to the Humber Arm Supergroup which includes the ... and Cow Head Groups. The allochthonous igneous and volcanic rocks with minor amounts of sedimentary rock form the ophiolitic sequences which embrace both the Bay of Islands and Hare Bay complexes. The Humber Arm allochthon is overlain by the neoautochthonous Long Point and Clam Bank Formations.

THE ALLOCHTHONOUS SEQUENCE

The Cow Head Group

The carbonate conglomerates at Cow Head and nearby localities are world-renowned for their extreme coarseness. In this paper only those conglomerates at and near the type locality are considered part of the Cow Head Group. The conglomerates were first described by Richardson (in Logan, 1863, p. 291) who could not account for their origin. Schuchert and Dunbar (1934, p. 73) and Dunbar (1934) described the conglomerates at Cow Head but incorrectly correlated them with similar conglomerates at Cape Cormorant and at Pistolet Bay. They concluded that the conglomerates were tectonic breccias formed at the nose of Middle Ordovician thrust faults.

Kindle and Whittington (1958), however, recognized that the conglomerates were an unusual type of stratified sediment interbedded with thin bedded limestone and shale of Middle Cambrian to Middle Ordovician age. Trilobites from clasts in conglomerate beds were found

166

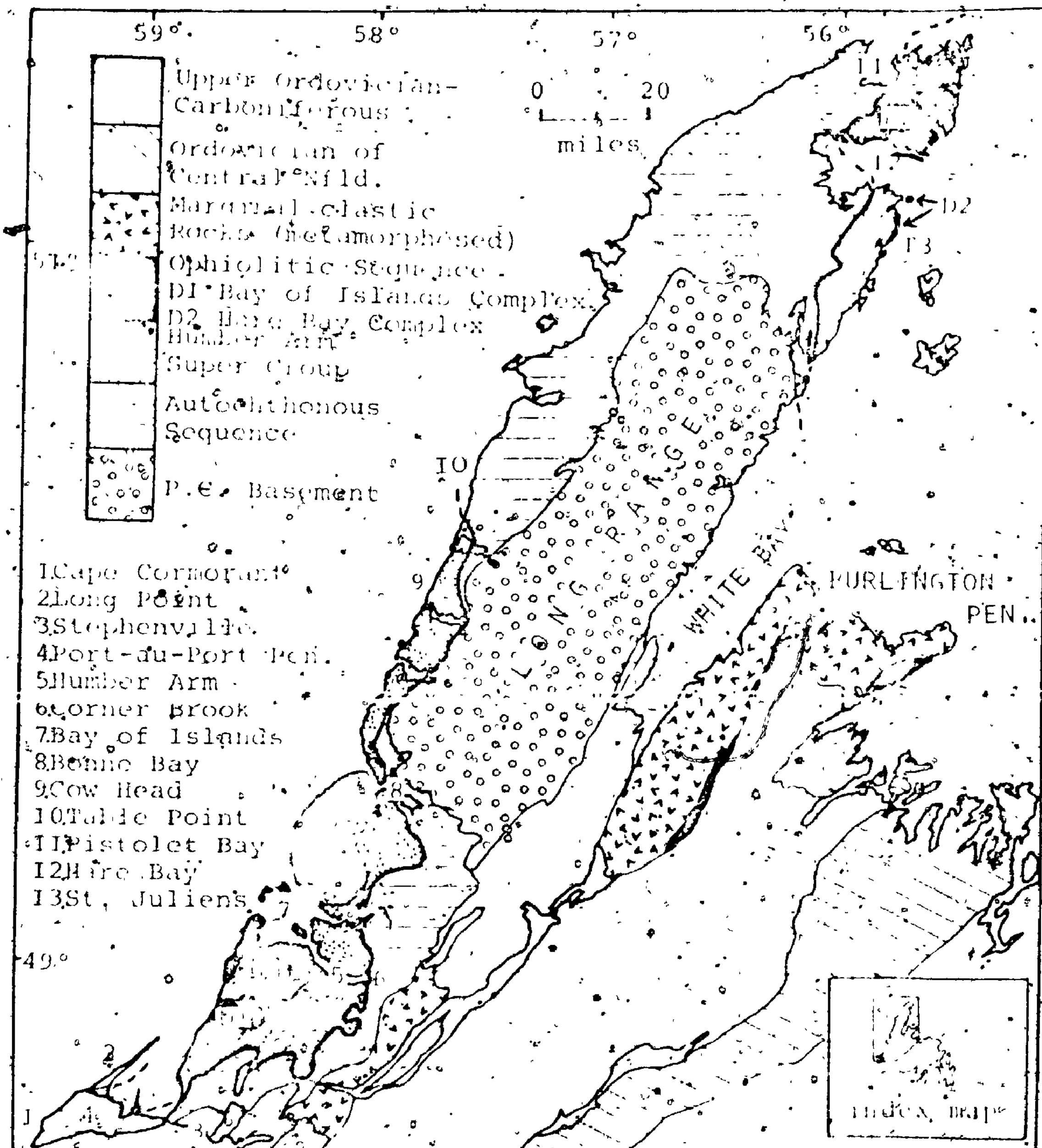


Figure 1. Generalized geological map of west Newfoundland

to be of essentially the same age as graptolites from the adjacent interbedded shale. Kindle and Whittington (1958, p. 341) characterized the rocks at Cow Head as a variety of flysch.

Baird (1960) in a comprehensive review of the conglomerates concluded that both shallow water and deep water conglomerates occurred in west Newfoundland, but accepted that the clasts were derived from carbonate rocks that crop out nearby. Rodgers and Neale (1963), on the other hand, included all of the limestone conglomerates of west Newfoundland in their proposed klippen with the inference that they were of deepwater origin and derived from the west. The present writer accepts the view of Rodgers and Neale but with several reservations.

The term "Cow Head Breccia" as used by previous authors includes all limestone conglomerates occurring in west Newfoundland, but three distinct types of conglomerate can be recognized, that a) at Cow Head, b) in the Curling Group, and c) near the top of the

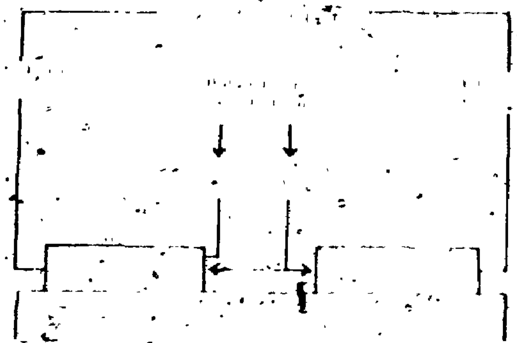


Figure [illegible] Nomenclature of [illegible] units of west Newfoundland

autochthonous sequence. These are examples of proximal flysch and many of the [illegible] limestones are turbidites. At Cow Head the conglomerates predominate and are part of a continuous succession derived from a persistent source of low relief because the clasts in each conglomerate bed are mutually coeval (Sanders and [illegible] 196[illegible], p. [illegible]). The most probable source was the over-steepened seaward edge of a carbonate bank that provided detritus from Middle Cambrian to Middle Ordovician time.

The carbonate [illegible] succession in the Curling Group, part of the Cooks limestone (Walthier 1949) [illegible] the Cow Head Group except that fine grained carbonate turbidites greatly predominate over limestone conglomerates which are thinner and not so coarse. The conglomerates of the Curling Group seem to be more distal than those of the Cow Head Group and form only a minor part of the succession. [illegible] from the clasts in the conglomerates like those at the Cow Head conglomerates are of the same age as those from the calcareous thin interbedded limestone.

The autochthonous carbonate conglomerates occur sporadically at or near the transition between the Table Head carbonate rocks and younger flysch between Cape Cormorant and Port au Port Bay. These are described in a later section.

The Curling Group

Most of the allochthonous sedimentary and minor interbedded volcanic rocks in west Newfoundland are included in the Curling Group. The type section of the group is along Humber Arm from Corner Brook to Bay of Islands. Several formations have been proposed within the group but none has been mapped regionally. A threefold division of the group is possible: lower quartzo-feldspathic flysch, carbonate flysch and upper quartzo-feldspathic flysch.

The lower quartzo-feldspathic flysch includes the Summerside, Meadow and Irishtown Formations of the Humber Arm allochthon (Bruckner 1966, Stevens 1965) and Mutton Point (Cooper 1937) and Canada Head (Betz 1939) Formations of the Hare Bay allochthon. The carbonate flysch includes the Cooks Brook Formation (Bruckner 1966), the Middle Arm Point Formation (Stevens 1965, Bruckner 1966), the Cooks limestone (Walthier 1949) and the Green Point Formation (Schuchert and Dunbar 1934). The upper quartzo-feldspathic flysch includes the Woods Island Formation (Stevens 1965), the Blow-me-Down Brook Formation (Bruckner 1966), and some of the unnamed green sandstones described by Kindle and Whittington (1958).

The lower quartzo-feldspathic flysch is much like some of the Sillery Formation (Logan 1863, p. 234; Hubert 1965) of the Quebec allochthon described elsewhere in this volume, and the Mud Pond, Zion Hill and Rensselaer members of the Bull Formation in the Taconic allochthon (Zen 1961). The oldest part of the division in the Humber Arm allochthon consists of green and minor red thick-bedded greywacke with interbedded green and red slate. Some of the greywacke is pebbly and crudely graded; its source was a plutonic complex such as the Grenville province of the Canadian Shield. Both the greywacke and the basement Grenville gneiss are characterized by blue quartz. Mafic volcanic fragments in the greywacke could have been derived from Lower Cambrian volcanic flows like those exposed at the base of the autochthonous sequence (Williams and Stevens 19[illegible]).

The green and red slate grade upward into a succession of dark coloured shale, arkosic greywacke, white orthoquartzite, conglomerate and pebbly mudstone, most of which show resedimentation features. Thin bedded graded oolitic beds, in places with clastic quartz matrix, are a minor but interesting rock type. Oolite also occurs as slump blocks and clasts in the conglomerate. Conglomeratic lenses with clasts dispersed in a matrix of well rounded coarse quartz sand occur near the top of the division. Clasts include plutonic basement fragments up to five feet in diameter (Walthier 1949, p. [illegible]), white vein quartz and sedimentary rocks, especially limestone and white quartzite similar to the shallow water Lower Cambrian rocks of the autochthon. Some of the limestone clasts contain Lower Cambrian trilobites (Stevens 19[illegible]). The conglomerates are unusual inasmuch as well rounded clasts of hard rock and subrounded soft rock clasts occur together.

Most of the sediments in the Hare Bay allochthon are referred to the lower quartzo-feldspathic flysch division of the Curling Group and can be lithologically correlated with the lower part of the division in the Humber Arm allochthon. Only one occurrence of the coarse conglomerate [illegible] is known (Murray and Howley 1881, p. [illegible]). The sediments are locally interbedded with volcanic flows and cut by minor mafic intrusions unknown in the Humber Arm allochthon.

The origin of the lower clastic divisions is a problem of long standing. The consensus of opinion has favoured a shelf edge origin (Schuchert and Dunbar, 1934, p. 67; Stevens, 1965, p. 101; Lilly, 1963, p. [illegible]) but it is more probable that the rocks represent a deep water turbidite fan similar in all respects to that described by Hubert et al. elsewhere in this volume from the south shore of the St. Lawrence River. The conglomerates are like those of the Kamouraska type and can likewise be interpreted as lenticular deposits fed from submarine canyons. It is probable that the rocks were derived from an eastern source though confirmation from sedimentary structures is lacking and are analogous to sediments of the present day Atlantic continental rise described by Dietz (1963) as flysch.

The middle division of the Curling Group in the Humber Arm allochthon consists of shale with thin to medium bedded limestone and dolomite, and calcareous conglomerate. The older part of the division consists mainly of black shale, thin limestone, and a variety of limestone conglomerate. Green and black laminated shale with a few beds of carbonate conglomerate make up the youngest part of the division. The division is of Middle Cambrian to late Arenig age. A. R. Palmer (pers. comm.) suggests that Middle Cambrian trilobites found in the strata near the base of the division are characteristic of the outer [illegible] bank that once fringed North America.

The conglomerate and much of the inter-bedded limestone show resedimentation features and the whole sequence is best interpreted as carbonate flysch intermixed with pelagic sediment. It differs from the Cow Head sequence only in the relative paucity of carbonate conglomerate and the abundance of dolomitic interbeds. It is difficult, however, to distinguish between distal carbonate turbidites and pelagic carbonate sediments, especially when the beds have been extensively reworked or dolomitized.

Different slices in the Humber Arm allochthon contain different proportions of shale, conglomerate and carbonate rock and the thickness of the carbonate beds varies. It might be possible to reconstruct the relative positions of the slices before emplacement if it is assumed that the thick bedded sections rich in conglomerate and carbonate rock were deposited nearest the source of the turbidity currents.

Only one thin [illegible] of the carbonate flysch division has been recognized in the Hare Bay allochthon where it [illegible] to the North West Arm Formation (Cooper, 1937). The rocks are essentially similar to those in the Humber Arm allochthon except that black chert occurs and the carbonate beds contain more quartz and feldspathic material. A few [illegible] graptolites have been recovered from the formation (Kindle, 1945; Tuke, 1968).

An easterly derived quartz-feldspathic flysch forms the upper division of the Curling Group in the Humber Arm allochthon but has not been recognized in the Hare Bay allochthon. This flysch overlies the carbonate and shale with a gradational contact characterized by siliceous rocks. In the Humber Arm area (Stevens, 1965) the contact is often marked by a silicified green shale up to 100 feet thick with thin silty interbeds. In other areas the transition is marked by bedded red, green or dark brown chert of both primary and secondary origin. The first hundred feet of quartzo-feldspathic flysch is thin to thick bedded green fine to medium grained greywacke with interbedded green or red shale. This is overlain by massive beds up to 200 feet thick of coarse grained arkose with little or no internal structure. The beds are massive enough to resemble granite sills when seen from a distance. The base of the arkose is sometimes graded and often shows load, flute marks and load casts. Sedimentary dikes, sills and parallel laccoliths, sometimes with sedimentary intrusion breccia, occur in the beds under the arkose, suggesting that the arkose was rapidly deposited on unconsolidated sediments. The grain size at the base of the beds tends to be coarser than at the top of the beds but the difference is not marked except in the top few feet of arkose.

[illegible] sources contributed detritus to the arkose: [illegible] source [illegible] [illegible] and [illegible] [illegible] [illegible] volcanic rocks, and [illegible] [illegible] [illegible] similar to the older part of the Curling sequence. The arkose is interpreted as large submarine flows of coarse debris into the flysch basin. More typical finer grained and thinner bedded flysch with thin beds of arkose succeeds the massive arkose.

In the Humber Arm area the uppermost 400 feet of well bedded arkose, below the tectonic contact with the ophiolite sequence, exhibit sporadic large scale cross beds. Glauconite is a prominent constituent of the arkose. These beds seem to be shallow water, possibly topset deltaic deposits, but are poorly understood and could perhaps be deep water proximal flysch. They are separated from the underlying flysch by an enigmatic melange of great but unknown thickness that can be traced about 100 miles from Bonne Bay to Fox Island River near Stephenville. In [illegible] the melange cuts out the quartzo-feldspathic flysch and rests on the carbonate flysch. The melange consists of blocks of greywacke, carbonate rock, competent shale and scattered ophiolitic rock set in a chaotic shaly matrix with phacoidal cleavage. The blocks range from a fraction of an inch to several hundred yards in diameter and sometimes a limited stratigraphy can be recognized within the melange. A more detailed description of the melange is given in Stevens (1965). It was originally interpreted as a tectonic melange separating two slices of the allochthon. Like other melanges in west Newfoundland, evidence for a tectonic origin abounds. Blocks are [illegible] deformed and [illegible] by the shaley matrix which was [illegible] and [illegible] cleaved before the development of the regional slaty cleavage. Horne (1969), however, has shown that similar melanges in central Newfoundland are [illegible] that have been [illegible] deformed so that they show the results of both sedimentary and tectonic deformations. It seems probable the melange in the upper part of the Humber Arm allochthon [illegible] interpreted as an [illegible] derived from an [illegible] deformed by the overriding [illegible] and cut by the regional cleavage. [illegible] could be [illegible] mass of [illegible] rock that slid onto the [illegible] front of the ophiolites [illegible] a deep water [illegible] on the [illegible]

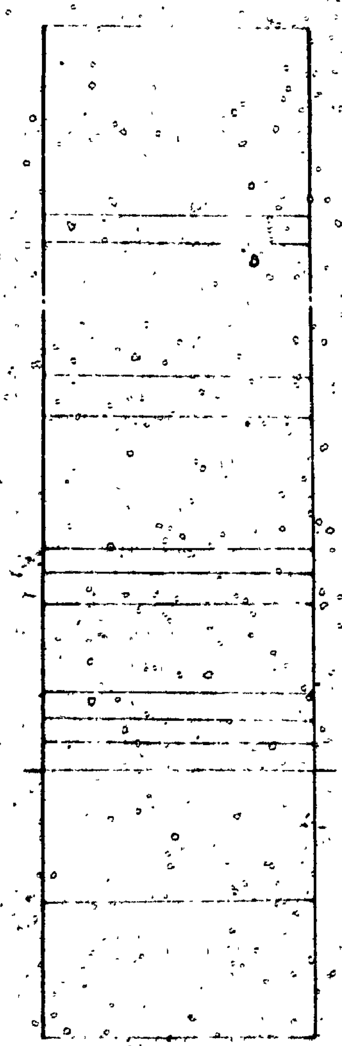


Figure 4. [illegible] Humber Arm [illegible] movement zone.

The upper quartzo-feldspathic flysch occupies an important stratigraphic position between slices in the Humber Arm allochthon. The [illegible] successions of many of the slices are terminated by the flysch which is in tectonic contact with the overlying slice (Figure 4).

Deposition of the upper quartzo-feldspathic flysch [illegible] significant point in the evolution of the [illegible] cline. Previously, the sediments were probably derived from the [illegible] and [illegible] Ordovician [illegible] and were [illegible] the [illegible]. By [illegible] the polarity of the geosyncline had reversed and the [illegible] provided sediment that was transported towards the craton.

The Ophiolite Sequence

Black ophiolites form the upper [illegible] of both allochthons. The Bay of Islands Complex (Smith 1958; Cooper 1936) is thrust onto the upper quartzo-feldspathic flysch, but the [illegible] Complex (Cooper 1937) is thrust onto the lower quartzo-feldspathic flysch. The ophiolite complexes include a basal [illegible] before the intrusion of the [illegible] both ultramafic rocks including serpentinite, peridotite and [illegible] and gabbro. The [illegible] of the intrusive [illegible] pillowed volcanic rock with interbedded black shale and chert [illegible] A profusion of mafic dikes [illegible] contact between the [illegible] and the volcanic rocks of the roof. The roof of the [illegible] Complex [illegible] probably [illegible] Bay of Islands Complex where [illegible] is preserved. [illegible] fragments like those in the ophiolite complexes are abundant in the [illegible] flysch of the Humber Arm allochthon and the intrusion [illegible] rock [illegible] the intrusion must be of [illegible] or [illegible] (Stevens [illegible] 1969).

The basal metamorphic [illegible] of the ophiolite complexes [illegible] volcanic rocks [illegible] green and black shales [illegible] rocks. A metamorphosed [illegible] facies resembling a [illegible] is however interbedded with the [illegible] of St. Julien Island in the [illegible] Bay [illegible] (Murray and Howley [illegible]). The [illegible] consists of [illegible] up to [illegible] in a [illegible] sandy [illegible] matrix and [illegible] the plane of schistosity. [illegible] include [illegible] of [illegible] porphyry and [illegible] derived from [illegible] the [illegible] rather than from the craton. The [illegible] of the [illegible] is not known but it must be older than the ultramafic rocks that thermally metamorphosed the green schist into amphibolite. An Upper Cambrian age is suggested by regional relationships

THE AUTOCHTHONOUS SEQUENCE

The oldest part of the autochthonous sequence is Lower Cambrian (Schuchert and Dunbar, 1934) and rests on a crystalline basement of Grenville gneiss (see Clifford and Baird 1962). Rock types include arkose, hematitic arkose, quartzite, thin to thick bedded limestone, archaeocyathid reefs, and shale rich in [illegible] (Stevens, 1965). The rocks were undoubtedly deposited in shallow water. Locally terrestrial basaltic flows occur at or near the base of the section and were fed by dikes that cut the basement (Williams and Stevens, 1969). Rocks of Middle Cambrian age include massive shallow water carbonate rocks and clean quartzite. A shallow water carbonate bank covered all of west Newfoundland by Upper Cambrian time except the extreme southwest part, where back reef quartzite was deposited. The bank remained stable until the end of the Lower Ordovician when, contemporaneous with the first appearance of easterly derived flysch in the Curling sequence, it sank faster than the rate of sedimentation, and deeper water limestone and shale of the Table Head Formation were deposited in the miogeosyncline. About 6000 feet of shallow water rocks were laid down.

The Table Head Formation is informally divided into three members (Schuchert and Dunbar, [illegible] Kindle, 196[illegible]). The lower Table Head is made up of nodular, poorly bedded limestone about 800 feet thick at the type section and is probably a bank edge deposit. The middle Table Head is about 250 feet of thin to medium bedded limestone including some turbidites. Radiolarian-bearing limestone of possible pelagic origin and black to brown interbedded shale. The middle Table Head resembles a basin slope or margin deposit and is best described as a carbonate flysch. About 30 feet of dark graptolitic shale of basinal aspect completes the upper Table Head. Thick limestone conglomerates occur at various horizons above the lower Table Head from Pistolet Bay to Cape Cormorant on the Port au Port Peninsula where they are particularly well developed. No conglomerate occurs at the Table Head type section but slumped horizons are common. The conglomerate horizons have been correlated by previous authors with those of the Cow Head Group but differ in several important ways. The Table Head conglomerates are interbedded with Middle Ordovician graptolitic shale and are essentially coeval and somewhat younger than the youngest conglomerate in the Cow Head Group. In some places the clasts in the Table Head conglomerates are largely derived from one source, frequently the middle Table Head, but more commonly represent carbonate rocks of different ages. The source of the Table Head conglomerate must have had much greater stratigraphic relief than that of the Cow Head conglomerate and was probably a series of fault scarps related to the collapse of the miogeosyncline. Up to 500 feet of autochthonous conglomerate, limestone and shale were deposited at Cape Cormorant during the span of a single graptolite zone whereas the Cow Head is condensed and only 700 or 800 feet of sediment were deposited during all of Middle Cambrian to Middle Ordovician time.

There is some evidence that the Table Head is diachronous. Its conodont faunas suggest (J. Fahraeus, per. comm.) that the middle Table Head at Hare Bay, to the east of the area, is older than the type middle Table Head farther west. Also part of the lower Table Head on Port au Port Peninsula seems to be as young as the type middle Table Head.

The Table Head is provisionally interpreted as a migrating series of facies that progressed westward as the sea deepened over the miogeosyncline. The Table Head and Cow Head conglomerates are analogous inasmuch as both formed at the eastern margin of a carbonate bank, whereas the middle and upper Table Head are analogous to the carbonate flysch and shale of the Curling Group. The easterly derived flysch above the Table Head is the external part of the flysch fan that spread over the Curling and Cow Head Groups from tectonic lands within the geosyncline.

From Middle Cambrian to Lower Ordovician time shallow water carbonate rocks were deposited [illegible]. It is suggested that these rocks passed eastward into deeper water carbonate rocks of the lower and middle Table Head facies which were the source of much of the limestone detritus in the Cow Head conglomerate (Figure [illegible]). No trace of this older Table Head facies remains unless it is represented by the Brent Island and part of the South Arm limestones described by Cooper (1937, p. [illegible]) from Hare Bay. The Table Head facies is thought to have been intermediate between the shallow water carbonate rocks of the shelf and the fine turbidite facies of the allochthons. Near the end of the Lower Ordovician the facies belts — shallow water limestone, Table Head limestone, conglomerate, limestone — slowly migrated westward as the west Newfoundland miogeosyncline foundered.

The thick succession of easterly derived flysch which follows the upper Table Head is the external part of the flysch wedge developed in the upper part of the Humber Arm allochthon. The flysch under the Hare Bay allochthon is referred to the Goose Tickle Formation (Cooper, 1937; Tuke, 1968) and is of Llanvirn age. The Goose Tickle is about 1000 feet thick at the type section. Lenses and thin beds of coarse breccia and conglomerate derived from the Hare Bay allochthon occur near the top of the Goose Tickle. Although most of the clasts were derived from a single unit of the allochthon (Tuke, 1968) detritus can be found from all units of the Hare Bay allochthon including the ophiolites. The occurrence of clasts of shallow water

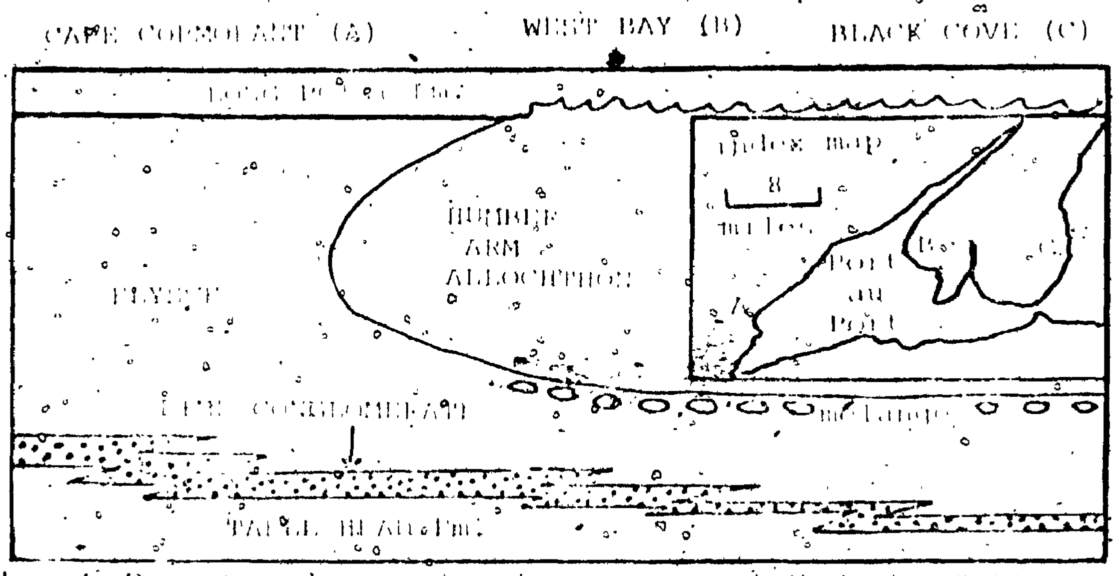


Figure 17. D[illegible] [illegible] across the south western margin of the Humber Arm allochthon

limestone. Sometimes [illegible] a puzzling feature of the conglomerates and breccias as they have no apparent source in the Hare Bay allochthon. Some of the breccias and conglomerates are turbidite [illegible] with abundant shales [illegible] mudflows.

Much of the [illegible] under the Humber Arm allochthon was [illegible] deformed during emplacement of the [illegible] and by later movement so that it [illegible] difficult to distinguish between [illegible] allochthonous flysch. In the Port au Port [illegible] however, the autochthonous flysch is well preserved. The observed relationships are shown in Figure 17. North of Stephenville east of Port au Port Peninsula the flysch is overlain by the Humber Arm allochthon with an [illegible] melange. The allochthon is [illegible] overlain by the late Middle Ordovician Long Point Formation of shallow water [illegible] limestone and shale in the central part of the Port au Port Peninsula (Rodgers [illegible]). At the western end of the peninsula [illegible] the flysch seems to pass upward [illegible] Long Point Formation with no [illegible] rocks present in the [illegible] [illegible] feet of [illegible] are exposed between the limestones [illegible] of Cape Cormorant and the base of the Long Point Formation.

The westerly derived calcareous flysch of the middle of Table Head and the overlying quartzofeldspathic flysch derived from the east are separated by a thin turbidite free dark shale horizon of the upper Table Head. There is little or no interbedding of the two turbidite types. The maximum clast size in the calcareous turbidites as well as the turbidite bed thickness decreases gradually from the base of Cape Cormorant section up to the dark shale horizon showing that the turbidity currents became progressively weaker perhaps because of the general westward migration of the autochthonous carbonate facies including the bank edge that [illegible] turbidite sedimentation between the two turbidite sequences is evident at many other localities and the dark shales often bear profuse graptolites as at Table Point (Whittington and Kindle 1969) and Black Cove (Morris and Kay 1966). The flysch basin seems to have been temporarily out of reach of both easterly and westerly derived turbidites and received only pelagic basinal sediments.

The first greywacke horizons of the easterly derived flysch are predominantly fine grained and show the characteristics of distal turbidites (Plate 1 figure 1). These pass gradually upward into flysch with coarse grained and thick bedded greywackes interpreted as proximal turbidites (Plate 1 figure 2). Contorted shale with exotic blocks is associated with the proximal turbidites. The vertical gradation from distal to proximal turbidites might be due to the source gliding into the basin of deposition. Most but not all of the lithic fragments in the greywackes can be matched with rocks in the Humber Arm allochthon. Detritus from the ophiolites is particularly prominent. The uppermost beds exposed are calcareous sandstone which resembles basal beds of the Long Point Formation exposed on islands a few hundred yards offshore. The contact is under water but it seems reasonable to assume that the greywackes grade into the basal Long Point because the lithologies of the units are similar and they are structurally conformable. If a gradation exists the original western front of the Humber Arm allochthon occurs on the Port au Port

PLATE 1

FIGURE 1. — [illegible] at the [illegible] of the quartzo-feld[illegible] at Cape Cormorant.

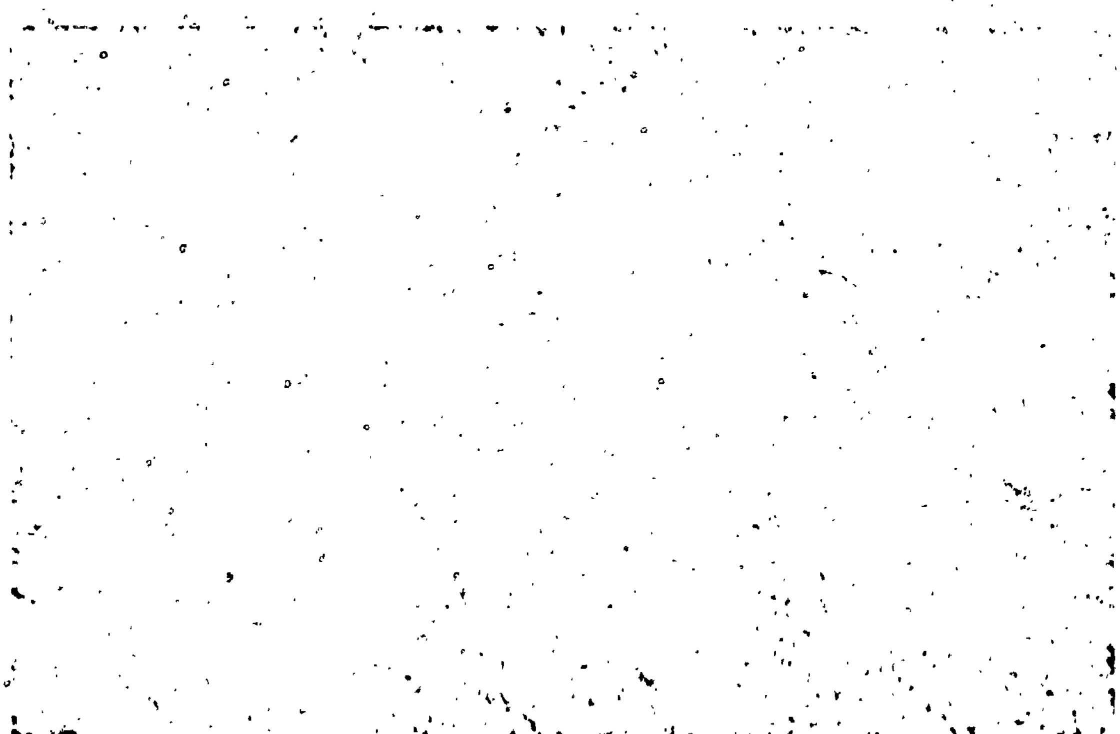


FIGURE 2. — [illegible] about 2000 feet above the [illegible] shown in Figure 1.

Peninsula between Cape Cormorant and the village of Lourdes.

Parautochthonous Sequences

Slices of carbonate rock, flysch and chert are locally intercalated between the autochthonous flysch and the base of the Humber Arm allochthon. Most have not been investigated in detail and are small. The slices are interpreted as parautochthonous scales dragged under the allochthon. Good exposures of parautochthonous flysch, the Goulds Pond Formation of Troelsen (1947), are seen in Bonne Bay where an olistostrome derived from the front of the Humber Arm allochthon occurs near the top of the flysch. The Pelican Hills Klippe (Lilly, 1963, p. 90), made up of about 400 feet of carbonate rock resembling the autochthonous carbonates, can also be interpreted as a parautochthonous slice beneath the Humber Arm allochthon.

AGE OF THE EMPLACEMENT OF THE ALLOCHTHONS

Rodgers (1965) concluded that the Humber Arm allochthon was emplaced in mid Middle Ordovician time because it is unconformably overlain by the Long Point Formation of Wilderness age. Berry (1960) correlated the Wilderness Stage with zone 13 of his Marathon graptolite succession and with the lower part of the Caradoc of the British Isles. The youngest graptolites collected by the writer [illegible] under the Humber Arm allochthon seem to be of Llandeilian age (zone 10 according to B.D. Erdtmann and F. Ray, pers. comm.), so that the allochthon seems to have been emplaced between zones 10 and 13 during Llandeilian or early Caradocian time.

Graptolites from the youngest preserved parts of the Goose Tickle Formation are of Llanvirn age so the Hare Bay allochthon may have been emplaced at about the same time as the Humber Arm allochthon or perhaps a little earlier. Some of the movement zones, however, have been reactivated, probably during the elevation of the Long Range horst. It will be shown that the allochthons were already moving during late Arenig time, so that the transportation was a slow process.

DISCUSSION

Flysch successions yield several different sorts of data of tectonic value. In general, well dated flysch successions provide paleogeographic data and indicate the composition of their source terranes, two basic requirements for regional tectonic analysis. A preliminary study of the flysch successions in west Newfoundland helps clarify the original relationships of the four Cambro-Ordovician sequences and provide some information on the early tectonic evolution of both west and central Newfoundland.

Figure 8 shows a palinspastic reconstruction of the continental margin prior to deposition of the late Arenig easterly derived flysch. The facies distribution resembles a continental terrace wedge–continental rise prism couple like that described by Dietz (1963, p. 316). The continental terrace wedge, the miogeosyncline, consists of autochthonous shallow water sediments. Mafic igneous activity immediately preceded the establishment of the miogeosyncline.

The continental rise prism consists of the allochthonous Cow Head and Curling Groups, as well as the metamorphosed clastic rocks of the Burlington Peninsula described by Church (1969), Neale and Kennedy (1967), and Williams (1961). Only the transported thin inner edge of the prism has escaped metamorphism and severe deformation. The lithology of the continental terrace wedge and continental rise prism can be correlated in a general way. The hematite-rich Lower Cambrian beds of the continental terrace wedge have their equivalent in the reddish turbidites and shale of Lower Cambrian age in the transported part of the continental rise prism. The clean quartz turbidites often with shallow water limestone pebbles could have been derived from a source like the autochthonous back bank sandstones. The transition from quartzo-feldspathic flysch to carbonate flysch near the Lower-Middle Cambrian boundary in the Curling sequence reflects the establishment of a carbonate bank in the source area of the turbidites in Middle Cambrian time, probably due to the maturing of the continental margin (as described by Dietz, 1963, p. 317).

The protoliths of the metamorphosed part of the continental rise prism generally resemble the Curling Group but are much thicker and probably include Precambrian rocks. Not all of the metamorphosed part of the rise prism, however, need have been deposited in deep water if the continental margin evolved by faulting and subsidence as shown by Carey (1958, p. 184, figure 3).

Gravity data (Weaver, 1967) suggests that the present eastern edge of the miogeosyncline, the Cabot fault zone, approximately coincides with the change from crust of the "Grenville type" to that of the "Appalachian type". The oceanward edge of the continental terrace wedge therefore might have coincided with the edge of the old North American continent as predicted by Dietz's model of the Appalachian orogene (Dietz, 1963, p. 339, and Rodgers, 1969, p. 117).

The seismic profiles of Sheridan and Drake (1968), however, show a layer of Precambrian shield east of the Cabot Fault zone. This material might be the metamorphosed continental rise prism but might also include some basement material. The configuration of the basement at the old continental margin is not yet clear, but it might be expected that it resembled that of the present day Atlantic margin (Drake *et al.*, 1968) or that part of the Red Sea underlain by continental crust (Drake and Girdler, 1964).

174

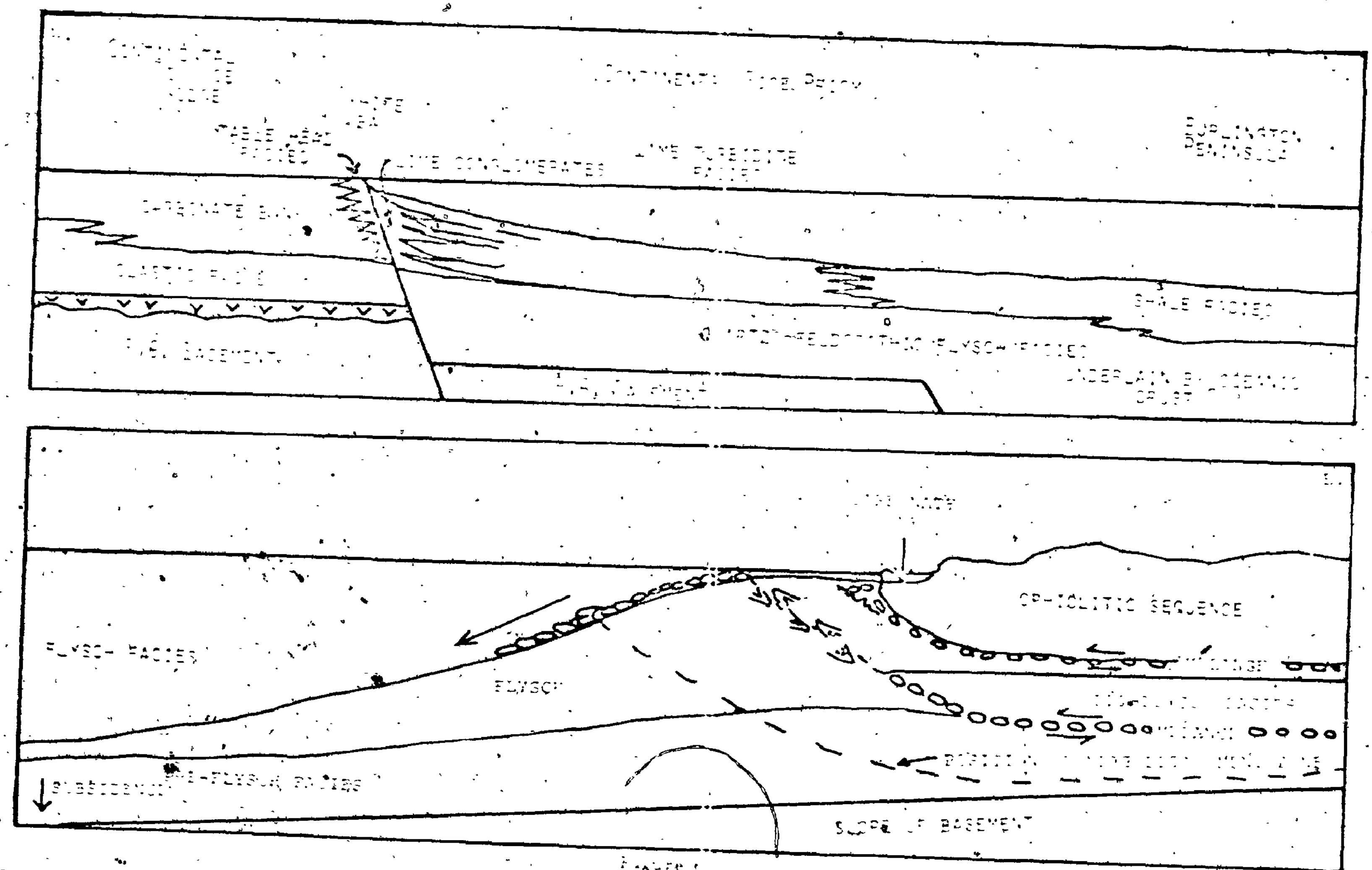


Figure 5 (Upper). Reconstruction of west Newfoundland in early Arenig time

Figure 6 (Lower). Reconstruction of the emplacement of the Humber Arm allochthon

The ophiolitic sequence is not shown in Figure 5 but it probably was the most easterly of the sequences and might represent oceanic crust originally east of the continental rise. This interpretation of the ophiolites is in accord with recent interpretations of the Cyprus (Gass, 1966), Oman (Reinhardt, 1969), and New Guinea (Davies, 1968) ophiolites. The occurrence of high pressure assemblages in the ultramafic rocks of the Newfoundland ophiolites and the association, ultramafic rock, gabbro, pillow lava, black shale, and chert supports this conclusion but other explanations are possible.

The conglomerate in the basal greenschists of the ophiolitic complexes is the first recognized sign of instability along the continental margin, and seems to have been derived from the continental rise prism during an early stage of its deformation. Stronger deformation of the continental margin is apparent during late Arenig time. The miogeosyncline margin subsided rapidly, subsidence being at least 5,000 feet from late Arenig to Caradoc compared with about 6,000 feet during the whole of the Cambrian and most of the Arenig. Also in late Arenig time internally derived flysch first appeared in the Curling Group and later spread westward to cover Cow Head Group in early Llanvirn (Kindle and Whittington, 1958) and the autochthon in late Llanvirn. The youngest beds in each of the slices of the Humber Arm allochthon consist of the internally derived flysch (Figure 3) with abundant ophiolitic fragments such as chromite. Since the ophiolites are the highest structural slice of each allochthon but are coeval with parts of the Curling, Cow Head, and autochthonous sequences, the ophiolites must have overrun the other successions before they were covered by other tectonic slices. The ophiolite slices must have been the first to move, probably in the late Arenig.

The emplacement of the allochthons, at least in the later stages, seems to have been by gravity sliding as suggested by Rodgers and Neale (1963). It is here suggested that the ophiolites, at least two miles thick in the Bay of Islands Complex, controlled the emplacement, peeling the underlying slices from their substrate as they slid westwards. The process is illustrated in Figure 6. The motive force in the later stages is gravity rather than crustal compression, but the process is otherwise analogous to peel thrusting as described by Bucher (1955, p. 355). This type of tectonic activity might be called "gravity slide peeling".

Since the ophiolites were providing detritus to the flysch they later overran, they must have been exposed to erosion and at least partially above sea level even though the base was below sea level. The ophiolites and some of the allochthonous sediment must have been emplaced as migrating islands or archipelagos. It is possible therefore that the shallow water limestone detritus, mixed with detritus from the Hare Bay allochthon, found in Goose Tickle Formation was derived from small carbonate banks fringing the moving emergent allochthon.

Two sorts of melange developed during the emplacement of the allochthons: a) tectonic melange formed in the decollement zones, locally in association with recumbent folds, b) sedimentary melange (wildflysch and olistostromes) developed as part of the flysch facies in front of the allochthons. The maximum size of the blocks in the sedimentary melange is difficult to estimate because the blocks grade, by definition, into tectonic slices emplaced by gravity sliding into the flysch basin in front of the main allochthons. The allochthons, gradually sliding westwards into unconsolidated sediment on the rim of the basin, must have been an effective trigger for slumps, slides, and turbidity currents. The various phenomena associated with the movement of the Humber Arm allochthon are shown in Figure 6.

TECTONIC CLASSIFICATION OF FLYSCH IN WEST NEWFOUNDLAND

The flysch in west Newfoundland formed in two different tectonic environments. The greatest volume of flysch is interpreted as part of a former continental rise prism derived from the continents via a continental terrace wedge. This can be called *Atlantic type flysch* because it was deposited under a tectonic regime like that of the continental rises in the present Atlantic Ocean (Dewey, 1969). Atlantic type flysch is associated with young to mature ocean basins as defined by Wilson (1968). Rift and block fault tectonics at the continental margin provided the relief necessary for the thick accumulation of flysch.

The upper flysch of the allochthons and all of the autochthonous flysch was derived from the direction of the ocean from the allochthons themselves and also from tectonic lands produced by the deformation of the thickest part of the continental rise prism. This can be called *Pacific type flysch* because it forms only at tectonically active continental margins such as those around the present Pacific Ocean. A marginal cordillera can, as Kay (1966) pointed out, shed detritus toward the continent, as in the case of the west Newfoundland Pacific type flysch, or toward the ocean basins, as in the case of the central Newfoundland and Pacific type flysch. It should be possible to distinguish Pacific flysch, deposited on the continental rise and ocean floor, from Atlantic flysch on the basis of the inferred source terrain even if dispersal directions are parallel to the tectonic strike. Pacific flysch contains detritus that can be matched with rocks of the newly formed cordillera while the lithic fragments in Atlantic flysch should include those derived from ancient plutonic complexes of the shield. Fragments from a continental terrace wedge, such as shallow water limestone, might be common in both types of flysch. A closing ocean basin, as defined by Wilson (1968) and related compressional tectonics is necessary for the formation of Pacific type flysch. The elevation of the ocean-ward continental margin together with the collapse of the miogeosyncline, provide the submarine relief necessary for flysch sedimentation. If an ocean basin closes completely, Pacific flysch and allochthonous ophiolites may be the only geological record of its former existence. Other examples of Pacific type flysch include the Martinsburg Formation of the Appalachian region (McBride, 1962), the Patagonian flysch of the Andes Mountains (Scott, 1966), and the type of flysch of the Swiss Alps (Trümpy, 1960).

The extensive ophiolite complexes of Bay of Islands and Hare Bay may be only small erosional remnants of a much larger sheet because virtually all post-middle Arenig clastic rock in west Newfoundland contains a significant amount of ultramafic detritus. This lends some credence to the suggestion that the ophiolites are parts of the lower Paleozoic ocean floor thrust out of the ocean and transported onto the continent during the closing of the ocean.

The integration of the deformation and metamorphism of the marginal metamorphic rocks with the overthrusting of the ocean floor remains a task for the future, but the ophiolitic slices pinched into the metamorphic rocks of the Burlington Peninsula (Figure 1) greatly resemble the transported ophiolites (greenschist overlain by peridotite, gabbro, and mafic volcanic rocks, shale and chert) and might be the remains of the same sheet, rooted somewhere east of the Burlington Peninsula.

CONCLUSIONS

The occurrence of Atlantic and Pacific types of flysch associated with possible allochthonous ocean floor in western Newfoundland suggests that the Cambro-Ordovician tectonic regime of Newfoundland is related to a cycle of ocean birth and destruction. Wilson (1966, 1967) has already postulated the destruction of a proto-Atlantic Ocean. During the deposition of the Atlantic type flysch the former continental margin was deformed by vertical movements of tensional origin. During the deposition of the Pacific type flysch, however, the margin was deformed by compression giving rise to both vertical buckling and horizontal movements.

ACKNOWLEDGMENTS

The present study of west Newfoundland was started under the direction of H. D. Lilly and W. D. Brückner at Memorial University of Newfoundland and continued at the University of Western Ontario directed by W. R. Church. The Geological Survey of Canada provided support for field work during 1966 and 1967. The problem has been discussed with J. M. Bird, J. Rodgers, H. Williams, G. M. Young, and E-an Zen. W. R. Church and G. M. Young have criticized the manuscript. The writer acknowledges his debt to these people and institutions.

REFERENCES

Baird, D. M. (1960) - Observations on the nature and origin of the Cow Head breccias of Newfoundland. Geol. Surv. Canada, Paper 60-3.

Berry, W. B. N. (1960) - Graptolite faunas of the Marathon region, West Texas: Univ. Texas Publ. 6005.

Betz, F., Jr. (1939) - Geology and mineral deposits of the Canada Bay area, Northern Newfoundland: Newfoundland Geol. Surv. Bull. No. 16.

Bruckner, W. D. (1966) - Stratigraphy and structure of West Central Newfoundland: *in* Poole, W. H. (editor) Guidebook, Geology of parts of Atlantic Provinces, Ann. Meeting, Geol. Assoc. Can., Min. Assoc. Can., pp. 137-151.

Bucher, W. H. (1955) - Deformation in orogenic Belts: Geol. Soc. Amer. Spec. Paper 62, pp. 343-368.

Carey, S. W. (1958) - A tectonic approach to continental drift, *in* Continental Drift, a symposium. Carey, S. W. (convener), University of Tasmania Press, pp. 177-358.

Church, W. R. (1969) - Metamorphic rocks of the Burlington Peninsula and adjoining areas of Newfoundland and their bearing on continental drift in North Atlantic, *in* Kay, M. (editor) North Atlantic - Geology and Continental Drift. Am. Assoc. Petrol. Geol. Mem. 12, pp. 212-233.

Clifford, P. M. and Baird, D. M. (1962) - Great Northern Peninsula of Newfoundland - Grenville Inlier: Canadian Inst. Mining and Met. Bull. No. 599, pp. 150-157, 267-277.

Cooper, J. R. (1936) - Geology of the southern half of the Bay of Islands igneous complex. Newfoundland Dept. Nat. Res., Geol. Sec. Bull. No. 4.

.... (1937) - Geology and mineral deposits of the Hare Bay area: Newfoundland Dept. Nat. Res., Geol. Sec. Bull. No. 9.

Davies, H. L. (1968) - Papuan Ultramafic Belt. XXIII Internat. Geol. Cong. vol. 1, pp. 209-220.

Dietz, R. S. (1963) - Collapsing continental rises - an actualistic concept of geosynclines and mountain building. J. Geol., vol. 71, pp. 314-333.

Drake, C. L., Ewing, J. I., and Stockard, H. (1968) - The continental margin of the eastern United States. Can. J. Earth Sci., vol. 5, pp. 993-1010.

Drake, C. L., and Girdler, R. W. (1964) - A geophysical study of the Red Sea: J. Roy. Astronom. Soc., vol. 8, pp. 473-494.

Dunbar, C. O. (1934) - Mid Ordovician thrust faulting in western Newfoundland, (Abs.), Geol. Soc. Amer. Proc. 1933, pp. 76-77.

Gass, I. G. (1967) - The ultramafic volcanic assemblage of the Troodos Massif, Cyprus, *in* Wyllie, P. J. (editor) Ultramafic and Related Rocks. John Wiley and Sons, Inc., pp. 121-134.

Horne, G. S. (1969) - Early Ordovician chaotic deposits in the Central Volcanic Belt of Northeastern Newfoundland. Bull. Geol. Soc. Amer., vol. 80, pp. 2451-2464.

Hubert, C. (1967). Tectonics of part of the Sillery Formation in the Chaudière-Matapedia segment of the Quebec Appalachians, in Clark, T. H. (editor), Appalachian Tectonics. Roy. Soc. Canada Spec. Publ. No. 10, pp. 33-40.

Johnson, H. (1941). Paleozoic lowlands of Western Newfoundland. New York Acad. Sci. Trans. ser. 2, vol. 3, pp. 141-145.

Kay, M. (1951). North American Geosynclines. Geol. Soc. Amer., Mem. 48.

——— (1966). Comparison of the Lower Paleozoic Volcanic and Non-Volcanic Geosynclinal Belts in Nevada and Newfoundland. Bull. Can. Petrol. Geol. vol. 14, pp. 579-599.

Kindle, C. H. (1945). Geology of the Pistolet Bay area. Summ. rept. Unpubl. rept., Geol. Surv., Nfld., St. John's.

——— and Whittington, H. B. (1958). Stratigraphy of the Cow Head region, Western Newfoundland. Geol. Soc. Amer. Bull., vol. 69, pp. 315-342.

Lilly, H. D. (1963). Geology of the Hughes Brook-Goose Arm Area, West Newfoundland. Memorial Univ. Newfoundland, Geol. Rept. no. 2, St. John's.

Logan, W. E. (1863). Geological Survey of Canada. Report of its progress from its commencement to 1863. Montreal.

McBride, E. F. (1962). Flysch and associated beds of the Martinsburg Formation (Ordovician), Central Appalachians. J. Sed. Pet., vol. 32, pp. 39-91.

Morris, R. W. and Kay, M. (1966). Ordovician Graptolites from the Middle Table Head Formation at Black Cove, Port au Port, Newfoundland. J. Pal., vol. 40, pp. 1223-1224.

Murray, A. M. and Howley, J. P. (1881). Geological Survey of Newfoundland from 1864-1880. London, Stanford.

Neale, E. R. W., and Kennedy, M. J. (1967). Relationships of the Fleur de Lys group to younger groups of the Burlington Peninsula, Newfoundland, in Geology of the Atlantic Region, Neale, E. R. W. and Williams, H. (editors); Geol. Assoc. Canada Spec. Paper No. 4, pp. 139-169.

Reinhardt, B. M. (1969). On the genesis and emplacement of Ophiolites in the Oman Mountain geosyncline. Schweiz. mineral. Petrogr. Mitt., vol. 49, pp. 1-30.

Rodgers, J. (1965). Long Point and Clam Bank Formations, Western Newfoundland. Proc. Geol. Assoc. Canada, vol. 16, pp. 83-94.

——— (1969). The eastern edge of the North American Continent during the Cambrian and Early Ordovician, in Studies of Appalachian Geology, Northern and Maritime (editors) Zen, E-an, White, W. S., Hadley, J. B., and Thompson, J. B. Jr., pp. 141-149, Interscience.

——— and Neale, E. R. W. (1963). Possible Taconic Klippen in western Newfoundland. Am. J. Sci., vol. 261, pp. 713-730.

Sanders, J. E. and Friedman, G. M. (1967). Origin and occurrence of limestones, in Carbonate Rocks (editors) Chilingar, G. V., Bissell, H. J., and Fairbridge, R. W., Elsevier, pp. 169-265.

Schuchert, C. and Dunbar, C. O. (1934). Stratigraphy of western Newfoundland. Geol. Soc. Amer., Mem. 1.

Scott, K. M. (1966). Sedimentary and dispersal pattern of a Cretaceous flysch sequence, Patagonian Andes, Southern Chile. Am. Assoc. Petrol. Geol. Bull., vol. 50, pp. 72-107.

Sheridan, R. E. and Drake, C. L. (1968). Seaward extension of the Canadian Appalachians. Can. J. Earth Sci., vol. 5, pp. 337-373.

Smith, C. H. (1958). Bay of Islands Igneous complex, western Newfoundland. Geol. Surv. Canada, Mem. 290.

Stevens, R. K. (1965). Geology of the Humber Arm, west Newfoundland. M.Sc. thesis, Memorial Univ. of Newfoundland.

——— (1968). Taconic Klippen of western Newfoundland (12 H, M), in Geol. Surv. Canada, Rept. of Activity, Pt. A, May to Oct. 1967, pp. 8-9.

———, Church, W. R., and St. Julien, P. (1969). Age of Ultramafic rocks in the North Western Appalachians. Geol. Soc. Amer., Abstr. 1969, pt. 7, pp. 215-216.

Troelsen, J. C. (1947). Geology of the Bonne Bay-Trout River area, Newfoundland. Ph.D. dissert., Yale Univ.

Trumpy, R. (1960). Paleotectonic evolution of the Central and Western Alps. Geol. Soc. Amer. Bull., vol. 71, pp. 843-908.

Tuke, M. F. (1968). Autochthonous and allochthonous rocks in the Pistolet Bay area in northernmost Newfoundland. Can. J. Earth Sci., vol. 5, pp. 501-513.

Walthier, T. N. (1949). Geology and mineral deposits of the area [illegible] Stephenville, western Newfoundland. Geology and Mineral deposits of the area between Lewis Hills and Bay St. George, western Newfoundland. Newfoundland Geol. Surv., Bull. 35.

Weaver, D. F. (1967). A geological interpretation of the Bouguer Anomaly Field of Newfoundland. Dominion Observatory Publ., Vol. XXXV, no. 5, pp. 223-251.

Whittington, H. B. and Kindle, C. H. (1963). Middle Ordovician Table Head Formation, western Newfoundland. Bull. Geol. Soc. Amer., vol. 74, pp. 745-758.

Williams, H. (1964). The Appalachians in northeastern Newfoundland — a two-sided symmetrical system. Am. J. Sci., vol. 262, pp. 1137-1158.

——— and Stevens, R. K. (1969). Geology of Belle Isle — Northern extremity of the deformed Appalachian miogeosynclinal belt. Can. J. Earth Sci., vol. 6, pp. 1145-1157.

Wilson, J. T. (1966). Did the Atlantic Ocean close and re-open? Nature, vol. 211, pp. 676.

——— (1967). Some implications of new ideas on Ocean-floor spreading upon the geology of the Appalachians, in Clark, T. H. (editor), Appalachian Tectonics. Roy. Soc. Canada, Spec. Publ. No. 10, pp. 94-99.

——— (1968). Static or mobile earth: The current scientific revolution, in Gondwanaland Revisited: New Evidence for Continental Drift. Proc. Am. Phil. Soc., vol. 112, pp. 309-320.

Zen, E-an. (1961). Stratigraphy and structure at the north end of the Taconic Range in west-central Vermont. Geol. Soc. Amer. Bull., vol. 72, pp. 293-338.

Reprinted from:

Contribution of the Department of Geology

University of Western Ontario

London, Canada.

Number 175,

Preliminary Report

3 p.

(with W.R. Church)

CONTRIBUTION OF THE
DEPARTMENT OF GEOLOGY
UNIVERSITY OF WESTERN ONTARIO
LONDON, CANADA NO. 175
PRELIMINARY RPT.

MANTLE PERIDOTITE AND THE EARLY PALEOZOIC OPHIOLITE COMPLEXES OF THE NEWFOUNDLAND APPALACHIANS

by

W. R. Church and R. K. Stevens

The early Ordovician ophiolite complexes of the Newfoundland Appalachians are considered to be remnants of a once extensive ophiolite sheet composed of a basal peridotite, an intermediate gabbroic layer, and upper layer of sheeted diabase, pillow lava, and chert and greywacke sediment (Stevens, Church and St. Julien, 1969). The basal peridotite of the allochthonous Bay of Islands complex has a lower lherzolite-harzburgite layer with thin magnesian amphibolite-pyroxenite layers containing kaersutite, titaniferous phlogopite, ceylonite, aluminous pyroxenes, and pyropic garnet. The chemistry of these minerals closely resembles that of the same minerals in the upper mantle lherzolites and amphibole-ariegites of the type-locality at Lherz, French Pyrenees. The gabbroic rocks are intrusive into the peridotite which occurs as feldspar-metasomatised xenoliths in the gabbro. The sheeted diabases cut the gabbros and pillow lavas, and locally the peridotite. The volcanic rocks are tholeiitic and spilitic. The Newfoundland ophiolite complexes are comparable to those of the Oman (Rheinhardt, 1969), the Sesia Lanzo zone of the Western Alps (Nicolas, 1968), Papua (Davies, 1968) and New Caledonia (Avias, 1967). They are however unique in having high-pressure mantle assemblages, and well preserved high-temperature garnet-pyroxenite contact aureoles which are in places superposed on a garnet-biotite grade regional metamorphic fabric. These features relate the Newfoundland peridotites to intrusive ultramafic rocks such as those of Mount Albert (Smith and MacGregor, 1960), the Lizard (Green, 1964), Beni Bouchera (Kornprobst, 1969), La Ronda (Dickey, 1969) and the Ivrea Zone (Nicolas, 1968). The high-temperature aureoles of the Newfoundland complexes also distinguish them from the Papuan and New Caledonian allochthonous ophiolite sheets (Avias, 1967) considered to be 'cold' oceanic plates, and the Franciscan ultramafic rocks emplaced into Benioff fault zones during tectonism and low-temperature blueschist metamorphism of underlying oceanic sedimentary and volcanic rock (Ernst, 1969; Blake et al., 1969).

The existence of early Paleozoic ophiolite complexes in the Appalachians contradicts recent assertions (Moore, 1969) that ophiolites are restricted to the [illegible]zoic, and lends little support to recent models on the evolution of the Caledonian/Appalachian orogen (cf. Dewey, 1969) whereby the peridotites are regarded as relatively [illegible] intrusive [illegible] derived from a hypothetical basaltic root beneath the [illegible] Moine-Dalradian orthotectonic belt (Church, 19[illegible]). The present interpretation of the ophiolite complexes of the Newfoundland Appalachians suggests that they are a feature of considerable tectonic significance in the evolution

of the Caledonian/Appalachian orogen, their emplacement separating a late-Cambrian phase of tectogenic deformation and metamorphism from the mid-Ordovician epeirogenic movements responsible for the development of the Western and Central Newfoundland flysch troughs, and the emplacement of the Western Newfoundland Taconic klippen (Stevens, 1970).

Along with the Omani occurrence, the Newfoundland ophiolite complexes afford one of the best opportunities to resolve the question whether ophiolites in orogenic belts represent allochthonous oceanic crust which once separated independent continental masses growing by accretion, or pseudo-oceanic floors extruded directly over sialic crust up along zones of distension within an intracratonic orogen undergoing basification.

REFERENCES

Avias, J. 1967. Overthrust structures of the main ultrabasic New Caledonian massives. Tectonophysics, 4, p. 531-541.

Bird, J. M. and Dewey, J. F. 1970. Lithosphere Plate: continental margin tectonics and the evolution of the Appalachian orogen, 81, p. 1031-1060.

Blake, M. C. Jr., Irwin, W. P., and Coleman, R. G. 1969. Blueschists-facies metamorphism related to regional thrust faulting. Tectonophysics 8, p. 237-247.

Church, W. R. 1969. Metamorphic rocks of Burlington peninsula and adjoining areas of Newfoundland, and their bearing on continental drift in North Atlantic. North Atlantic Geology and continental drift (Marshall Kay ed.), p. 212-233.

Davies, H. L. 1968. Papuan Ultramafic Belt. International Geological Congress, Report of the twenty-third session Czechoslovakia, 1968, p. 209-220.

Dewey, J. F. 1969. Evolution of the Appalachian/Caledonian orogeny. Nature, 222, p. 124-129.

Dickey, J. S. Jr., 1969. Partial fusion products in alpine-type peridotites: Serrania de La Ronda and other examples. Prog. Geol. Soc. Am. Ann. Meeting, Atlantic City, N. J., p. 147 (Abst.).

Ernst, W. G., 1969. Tectonic contact between the Franciscan melange and the Great Valley [illegible], a late Mesozoic [illegible] zone. [illegible] Ann. Meet, Geol. Soc. Am., Atlantic City, p. 59.

Green, D. H. 1964. The petrogenesis of the high-temperature peridotite intrusion in the Lizard area. Cornwall. Jour. [illegible]

Kornprobst, J. 1969. Le massif ultrabasique de Beni Bouchera (Rif Interne, Maroc); Etude des peridotites de haute temperature et de haute pression, et des pyroxenolites, a grenat ou sans grenat, qui leur sont associees. Contr. Miner. and Petrol., 23, p. 283-322.

Moore, E. M. 1969. Petrology and structure of the Vourinos ophiolitic complex of Northern Greece. Geol. Soc. America Special Paper No. 118, 74 p.

Nicolas, A. 1968. Relations structurales entre le massif ultrabasique de Lanzo, ses satellites, et la zone de Sesia Lanzo. Bull. Suisse Miner. Petrog., 48, p. 145-156.

Reinhardt, B. M. 1969. On the genesis and emplacement of ophiolites in the Oman Mountains geosyncline. Schweitz. Mineral. Petrog. Mitt., 49, p. 1-30.

Smith, C. H., and MacGregor, I. D. 1960. Ultrabasic intrusive conditions illustrated by the Mount Albert ultrabasic pluton Gaspe, Quebec. Geol. Soc. Am. Bull., 71, p. 1978 (Abst.).

Stevens, R. K. 1970. Flysch sedimentation and Ordovician tectonics in West Newfoundland. Geol. Assoc. Canada Spec. Paper No. 7 (in press).

Stevens, R. K., Church, W. R. and St. Julien, P. 1969. Age of ultramafic rocks in the northwestern Appalachians. Prog. Geol. Soc. Am. Ann. Meeting, Atlantic City, p. 215-216 (Abst.).

143

Reprinted from:

Journal of Geophysical Research,
Volume 76, Number 5, 1971,
p. 1460-1466

(with W.R. Church)

[illegible] granodiorite, [illegible] porphyry. [illegible]

[illegible]

Taconic [illegible] [*Hess*, 19[illegible]; *Dietz*, 1963; *Poole*, 19[illegible]; *Bird and Dewey*, 1970].

Recent work in the Newfoundland Appalachian [illegible] (partly unpublished) [*Rodgers and Neale*, 19[illegible]; *Kay*, 1966; *Church*, 1969; *Horne* [illegible] *Helwig*, 1969; *Williams*, 1969; *Stevens*, 1970], [illegible] considerable [illegible] of the older concept on the structure of the Appalachian and its evolution. *Stevens* [1970] [illegible] and detailed the existence of the allochthonous rocks of the Western platform. He [illegible] that the ultramafic [illegible] complexes were emplaced by early Ordovician time and [illegible] allochthon are composed of a number of [illegible] emplaced in a westerly [illegible] that developed in early Ordovician [illegible] the Baie des [illegible] of the [illegible] sequence of the orthotectonic zone (Figure 1). *Church and Stevens* [1971] [illegible] the allochthonous [illegible] were derived [illegible] now [illegible] White Bay fault zone. A [illegible] zone [illegible] is represented by a vertical belt of Ordovician and Siluro-Devonian rocks extending [illegible] Notre Dame [illegible] (Burlington peninsula) [illegible] [illegible] [illegible].

Kay [1969] and *Horne and Helwig* [1969] have shown that the late Ordovician Taconic orogeny [illegible] recorded in central Newfoundland; [illegible] support the [illegible] tectonic [illegible] of the [illegible] orthotectonic [illegible] formed [illegible] the late [illegible] the late Ordovician [illegible].

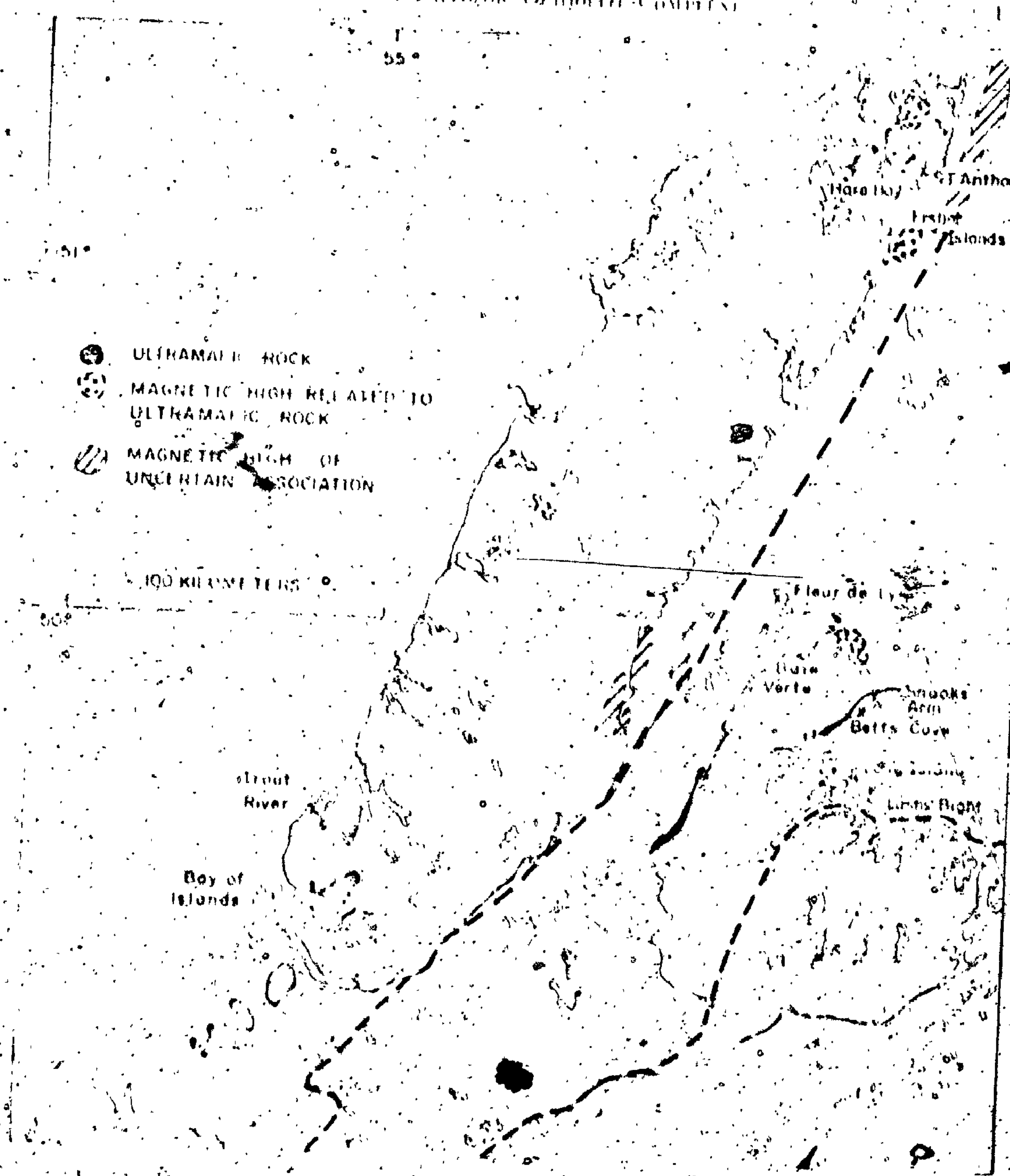
The [illegible] plate tectonic theory has also [illegible] [illegible] of the evolution of the Appalachian and has [illegible] of the [illegible] of the Western platform [illegible] [illegible] [illegible] [illegible] 1969; *Stevens*, 1970; [illegible] 1970]. In the [illegible] [illegible] the hypothesis that the ultramafic mafic complexes of Newfoundland are ophiolite sequences that are [illegible] representative of oceanic [illegible].

NEWFOUNDLAND OPHIOLITE COMPLEXES

Ophiolites are considered to be stratiform [illegible] units composed ideally of the sequence peridotite, gabbro, 'sheeted' diabase, and pillow lava, with associated chert and graywacke. The gabbro or sheeted diabase units may not always be represented. Typical examples of Tethyan [illegible] ophiolites are found in Oman [*Reinhardt*, 1969], in Vourinos, northern Greece [*Moores*, 1969], and in Sesia Lanzo, western Alps [*Nicolas*, 1967].

Ultramafic mafic complexes with characteristics of ophiolites as defined above occur as part of the allochthon of the Northwest platform and [illegible] orthotectonic zone (Figure 2). The most typical example of ophiolite occurs at Betts Cove, eastern Burlington peninsula, where the [illegible] of the sequence is composed of harzburgite that contains pyroxenite both as parallel layers [illegible] [illegible] [illegible]. Above the peridotite [illegible] layer of mixed [illegible] pyroxenite and peridotite, followed by gabbro [illegible] [illegible] of the ultramafic [illegible]. The [illegible] diabase, which [illegible] [illegible] [illegible] between the gabbro and the pillow lava [illegible] [illegible] [illegible] Tethyan ophiolite of Oman [illegible] [illegible] the ultramafic, the [illegible] cut neither the basal peridotite [illegible] lava sequence. Above the pillow lava [illegible] sequence of graywacke, volcanic [illegible] and [illegible] pyroxene [illegible] and other pillow lava [illegible].

The Bay of Islands and Hare Bay ophiolite sequences are characterized by [illegible] harzburgite, [illegible] [illegible] [illegible] [illegible] peridotite. The sheeted diabase [illegible] in the Bay of Islands [illegible] [illegible] sheeted [illegible] from the Hare Bay complex [illegible] and pillow lava [illegible] the Bay of Islands complex [illegible] [illegible] between the [illegible] [illegible] the pillow lava [illegible] [illegible] [illegible], 1968], and blocks of peridotite [illegible] [illegible] [illegible] in the gabbro. The peridotite is largely composed of dunite and harzburgite. However, [illegible] of the peridotite unit, the [illegible] harzburgite rocks [illegible] than layers of [illegible] pyroxenite and rock [illegible] coexist with garnet, [illegible] aluminous pyroxene, and [illegible]


55°
51°
50°
ULTRAMAFIC ROCK
MAGNETIC HIGH RELATED TO ULTRAMAFIC ROCK
MAGNETIC HIGH OF UNCERTAIN ASSOCIATION
100 KILOMETERS
St Anthony
Fishot Islands
Fleur de Lys
Baie Verte
Snooks Arm
Betts Cove
Little Bay
Lushs Bight
Trout River
Bay of Islands

[illegible]

[illegible] amphibolite [illegible] present beneath the [illegible] and [illegible] ophiolite complexes [*Moore*, 1967; *Rowley* [illegible]].

The [illegible] Hare Bay complex, although [illegible] and [illegible] by faults, [illegible] low [illegible] dip. However, [illegible] St. Anthony and the [illegible] Islands in the Hare Bay [illegible] vertical [illegible] amphibolite [illegible] of the Northwest platform [illegible] the [illegible] extension of the Hare Bay [illegible] White Bay [illegible] the [illegible] orthotectonic zone [illegible] and the [illegible] [illegible].

Small [illegible] rocks [illegible] in the [illegible] Notre Dame Bay [illegible] rocks along with [illegible] comparable to [illegible] of the [illegible] ophiolite complex [illegible] Island [illegible] Notre Dame Bay [illegible] orthotectonic zone and [illegible] cover of ophiolite and younger rocks. [illegible] ophiolite [illegible] of the Western [illegible] group [illegible] 1969].

[illegible] Cove [illegible] ophiolites of western Newfoundland [illegible] Ordovician [illegible] [illegible] 1969].

CONCLUSIONS

The [illegible] form part of the Newfoundland [illegible] involve the [illegible] Ordovician [illegible] volcanic rocks [illegible] tion by [illegible] Late Cambrian [illegible] tectonic deformation and metamorphism of the [illegible] and volcanic rocks and intrusion of gabbro, [illegible] porphyry and [illegible] Early Ordovician emplacement of ophiolite complexes [illegible] of the [illegible] formation of the western Newfoundland and central Newfoundland [illegible] gravity slide emplacement of the Northwest platform [illegible] and the [illegible] [*Dawson*, [illegible], 1969] of the Exploits zone and extrusion of [illegible] volcanic rocks. (4) [illegible] deposits in the Exploits zone, [illegible] with [illegible] the orthotectonic zone, until Late Silurian [illegible] Late Silurian early Devonian [illegible] Acadian [illegible] the development of [illegible] troughs within the [illegible] filled with [illegible] and [illegible] volcanic rocks [illegible] Acadian deformation and plutonic activity [illegible] to have been [illegible] to Silurian [illegible] Ordovician volcanic [illegible] 1969].

[illegible] 1958; [illegible] the ophiolite complexes of Newfoundland have been [illegible] serpentinite, the evidence presented above, in particular the [illegible] Betts Cove, [illegible] that the ophiolites [illegible] oceanic lithosphere. The [illegible] most clearly indicated by the [illegible] of the Bay of Islands [illegible] and [illegible] Newfoundland [illegible] complex [illegible] which [illegible] oceanic lithosphere [illegible] the ophiolite complexes of [illegible] [*Reinhardt*, 1969], Papua [*Davies*, 1968], New Caledonia [illegible] 1969], the [illegible] of the western Alps [illegible] 1969], and the Dinarides of Yugoslavia [*Ko* [illegible], 1968, 1970]. The ophiolites of western Newfoundland

Continental [illegible] tectonics and the evolution of the Appalachian orogen, *Bull. Geol. Soc. Amer.*, 81, 1031, 1970.

Church, W. R., [illegible] evolution of northeast Newfoundland: Comparison with that of the British [illegible], *M. [illegible]*, 7, 10, 1967.

Church, W. R., Metamorphic rocks of Burlington peninsula and adjoining areas of Newfoundland, and their bearing on continental drift in the North Atlantic, in *North Atlantic—Geology and Continental Drift*, *Amer. Ass. Petrol. Geol. Mem. 12*, edited by M. Kay, pp. 212–233, 1969.

Church, W. R., and R. K. Stevens, Crustal evolution of the western margin of the Newfoundland Appalachians, *Program Annu. Meet. Geol. Soc. Amer.*, [illegible], 1968.

Church, W. R., and R. K. Stevens, Mantle peridotite and [illegible] complexes of the Newfoundland Appalachians, *Program Int. Symp. Mech. Prop. Mantle*, [illegible] International Upper Mantle Committee, 1970.

Dawe, H. [illegible] Belt, in [illegible], *Geol. [illegible]*, p. 200, 1968.

Dickey, J. S., Jr., Partial fusion products in alpine-type [illegible] Serrania de la Ronda and [illegible], *Program Annu. Meet. Geol. Soc. Amer.*, [illegible], 47, 1969.

[illegible], *Bull. Geol. Soc. Amer.*, [illegible], 917, 1968.

[illegible] W. [illegible] between the [illegible] Great Valley sequence [illegible], *Program Annu. Meet. Geol. Soc. Amer.*, Atlantic City, N. J., p. 59, 1969.

Fitton, J. G., and D. J. Hughes, Volcanism and plate tectonics in the British Ordovician, *Earth Planet. Sci. Lett.*, 8, 223, 1970.

Green, D. H., The petrogenesis of the high temperature peridotite intrusion in the Lizard area, [illegible], *J. Petrol.*, 5, 134, 1964.

Hess, H. H., [illegible], *Geol. Soc. Amer. Spec. Pap.*, [illegible], 1955.

Horne, G. S., Pre-Ordovician and [illegible] deposits in the [illegible] of north-central Newfoundland, *Bull. Geol. Soc. Amer.*, 80, 2451, 1969.

Horne, G. S., and J. F. Helwig, Ordovician stratigraphy of Notre Dame Bay, Newfoundland, in *North Atlantic—Geology and Continental Drift*, *Amer. Ass. Petrol. Geol. Mem. 12*, edited by M. Kay, [illegible], 1969.

[illegible] Notre Dame Bay [illegible], [illegible], 1965.

Kanamori, S., [illegible] metamorphic rocks [illegible], *[illegible]*, 1968.

Karamata, S., *Guide for the AZOPRO Excursion, Part I: Ultramafic Rocks*, [illegible] pp., Beograd, Yugoslavia, 1970.

Kay, M., Comparison of the Lower Paleozoic volcanic and non-volcanic geosynclinal belts in Nevada and Newfoundland, *Bull. Can. Petrol. Geol.*, 14, 579, 1966.

Kay, M. (Ed.), *North Atlantic—Geology and Continental Drift*, *Amer. Ass. Petrol. Geol. Mem. 12*, 1082 pp., 1969.

Kornprobst, J., Le massif ultrabasique des Beni Bouchera (Rif Interne, Maroc): Étude des péridotites de haute température et de haute pression, et des pyroxénolites, à grenat ou sans grenat, qui leur sont associées, *Contrib. Mineral. Petrol.*, 23, 283, 1969.

Maxwell, J. C., Continental drift and a dynamic earth, *Amer. Sci.*, 56, 35, 1968.

Moore, E. M., Petrology and structure of the Vourinos ophiolitic complex of Northern Greece, *Geol. Soc. Amer. Spec. Pap.*, 118, 74, 1969.

Nicolas, A., Géologie des Alpes piémontaises [illegible] du Grand Paradis [illegible], *Geol. [illegible] Grenoble*, [illegible], 1967.

Nicolas, A., Relations structurales [illegible] ultrabasique de Lanzo [illegible], *Schweiz. Mineral. Petrogr. Mitt.*, 48, 145, 1968.

Poole, W. H., [illegible] Appalachian region, in *Geology and Economic Minerals of Canada*, *Geol. Surv. Can.*, edited by R. J. W. Douglas, [illegible], 1967.

Reinhardt, B. M., On the genesis and emplacement of ophiolites in the Oman Mountains geosyncline, *Schweiz. Mineral. Petrogr. Mitt.*, [illegible], 1969.

Rodgers, J., and E. R. W. Neale, Possible 'Taconic' klippen in western Newfoundland, *Amer. J. Sci.*, 261, 713, 1963.

Smith, C. H., Bay of Islands igneous complex, western Newfoundland, *Geol. Surv. Can. Mem.* 290, 132 pp., 1958.

Stevens, R. K., Flysch sedimentation and Ordovician tectonics in West Newfoundland, *Geol. Ass. Can. Spec. Pap.*, 7, 165, 1970.

Stevens, R. K., W. R. Church, and P. St. Julien, Age of ultramafic rocks in the northern Appalachians, *Program Annu. Meet. Geol. Soc. Amer.*, [illegible], 215, 1969.

Williams, H., The Appalachians in northeastern Newfoundland: A two-sided symmetrical system, *Amer. J. Sci.*, 262, 1137, 1964.

Williams, H., Pre-Carboniferous development of Newfoundland Appalachians, in *North Atlantic—Geology and Continental Drift*, *Amer. Ass. Petrol. Geol. Mem. 12*, edited by M. Kay, pp. 32–58, 1969.

(Received September [illegible], 1970; revised November 4, 1970.)

Reprinted from:

XXIV International Geological Contress

Montreal, Quebec, 1972

Guidebook

Excursion A62-C62

A Cross Section Through the Appalachian

Orogen in Newfoundland

edited by E.R.W. Neale

(parts of p. 63-83)

Highway. Where the road runs parallel to Birchy Lake you will note high ground north of the lake underlain by Fleur de Lys schists and granites. Hummocky terrane with occasional steep hills (e.g. Mount Sykes) south of the lake are underlain by volcanic rocks and shallow-zone intrusions which are probably related to the Silurian/Devonian Mic Mac sequence. Birchy Lake is the locus of a fault zone (Neale and Nash, 1963) which is possibly part of the Lukes Arm - Lobster Cove system.

Just east of the Hampden access road we encounter several outcrops of Fleur de Lys greywackes. They are part of a sequence of quartz pebble greywackes and marbles that outcrop along the east shore of White Bay. They resemble the Ben Ledi Grits of the Upper Dalradian of Scotland and Ireland.

Thereafter we shall note red soils and other overburden that reflect the Carboniferous red beds of the Deer Lake Group.

Day 8

Purpose:

The examination of a geological section through central west Newfoundland from the Precambrian basement into the autochthonous and allochthonous Cambrian and Ordovician rocks.

The route from Deer Lake starts in the poorly exposed Carboniferous terrestrial sediments of the Humber Valley. Roadside exposures of phyllitic Lower Cambrian sediments can be seen soon after passing the junction of roads 1A and 44 (0.0 km). A spur of Precambrian basement outcrops on the road about 4 miles (6.5 km) from the junction. From this point onward the route encounters progressively stratigraphically higher strata but roadside outcrops are poor and are mainly the more resistant beds of Middle Cambrian oolitic limestone and the dolomites of the St. George Formation.

Dark shales exposed around the bridge over Barters Brook (25 miles, 40 km) belong to the upper part of the autochthon and have yielded poorly preserved Middle Ordovician graptolites. Crushed shale with blocks exposed for the next 2 km is interpreted as the basal mélange of the Humber Arm allochthon. More coherent exposures of conglomeratic quartzite and shale exposed at 28 miles (44.8 km) belong to the Irishtown Formation of probable Lower Cambrian age. These beds form the lowest part of the allochthon in this area and pass up into the shales and limestones of the Cooks Brook Formation. Good views of the brown weathered Table Mountain ultramafic body (possible lower Paleozoic oceanic mantle) can be seen during the descent into Bonne Bay down a hill known locally as "The Struggle".

The South Arm of Bonne Bay is in part controlled by erosion along another mélange zone believed to represent a higher movement zone in the allochthon. It might represent the same zone which is exposed at Frenchman's Head (Stop 9-3). Good exposures of the mélange occur in Sellars Brook at the bridge (30 miles, 48 km).

Stop 8-1: Serpentinite mélange at the falls in Shoal Brook, South Arm Bonne Bay (R. K. Stevens)

The upper mélange zone is exposed on Shoal Brook about 90 m from the road. Large blocks of sheared serpentinite occur at this locality. At the falls slivers of sandstone in crushed shale occur with the serpentinite blocks. Above the falls slightly deformed sandstone overlies this mélange zone and is itself overlain (i.e. overridden) by the allochthonous Bay of Islands Igneous complex.

Secondary calcic zeolites and the rare mineral xonotolite (6 $CaSiO_3 . 2H_2O$) have been reported from within the serpentinite blocks at this locality.

Stop 8-2: Trout River Pond (H. Williams and R. K. Stevens)

From Shoal Brook the road follows the southern shore of Bonne Bay to the junction of the Trout River road near Woody Point. The Trout River road trends south and after an initial climb bears west along a scenic U-shaped valley through the Bay of Islands complex. The barren, flat-topped plateau of Table Mountain to the south is composed of Cambrian-Ordovician ultramafic rocks that may represent oceanic mantle. If so, the Mohorovicic Discontinuity of early Paleozoic time is visible farther west where the brownish-weathering ultramafic rocks are overlain by grey-weathering gabbro. The tree-covered terrane north of the road (Lookout Hills) consists of well-foliated amphibolitic gabbro, granodiorite, and younger sheeted dykes, dyke breccias, and mafic volcanic rocks. The dykes, dyke breccias, and mafic volcanic rocks are all similar to those found elsewhere at the top of the main plutons of the Bay of Islands complex. The amphibolitic gabbro and granodiorite have no real correlatives in the rocks of Table Mountain or other plutons of the complex.

A section through the Bay of Islands complex is exposed along Trout River Pond (Stop 8-2, Fig. 14). The low ground around the west end of the pond is underlain by transported sediments with a few volcanic members, or else tectonic inclusions of volcanic rock, beneath the Bay of Islands complex. The Table Mountain massif lies to the northeast of the pond and the North Arm Mountain-Gregory Mountain massif lies to the south. A coastal complex similar to the rocks of Lookout Hills lies to the west. The pond seems to mark a fault with downthrow to the north so that a lower section through the complex is exposed in the Table Mountain massif than in the adjacent part of the North Arm Mountain-Gregory Mountain massif. Both plutons, however, share the same general succession of rock units as summarized in Fig. 13. A large Pleistocene delta occurs at the lower end of Trout River gorge. Near Trout River, the delta surface is just over 30 m above sea level. Around Trout River the surface merges into a wave cut platform cut in bedrock. A raised sea stack, known locally as the Old Man, can be seen west of Trout River.

Stop 8-3: Parautochthonous Flysch at Norris Point
(R. K. Stevens)

From Trout River, the route returns to Bonne Bay at the town of Woody Point. A ferry crossing is made to Norris Point at the junction of Bonne Bay and East Arm. From the ferry (no recorded fatalities to date), good views can be obtained across Bonne Bay: The Bay of Islands Igneous complex lies to the west; a greywacke sequence, perhaps the Lower Cambrian(?) Summerside Formation, lies to the south; to the north and west, the high ground is underlain by Precambrian basement capped by Lower Cambrian clastic rocks, and the lower ground is underlain by autochthonous rocks and the Humber Arm allochthon. As the ferry approaches Norris Point a shale and greywacke sequence can be seen to overlie the Table Head carbonate rocks opposite Norris Point. These shales and greywackes, the Gadd's Point Formation, and an associated mélange can be inspected at Norris Point.

The Gadd's Point Formation has a flysch-like aspect with thin, graded, fine-grained greywackes. As presently interpreted, this flysch was derived from the allochthon during its emplacement. Since much of the formation seems to be inverted it might be parautochthonous rather than strictly autochthonous. It passes westwards into a mélange contain-

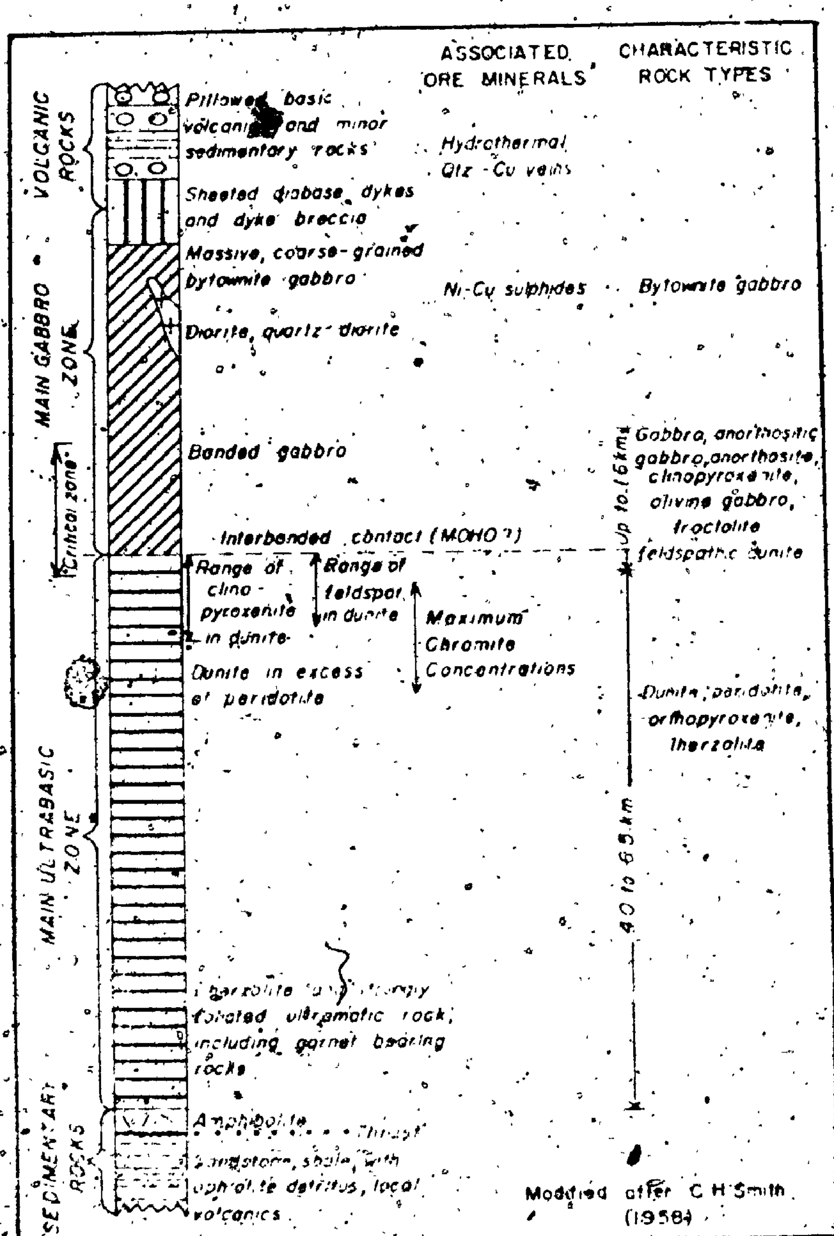


Fig. 13. Generalized columnar section of the ultrabasic massifs

ing large blocks of various sorts of sediment set in a shaly matrix. A prominent white block of limestone conglomerate occurs on the west side of the hill. Some of the conglomerate fragments contain *Maclurites*. It is not clear how this block originated. It might have been derived from a conglomerate unit within the allochthon, such as the Cow Head conglomerates; it might have been originally part of a limestone conglomerate sequence interbedded in the shaly, upper part of the allochthon; or it might have been derived from a carbonate bank growing on the partly emergent allochthon as it slid slowly westward.

Stop 8-4 Green Point Formation at Type Locality (R. K. Stevens)

From Norris Point to Green Point (14 miles, 21.6 km), the route passes through poorly exposed shale, limestone and minor greywacke of the Humber Arm allochthon. The geology of this area is not understood in detail but several different slices seem to be present. The Cambrian sandy rocks which characterize the allochthon farther south are not present.

At Green Point about 125 m of Tremadocian shale, silty limestone and limestone conglomerate are exposed. This is the type section of the Green Point Formation, known particularly for its Tremadocian graptolite fauna. The strata dip southwards and are overturned.

Many of the calcareous beds have been deposited by turbidity currents. Although no flute casts have been recorded at Green Point, similar rocks at Martin Point and Cow Head to the north show flute marks indicating a west to northwestern source. Many beds at Green Po[illegible]w current lineations. Syn-sedimentary folds are well shown in some beds and a prominent, Cow Head-like limestone conglomerate occurs at the Point. Thin limestone beds unconformably lap onto some of the blocks protruding from the upper surface of the conglomerate. The best graptolites occur to the north of the point.

Stop 8-5 A Section from Allochthon to Basement along the New North Shore Road (R. K. Stevens)

From Green Point the route is retraced southwards to the junction of the new North Shore road about 5 miles (8 km) south of Green Point. A section from the Humber Arm allochthon into the autochthon and then into the basement is exposed in cuts along this new road.

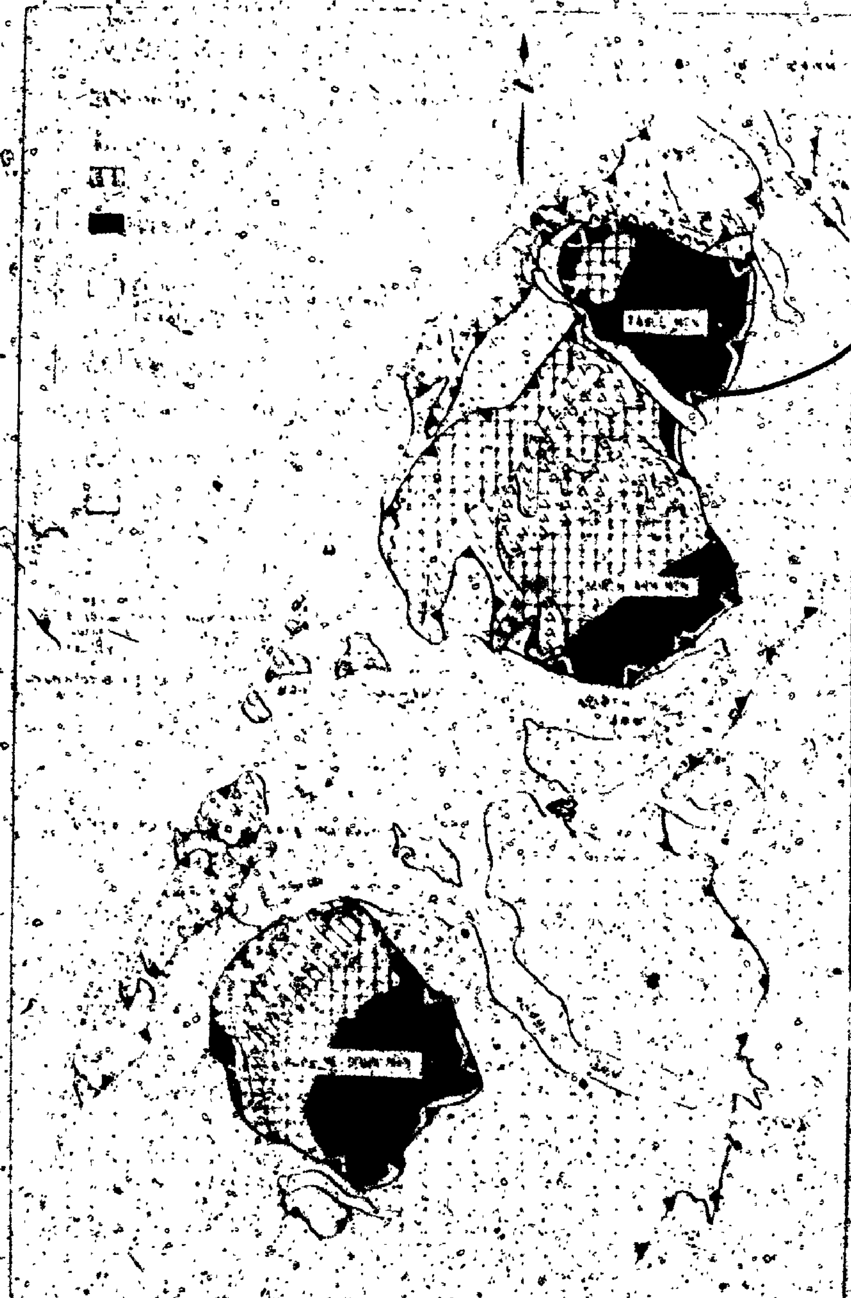


Fig. 14. General geology of Bay of Islands mafic-ultramafic complexes

The section starts at the junction in siliceous green and black argillites containing a late Arenigian graptolite fauna. These pass up into greywacke probably equivalent to the Blow Me Down Brook Formation of Humber Arm. Then follows 2 km of poor exposures; the terrane is underlain by a basal mélange. The first coherent beds encountered are autochthonous shales and greywackes with a prominent thick bed of ridge-forming limestone conglomerate. More shale and greywacke underlies the conglomerate bed. Dolomites and limestones of the St. George Formation occur in road cuts on the hill leading down to Deer Arm.

From Deer Arm southeastwards, the road runs almost parallel to the strike of Cambrian clastic rocks of the Labrador Group. The Cambrian-Precambrian contact can be seen in the hills immediately to the northwest of the road.

The actual stop is in fossiliferous limestone of probable Lower Cambrian age about 7 miles (11.2 km) from Rocky Harbour road junction. The limestone bed, about 3 m thick, is unusual because it is crammed with fossils resembling *Hyolithes*.

For about the next 12.5 miles (20 km) the road cuts through various rocks of the Labrador Group. Quartzite, shale and thin bedded limestone make up the bulk of the section.

Stop 8.6: Cambrian-Precambrian Unconformity
(R. K. Stevens)

An unconformity between Cambrian sediments and the Precambrian Grenville basement is exposed in a road cut about 19.5 miles (31.2 km) from the Rocky Harbour junction. About 7.5 m of sandy, silty and calcareous strata rest on gneissic rock veined with pegmatite. Fragments of the basement are common in the lower part of the sedimentary sequence. The exposure may be inspected in cuts on both sides of the road and in a stripped surface east of the road.

Continuing towards Deer Lake the route is in poorly exposed Precambrian gneisses for about a mile (1.5 km) and then crosses Lower Cambrian sediments. The new North Shore road rejoins the Bonne Bay highway at Wiltondale.

DAY 9

Purpose

To study the sedimentary and structural features of the Cambrian-Ordovician transported clastics of the Bay of Islands.

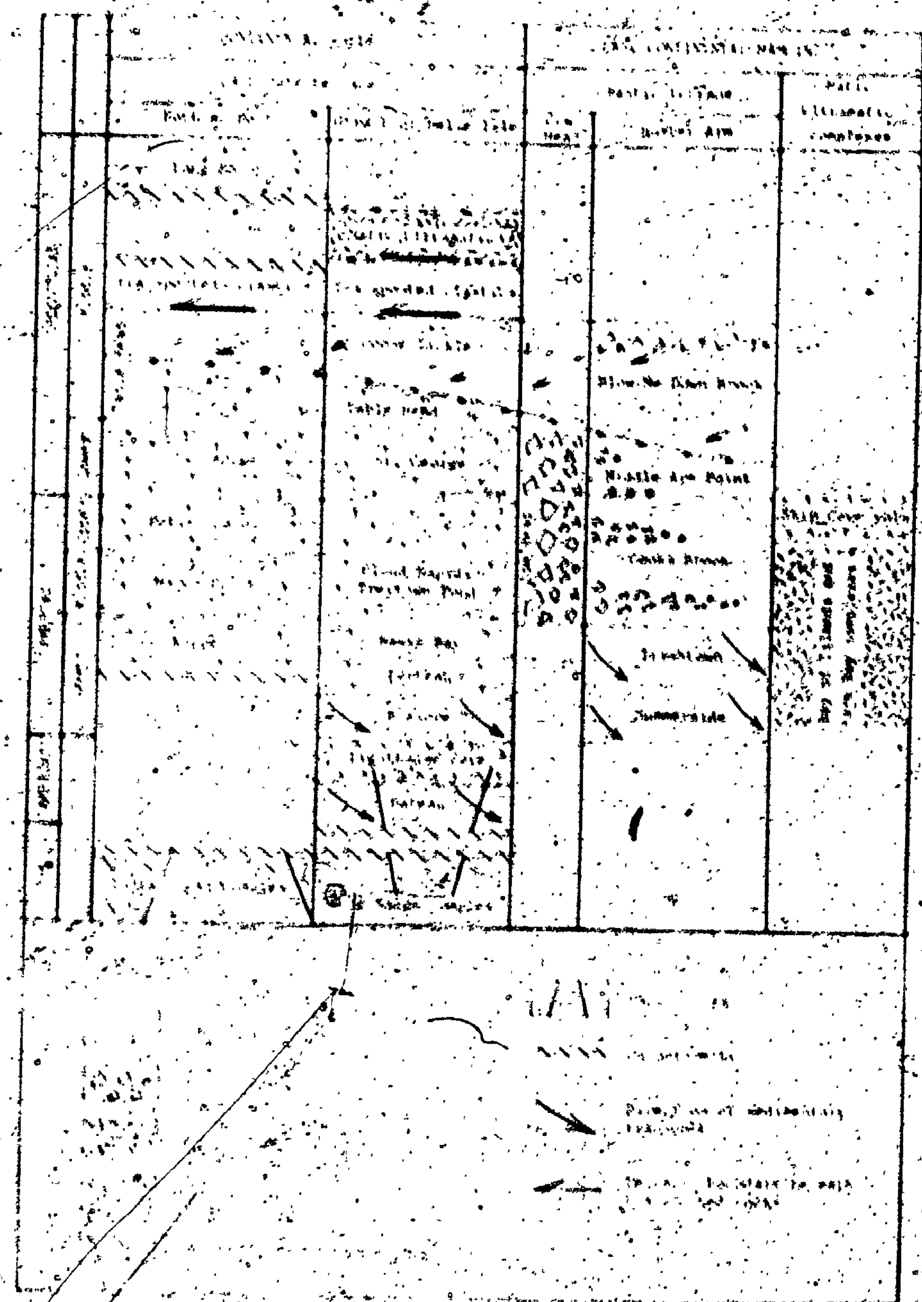


Fig. 12. Stratigraphic relationships of [illegible] in western Newfoundland [illegible]

region and to examine the salient features of the mafic-ultramafic complexes that form the uppermost structural slices above the transported sedimentary rocks. The general geology of the area is summarized in Figure 14 and the stratigraphic relationships, at deposition, among the west Newfoundland Cambrian-Ordovician autochthonous carbonate sequence, the transported clastic sequence, and the mafic-ultramafic complexes are summarized in Figure 15.

The autochthonous Cambrian-Ordovician carbonate succession is interpreted as a carbonate bank that evolved upon the slightly submerged eastern edge of the North American continent. It can be traced all the way from Newfoundland in the northeast for 2000 miles (3200 km) southwestward to Alabama in the southern United States. The Cambrian-Ordovician clastic succession is interpreted as a condensed, easterly, off-shore facies chiefly equivalent in age to the autochthonous succession. The lithology of clasts in the lowest formations (Summerside, Irishtown) of the clastic succession indicate derivation from the west, mostly prior to development of the carbonate bank. Limestone breccia beds, common in central formations (Cooks Brook, Middle Arm Point) are thought to represent bank-edge deposits. The uppermost formation (Blow-Me-Down Brook) represents the eastern part of a flysch wedge that eventually transgressed westward and spread across the carbonate succession. The flysch locally contains serpentinite fragments, chromite grains, and pyroxene crystals, implying that the mafic-ultramafic complexes were in an elevated position during its deposition.

The mafic-ultramafic complexes occur in separate slices that overlie the transported clastic sedimentary rocks. Some of these, especially the Blow-Me-Down Mountain pluton of the Bay of Islands Igneous complex, have all of the features of a typical ophiolite suite complete with sheeted dyke complex and mafic pillow lavas at its top. More westerly, coastal exposures of the mafic-ultramafic rocks are internally structurally complex and include much polyphase deformed amphibolitic gabbro and foliated granodiorite, all cut by sheeted dykes and dyke breccias and locally unconformably overlain by relatively undeformed mafic volcanic rocks.

Stop 9-1: Trans Canada Highway at the Tourist Chalet, Corner Brook Access Road (H. Williams)

This stop is almost directly upon the contact between autochthonous carbonate rocks to the east and south of the highway that are west-dipping and west-facing and transported rocks of the clastic terrane to the west. Looking westward toward Humber Arm we see rocks which belong to the transported clastic terrane that structurally overlies the carbonate succession. The large flat barren highland in the distance is made up of peridotite of the basal unit of the Blow-Me-Down Mountain pluton of the Bay of Islands Igneous complex.

Stop 9-2: The Cooks Brook Formation at Giles Point, Humber Arm (R. K. Stevens)

Giles Point is on Humber Arm 9 miles (14.4 km) along the south shore highway from Stop 9-1. Most of the route is through allochthonous quartzites and shales of the Lower Cambrian (?) Irishtown Formation. A path from the service station leads to the shore section. Rocks exposed here are at the base of the late Middle Cambrian Cooks Brook Formation and are characterized by limestone conglomerate. Shaly beds transitional into the underlying Irishtown Formation are exposed east of the conglomerate exposures.

Clasts in the Cooks Brook limestone conglomerates are not as coarse and the formation is thinner bedded than the well-known Cow Head Breccias but both belong to the same general lime conglomerate — lime turbidite facies. Fragments in the Giles Point exposures include limestone plates which are probably locally derived and also exotic blocks of carbonate rock which are probably of shallow water origin. A few oolitic limestone blocks are also present. Rocks in the shaly transition zone include fine-grained sandstones and limestones which are interpreted as turbidites. Several beds of graded, locally pyritized oolites also occur.

At least two phases of deformation are discernible in the complexly folded strata at Giles Point. The latest phase of deformation is associated with the formation of the Humber Arm synclinorium, a major south-plunging, post-emplacement structure.

Stop 9-3: Frenchman's Cove Mélange Zone (R. K. Stevens)

A mélange zone over a mile (1.6 km) thick forms the cliffs around Frenchman's Cove. The origin and significance of this zone is not yet clear. Typically the mélange consists of carbonate, greywacke and tough shale blocks set in a phacoidally cleaved black and green shaly matrix. The blocks vary in size and shape and some are intruded by the matrix. Some greywacke blocks resemble slumped beds and others resemble boudins. A crude alignment of blocks of similar lithology and a gross stratification of block lithologies show-that the mélange is not as chaotic as it appears at first sight. Some blocks have also been rotated parallel to the north-south trending regional cleavage.

All of the blocks at Frenchman's Cove can be matched by lithologies in the overlying Blow-Me-Down Brook Formation or by those of the Middle Arm Point and Cooks Brook Formations. The black and green shale matrix is similar to the shale of the Middle Arm Point Formation and contains fragments of Early Ordovician graptolites. However, a few exotic blocks occur elsewhere in the zone. For example, a large gabbro block forms the prominent hump on the eastern end of Woods Island which is visible from Frenchman's Cove.

A possible explanation of the Frenchman's Cove mélange is that it represents an olistostrome in a predominantly shaly sequence which was overrun and deformed by a higher slice of the allochthon, the base of which has become incorporated into the upper part of the mélange.

Additional features of interest include iron sulphide nodules and small (2-6 mm diameter) cone and double cone-shaped calcite fossils as yet unidentified.

Stop 9-4: Serpentinite Mélange on Lark Harbour Road one mile (1.6 km) west of Blow-Me-Down Brook (H. Williams)

Serpentinite mélange consists of serpentinite and gabbro blocks in a finely comminuted serpentine matrix. This zone, commonly several tens of feet thick separates gabbroic rocks of the Blow-Me-Down Pluton (above) from unmetamorphosed, poorly indurated sandstones at the top of the clastic terrane. The clastic sequence is exposed on the coast below the road.

A few miles farther west, the route passes the Big Nama Mine Adit at Mine Brook on Lark Harbour Road. The adit is collared in a large, reddish volcanic boulder about 15 m in diameter. The adit was driven to test the continuity at depth of a pyrite-chalcopyrite orebody which occurs in mafic volcanic rocks at a higher level in the pluton. Nearby red mélange contains large blocks of Blow-Me-Down sandstone within a scaly shale matrix. All of these rubbly rocks, characteristic of the basal contact of the pluton, are faulted against nearby mafic pillow lavas that occur upstream in Mine Brook. Farther along Lark Harbour Road, one-half mile (0.8 km) west of Mine Brook, mafic pillow lavas and agglomerates are exposed which are typical of those at the top of the Blow-Me-Down ophiolite succession. As we drive westward to our next stop we encounter gabbro, now on the west side of the Blow-Me-Down Pluton, indicating that the structure of the pluton is a broad open syncline with the ophiolite units truncated along its basal tectonic contact.

Stop 9-5: The Coastal Complex, 1.5 miles (2.4 km) north of York Harbour (Williams)

The granitic rocks at this locality are part of the coastal complex of the allochthonous sequence. The rocks are massive to weakly foliated and almost everywhere are cut by veinlets of clastic, gas-brecciated, granitic material. As seen in coastal exposures the granodiorite cuts amphibolitic gabbro and is itself cut by mafic dykes and dyke breccias that pass upward into mafic pillow lavas. The dykes, dyke breccias, and mafic lavas are all similar to the same rocks that occur toward and at the top of the Bay of Islands plutons. The strongly foliated amphibolitic gabbros that are cut by granites have no real correlatives among the plutonic rocks of the Bay of Islands plutons and their complex structural history suggests that they are older.

DAY 10

Purpose:

To examine an inlier of Precambrian (Grenville) basement, the autochthonous lower Paleozoic carbonate shelf rocks, mélange zones, the allochthonous lower Paleozoic clastic sequence, neoautochthonous carbonate rocks and post-klippe Devonian(?) and Carboniferous sequences.

Leaving Corner Brook we follow the Trans Canada Highway southwards, crossing the contact between the allochthonous Humber Arm clastic sequence and the autochthonous St. George and Table Head carbonate groups several times en route. Stephenville access road offers excellent exposures of stratified drift and the entire Port au Port Peninsula offers superb examples of pro-glacial deltas and raised beaches and benches described in a classic paper by MacClintock and Twenhofel (1940) and more recently by Brooks (1969).

Stop 10-1: Indian Head Range (V. S. Papezik)

The Indian Head Range is a Precambrian inlier in Paleozoic sedimentary rocks, about 25 km long and 5 km wide, extending northward from St. George's Bay about 4 miles (6 km) east of Stephenville. It is composed mainly of gneissic rocks of the granulite and amphibolite facies, minor granitic rocks and a small body of anorthosite at its southern end. The gneisses vary from plagioclase-orthopyroxene types to rocks consisting predominantly of quartz, K-feldspar, plagioclase and biotite, with local bands of feldspathic quartzite, biotite amphibolite, pyroxenite, etc. The rocks contain small lenses of iron oxides, and are commonly cut by thin veins of pegmatite.

Structurally, the anorthosite massif forms the core of a broad dome plunging northwards at 15-30 degrees; the gneisses mantling the core are crenulated but the main foliation generally has shallow dips (Heyl & Ronan, 1954). A granitic gneiss has been dated at 830 m.y., a pegmatite from a different locality gave an age of 900 m.y. by K/A methods. The Indian Head Range rocks probably belong to the Grenville Province of the Canadian Shield. They resemble the Precambrian rocks of the Great Northern Peninsula, and, like them, also resemble the Adirondack Mountains in New York.

The rocks can be examined at three easily accessible localities:

(a) Layered gneiss complex

A large road-cut at the cross-roads of the Trans-Canada Access Road and the Hansen Highway (Stephenville to Stephenville Crossing) shows crudely layered gneissic rocks characteristic of the Indian Head gneiss complex.

They are chiefly dark grey, medium-grained andesine-orthopyroxene gneiss with minor biotite which forms layers and lenses several metres thick interlayered with thinner layers of biotite amphibolite. This "basic" gneiss grades westward into a pinkish granitic gneiss consisting chiefly of quartz, K-feldspar, plagioclase (An_{30}) and biotite. The gneisses are cut by several thin veins of pegmatite.

The high hills along the highway to the west, bounded by steep cliffs, are formed by coarse-grained porphyritic granite, grading in places into gneissic granite and granitic augen-gneiss, all characterized by large porphyroblasts of red K-feldspar.

(b) Magnetite lens in granitic gneiss

The gneissic rocks of the Indian Head Range contain many small lenses of massive and disseminated magnetite and/or hematite with some ilmenite. Several of them were of sufficient size to warrant exploration by various mining companies over the last fifty years, and are now exposed in short adits and small open-cuts. Most of these are accessible only by long-abandoned mining roads, but a small example can be seen in a road-cut on the Hansen Highway, 2.4 miles (3.8 km) west of the previous stop.

The road-cut shows a flatly-dipping lens of disseminated magnetite less than 1 m thick, in a medium-grained altered granitic gneiss. The magnetite forms thin bands generally parallel to the gneissic foliation of the rock, coalescing locally into coarser-grained stringers up to several centimeters thick. The magnetite lens is surrounded by an iron-rich metasomatic aureole consisting mainly of dark amphibole, coarse-grained biotite (and chlorite), and massive to disseminated epidote; hornblende grains up to 1 cm across are present in the original granitic gneiss farther from the iron oxide lens.

(c) Indian Head Anorthosite

The southern tip of the Indian Head Range is formed by a relatively small (3 x 2 km) body of anorthosite and gabbroic anorthosite. The rock consists of remnants of light grey plagioclase crystals 5 to 50 cm long, enclosed in a white medium-grained cataclastic feldspathic matrix. Crystals and aggregates of partly altered hypersthene up to 1 m across are irregularly distributed throughout the rock. The feldspar is calcic andesine (An_{45-50}); bluish play of colours ("labradorite effect") can be seen in a few spots, but is not common. Magnetite and ilmenite are minor accessories.

The anorthosite of Indian Head was quarried during World War II for use in road and harbour construction. The quarry is no longer accessible, but blocks of anorthosite several metres across were used to build a nearby breakwater, where the rock can be easily examined.

Similar Precambrian anorthositic rocks constitute a large inlier, Steele Mountain, within the Carboniferous rocks east of St. George's Bay and Port au Port Peninsula.

Stop 10-2: Kippens (Romaines Brook) Evaporite Exposures (J. McKillop)

A 365 m long exposure of evaporites which constitute the basal part of the Carboniferous Codroy Group is exposed on the east bank about 150 m upstream from the bridge over Romaines Brook. The exposure is of high-purity gypsum ($CaSO_4 \cdot 2H_2O$), a product of hydration of previously existing anhydrite.

The evaporites underlie 100 acres in the immediate vicinity of the exposures and maximum thickness of the partially eroded sequence is less than 100 m. The surface is characterized by karst topography especially in the vicinity of the major outcrops. The gypsum and anhydrite are underlain by a 3 to 22 m thick carbonate member, the Ship Cove limestone, which rests upon the crystalline basement complex. The evaporite sequence thins progressively eastward and is absent about 600 m east of the outcrop.

The deposit was assessed by diamond drilling in 1955 (Newfoundland Mineral Resources Report No. 1) and it is interesting to note that at that time there was no exposure of gypsum on the shoreline at the mouth of the brook. Since that time, however, the rapid coastal erosion has exposed a mass of gypsum which is quite dissimilar in appearance to that exposed further upstream. It appears to be separated from the upstream exposures by a fault which has also brought sandstones and shaly sandstones into position downstream from the main gypsum outcrop on the east bank of the stream.

Looking across St. George's Bay from the bridge, on a clear day, the same evaporite sequence may be seen some 12 miles (19 km) to the southeast in the Flintkote quarry and in the stockpile at the St. George's dock.

The coastal lowlands from Kippens through St. George's are underlain by Carboniferous sedimentary rocks which have been correlated with similar rocks, across the Gulf, in Nova Scotia. A salt (halite) sequence over 800 m thick was encountered by drilling in the Mississippian rocks near St. George's in 1969.

St. George's Bay itself may well owe its development to the presence of great thicknesses of evaporites which, once borrowed from the sea, were reclaimed by their owner through the present process of erosion along this coastline.

Stop 10-3: From Autochthon to Allochthon at Black Cove-Black Point (R.K. Stevens)

The Black Cove — Black Point section trends northeastwards from the Port au Port isthmus through a nearly continuous section of the autochthonous St. George and Table Head Formations and the lower part of the Humber Arm allochthon. Only the upper (north-eastern) part of the section will be visited. The shore is reached by a rough foot path which joins the Point-au-Mal road about 2.4 miles (3.8 km) north of Port au Port.

The complete section starts in the carbonate rocks of the upper part of the St. George Group; about 60 m of well bedded dolomites and limestones are exposed. Well developed stromatolite reefs with heads up to 1 m across suggest shallow water deposition. Except for gastropods and trace fossils other organic remains are rare. About 1 km northeast of The Gravels, the St. George is overlain by Table Head limestone. The nature of the contact is not clear at this locality but at Aguathuna Quarry (Stop 10-4) the contact is a disconformity. The lowest 220 m of the Table Head consists of rubbly grey fossiliferous limestone.

At Black Cove the lower Table Head is faulted against 10.7 m of middle Table Head interbedded shale and limestone. These pass upward into 15 m of upper Table Head dark shales with abundant graptolites regarded by some as lower Llanvirnian but by others as upper Llanvirnian. An interformational zone of tight minor folds occurs near the top of the shale but no important movement has taken place across the disturbed zone. A graptolite-bearing graded calcarenite unit overlies the Black Cove shale and is overlain by a thin shale unit followed by a massive unit of limestone conglomerate perhaps 30 m thick striking nearly parallel with the shore for about 300 m. Most of the clasts in the conglomerate could have been derived from the Table Head formation though a few are more likely to have come from the St. George; some blocks are themselves conglomeratic. A few large shale blocks are also present. The conglomerate is crudely graded, with a tendency for the larger blocks to be near the base, though some large calcarenite blocks also occur near the top. Calcite mud forms the matrix in the lower part of the conglomerate but this becomes shaly towards the top.

The walking tour will start at the top of this conglomerate where it is overlain by a few feet of greenish-brown shale and calcarenite containing grapolites like those at Black Cove. These are followed conformably by about 75 m of shale and fine-grained greywacke. Information from other areas suggests that the source of the greywackes was to the east and was in part the Humber Arm allochthon that now lies on top of the sequence. Chromite grains are an important element of the heavy mineral suite. The greywacke beds seem to increase in thickness and coarseness up section. Graptolites occur in both the shale and the greywacke beds.

The upper few feet of the shale-greywacke sequence are somewhat deformed and overlain by a well-developed mélange zone. This is the base of the Humber Arm allochthon. The first coherent unit is a green chert. Blocks of this chert are common in the mélange and some are shaped and striated like faceted till stones, the striations invariably trend about east-west. For several hundred metres to the north, a complex of mélange zones and more coherent units is exposed. Most of the complex is truly allochthonous but the green chert contains poorly preserved graptolites indicating a Middle Ordovician age, perhaps somewhat younger than the underlying autochthonous shale and greywacke. This suggests that the chert was stripped from the autochthon by the overriding allochthon and is therefore parautochthonous.

Special attention should be paid to the lithologies in the mélange complex, particularly the blocks of very coarse-grained arkose since many of these rock types will be seen in a less deformed state further along the section.

From about the Fisherman's hut (approximately 4 miles, 6.4 km northeast of Port-au-Port) the allochthon is much more coherent, though still cut by zones of movement. The succession includes red and green siliceous rocks and shale, with a lens of limestone conglomerate containing a few metamorphic rock clasts. A few brachiopods of probable Lower Ordovician age have been collected from the conglomerate. Late Arenig graptolites have been collected from about this horizon elsewhere in west Newfoundland. Fine-grained greywacke beds succeed the shaly rocks and these pass up into an almost massive very coarse-grained arkose at Black Point. Several bedding planes show very large load casts. Examination of detritus in the arkose suggests that it was derived from plutonic, ophiolitic and sedimentary source terrains.

The overall structure of the allochthonous rocks and mélange complex is interpreted as a large overturned anticline. The core of the fold is well exposed in the west-facing cliff north of the Fisherman's hut, where it is modified by disharmonic folding and the local development of mélange. The normal, steeply north-dipping limb of the fold is exposed between Black Point and the Cove to the south. Facing criteria are abundant. It should be noted that the lithologies of the normal limb are also represented in the mélange complex which is interpreted as a highly deformed part of the overturned limb mixed with parautochthonous sediment which was stripped from the autochthon as the allochthonous mass slid into place.

Stop 10-4: Aguathuna Limestone Quarry (J. H. McKillop)

The Aguathuna quarry was developed in limestones of the autochthonous mid-Ordovician Table Head Group and produced more than ten million tons of metallurgical grade limestone during its period of operation (1913-1966).

The Table Head Group in the quarry area is approximately 245 m thick and is separated from the underlying St. George

Group dolostones by an erosional disconformity which can be observed in the quarry face. The whole sequence dips northward (toward the bay) at approximately 20°.

The autochthonous Table Head and St. George Groups, comprising a total thickness of approximately 700 m on the Port au Port Peninsula are overlain by clastic rocks of the Humber Arm Klippen on Shoal Point and to the west of the Point.

A quarter mile (0.4 km) wide belt of Mississippian (Codroy Group) sedimentary rocks is exposed on the southwest shore of Port au Port Bay (west of the quarry). They were deposited upon the partially eroded surface of the Ordovician carbonate sequence. Gypsum and anhydrite comprise a significant part of the sequence, which is characterized in its surface expression by a line of sink holes extending through the belt which is over 6.4 km long.

There is a remnant of Mississippian fossiliferous, dolomitic limestone on the quarry floor, well out from the face, which was deposited in one of the small surface depressions developed in the Table Head Group. Numerous small fossil brachiopods (*Dielasma latum* Bell) and other fossils are present in the remnant.

Stop 10-5: Autochthon-Allochthon Contact at Piccadilly; West Bay, Port au Port Peninsula (R. K. Stevens).

The route from Aguathuna Quarry (about 12 miles, 19.2 km) follows a strike section of the St. George Formation for about 9 miles (14.5 km). A few red patches of Carboniferous shale and sandstone occur along the roadside. From Abrahams Cove, the route runs northwards and generally up section, though the section is complicated by high angle faulting. Piccadilly Head is made up of autochthonous limestone breccia of Middle Ordovician age.

The coastal section starting immediately west of the Piccadilly Head Provincial Park exposes allochthonous or possibly parautochthonous shales and greywackes in fault contact with parautochthonous green chert, mélange and impure limestone and shale. In general, the succession is similar to that of the autochthon-allochthon contact exposed in the Black Cove section (Stop 10-3).

Two features of the Piccadilly section merit special attention:

1) The shale-greywacke sequence has been thrown into a remarkable series of recumbent folds, probably by the passage of the allochthon. Some of the beds have broken down into mélange and there are indications that the rocks were not

fully consolidated during deformation. The allochthon seems to have moved from east to west at this location.

21. A prolific graptolite fauna has been collected from the nuppler limestones and shales. To date 39 different species have been collected from this locality. The fauna resembles that at Black Cove and is of probable Llanvirnian age.

Stop 10-6: Long Point and Clam Bank Groups at Clam Bank Cove, near Lourdes (J. Rodgers and F. O'Brien)

The Clam Bank formation is well exposed from the south side of Clam Bank Cove southwestward along the shore for 3 miles (5 km). Most of the formation consists of redbeds, but at the cove and to the southwest, beds of fossiliferous limestone are intercalated. The fossils were formerly assigned to the Lower Devonian but are now assigned to the Pridoli stage at the top of the Silurian and equated with the lower part of the Stonehouse Formation of Arisaig, Nova Scotia (Berry and Boucot, 1970; O'Brien, unpubl. M.Sc. thesis). These neo-autochthonous rocks are overturned, dipping southeast but facing northwest.

At the northeast corner of the cove, the top of the Long Point formation is exposed in a small waterfall; the rocks are shale, siltstone, and sandstone (greywacke), mostly grey or brown but with a distinct maroon cast toward the top. Middle Ordovician graptolites occur in the greywacke just below the color change, suggesting that red sediments were present in this region at that time. These relations led Rodgers and Neale (1963, p. 728) to suggest a conformable sequence from the Middle Ordovician Long Point into the Silurian or Devonian Clam Bank, but because of the great age difference Rodgers (1965, p. 93) later suggested a disconformity. O'Brien (unpubl. M.Sc. thesis) claims that a fault intervenes between redbeds at the top of the Long Point Formation and the basal beds of the Clam Bank Formation both at Clam Bank Cove and at nearby Salmon Cove.

REFERENCES

Anderson, M. M. and Misra, S. B. (1968): Fossils found in the Precambrian Conception Group of southeastern Newfoundland. Nature, v. 220, pp. 680-681.

Berry, W. B. N. and Boucot, A. J. (1970): Correlation of the North American Silurian Rocks. Geol. Soc. Amer. Spec. Paper 102, 289p.

Bird, J. and Dewey, J. F. (1970): Lithosphere plate-continental margin tectonics and the evolution of the Appalachian orogen. Bull. Geol. Soc. America, v. 81, pp. 1031-1060.

Brookes, I. (1969): Late glacial marine overlap in western Newfoundland. Can. Jour. Earth Sci., v. 6, pp. 1397-1404.

[illegible], W. D. (1969): Geology of eastern part of Avalon Peninsula, Newfoundland — a summary. Amer. Assoc. Petrol. Geol. Mem. 12, pp. 1[illegible]-138.

Brückner, W. D. and Anderson, M. M. (1971): Late Precambrian glacial deposits in southeastern Newfoundland — a preliminary note. Proc. Geol. Assoc. Canada, v. 24, pp. 95-102.

Church, W. R. (1969): Structural evolution of northeast Newfoundland, comparison with that of the British Caledonides. Maritime Sediments, v. [illegible], no. 3, pp. 1-14.

Church, W. R. and Stevens, R. K. (1971): Early Paleozoic ophiolite complexes of the Newfoundland Appalachians as mantle-oceanic crust sequences. Jour. Geophys. Res., v. 76, pp. 1460-1466.

Dewey, J. F. (1969): Evolution of the Appalachian/Caledonian orogen. Nature, v. 222, pp. 124-129.

Dewey, J. F. and Bird, J. M. (1970): Mountain Belts and the new Global Tectonics. Jour. Geophys. Res. v. 75, pp. 2625-2647.

Fairbairn, H. W. et al. (1966): Whole rock age and initial Sr^{87}/Sr^{86} of volcanics underlying fossiliferous Lower Cambrian in the Atlantic Provinces of Canada. Can. Jour. Earth Sci., v. 3, pp. 509-521.

Fogwill, D. (1970): Mineral Deposits and Prospecting Environments of Newfoundland. Nfld. Dept. Mines, Agric. & Resources, Information Circular no. 14.

Harland, W. B. (1964): Critical evidence for a great infra-Cambrian glaciation. Geol. Rdsch., v. 54, pp. 45-61.

Helwig, J. and Sarpi, E. (1969): Plutonic pebble conglomerates, New World Island, Newfoundland, and history of eugeosynclines. Amer. Assoc. Petrol. Geol., Mem. 12, pp. 443-466.

Heyl, G. R. (1936): Geology and mineral resources of the Bay of Exploits area. Nfld. Dept. Nat. Res. Geol. Bull. 3, 66p.

Heyl, A. V. and Ronan, J. J. (1954): The iron deposits of Indian Head area, Newfoundland. Geol. Surv. Canada Bull. 22, pp. 42-62.

Horne, G. S. and Helwig, J. (1969): Ordovician stratigraphy of Notre Dame Bay, Newfoundland. Amer. Assoc. Petrol. Geol., Mem. 12, pp. 388-407.

Howell, B. (1925): The faunas of the Cambrian Paradoxides beds at Manuels, Newfoundland. Bull. Amer. Paleont., v. 11, no. 43.

Hughes, C. J. (1970): The Late Precambrian Avalonian orogeny in Avalon, southeast Newfoundland. Amer. Jour. Sci., v. 269, pp. 183-190.

Hughes, C. J. and Brückner, W. D. (1971): Late Precambrian rocks of eastern Avalon Peninsula, Newfoundland — a volcanic island complex. Can. Jour. Earth Sci., v. 8, pp. 899-915.

Hughes, C. J. and Malpas, J. G. (1971): Metasomatism in the Late Precambrian Bull Arm Formation in southeastern Newfoundland. Proc. Geol. Assoc. Canada, v. 24, pp. 85-93.

Jenness, S. E. (1958): Geology of the Gander River ultrabasic belt. Geol. Surv. Nfld. Rept. 12.

Jenness, S. E. (1963): Terra Nova and Bonavista map-areas, Newfoundland. Geol. Surv. Canada Mem. 327, 184p.

Kay, M. (1966): Newfoundland structures and continental drift. Bull. Can. Petrol. Geol., v. 14, pp. [illegible].

Kay, M. (1969): Stratigraphy and structure of northeast Newfoundland bearing on drift in the North Atlantic. Amer. Assoc. Petrol. Geol. Bull., v. 51, pp. [illegible].

Kay, M. and Eldredge, N. (1968). Cambrian trilobites of central Newfoundland Volcanic belt. Geol. Mag., v. 105, pp. 372-377.

Kennedy, M. J. (1971). Structure and stratigraphy of the Fleur de Lys Supergroup in the Fleur de Lys area, Burlington Peninsula, Newfoundland. Proc. Geol. Assoc. Canada, v. 24, pp. 59-71.

Kennedy, M. J. and Phillips, W. E. A. (1971). Ultramafic rocks of Burlington Peninsula, Newfoundland. Proc. Geol. Assoc. Canada, v. 24, pp. 35-46.

Kindle and Whittington (1958). Stratigraphy of the Cow Head region, western Newfoundland. Geol. Soc. Amer. Bull., v. 69, p. 315-342.

Lilly, H. D. (1965). Submarine examination of the Virgin Rocks area, Grand Banks, Newfoundland. Geol. Soc. Amer. Bull., v. 76, pp. 131-132.

Lock, B. E. (1969). Silurian rocks of west White Bay, Newfoundland. Amer. Assoc. Petrol. Geol. Mem. 12, pp. 433-442.

MacClintock, P. and Twenhofel, W. (1940). Wisconsin glaciation of Newfoundland. Geol. Soc. Amer. Bull., v. 51, pp. 1729-1756.

Marten, B. E. (1971). Stratigraphy of volcanic rocks in the Western Arm area of the central Newfoundland Appalachians. Proc. Geol. Assoc. Canada, v. 24, pp. 73-84.

McCartney, W. D. (1965). Metallogeny of Post-Precambrian geosynclines. Geol. Surv. Canada Paper 65-6, pp. 33-42.

McCartney, W. D. (1967). Whitbourne map area, Newfoundland. Geol. Surv. Canada, Mem. 341, 135p.

McCartney, W. D. and Potter, R. R. (1962). Mineralization as related to structural deformation, igneous activity and sedimentation in folded geosynclines. Can. Min. Jour., v. 83, pp. 83-87.

Misra, S. B. (1969). Late Precambrian (?) fossils from southeastern Newfoundland. Geol. Soc. Amer. Bull., v. 80, pp. 2133-2140.

Misra, S. B. (1971). Stratigraphy and depositional history of Late Precambrian coelenterate-bearing rocks, southeastern Newfoundland. Geol. Soc. Amer. Bull., v. 82, pp. 979-988.

Neale, E. R. W. (1957). Ambiguous intrusive relationship of the Betts Cove-Tilt Cove serpentinite belt, Newfoundland. Proc. Geol. Assoc. Canada, v. 9, pp. 95-107.

Neale, E. R. W. and Nash, W. A. (1963). Sandy Lake (east half), Newfoundland. Geol. Surv. Canada Paper [illegible].

Papezik, V. S. (1969). Late Precambrian ignimbrites of the Avalon Peninsula, Newfoundland. Can. Jour. Earth Sci., v. 6, pp. 1405-1414.

Papezik, V. S. (1970). Petrochemistry of volcanic rocks of the Harbour Main Group, Avalon Peninsula, Newfoundland. Can. Jour. Earth Sci., v. 7, pp. 1485-1498.

Papezik, V. S. and Fleming, J. (1967). Volcanic rocks of the Whalesback area, Newfoundland. Geol. Assoc. Canada Spec. Paper 4, pp. 181-192.

Phillips, W. E. A., Kennedy, M. J. and Dunlop, G. M. (1969). Geologic comparison of western Ireland and northeastern Newfoundland. Amer. Assoc. Petrol. Geol. Mem. 12, pp. 194-211.

Rodgers, J. (1965). Long Point and Clam Bank Formations, western Newfoundland. Proc. Geol. Assoc. Canada, v. 16, pp. 83-94.

Rodgers, J. (1968). The eastern edge of the North American continent during Cambrian and early Ordovician; Studies of Appalachian Geology: northern and maritime, Interscience, New York, pp. 141-149.

Rodgers, J. and Neale, E. R. W. (1963). Possible "Taconic" Klippen in western Newfoundland. Amer. Jour. Sci., v. 261, pp. 713-730.

Rose, E. R. (1952). Torbay map-area, Newfoundland. Geol. Surv. Canada Mem. 265, 64p.

Sheridan, R. E. and Drake, C. L. (1968). Seaward extension of the Canadian Appalachians. Can. Jour. Earth Sci., v. 5, pp. 337-373.

Smith, C. H. (1958). Bay of Islands igneous complex, western Newfoundland. Geol. Surv. Canada, Mem. 290, 132p.

Smitheringale, W. G. (1972). Low-Potash Lush's Bight Tholeiites: Ancient Oceanic Crust in Newfoundland. Can. Jour. Earth Sci. (in press).

Smyth, W. R. (1971). Stratigraphy and structure of part of the Hare Bay allochthon, Newfoundland. Proc. Geol. Assoc. Canada, v. 24, pp. 47-58.

Snelgrove, A. K. (1931). Geology and ore deposits of Betts Cove - Tilt Cove area, Newfoundland. Bull. Can. Min. Met., no. 228, pp. 477-519.

Stevens, R. K. (1970). Cambro-Ordovician flysch sedimentation and tectonics in west Newfoundland and their possible bearing on a proto-Atlantic Ocean. Geol. Assoc. Canada Sp. Paper 7, pp. 165-177.

Twenhofel, W. H. and MacClintock, P. (1940). Surface of Newfoundland. Bull. Geol. Soc. Amer., v. 51, pp. 1665-1728.

Upadhyay, H. D., Dewey, J. F. and Neale, E. R. W. (1971). The Betts Cove Ophiolite Complex, Newfoundland: Appalachian oceanic crust and mantle. Proc. Geol. Assoc. Canada, v. 24, pp. 27-34.

Walthier, T. N. (1949). Geology and mineral deposits of the area between Corner Brook and Stephenville, Newfoundland. Geol. Surv. Nfld. Bull. 35, 62p.

Weaver, D. F. (1967). A geological interpretation of the Bouguer anomaly field of Newfoundland. Dom. Observ. Canada Pub., v. 35, n. 5.

Williams, H. (1964). The Appalachians in northeastern Newfoundland - a two-sided symmetrical system. Am. Jour. Sci., v. 262, pp. 1137-1158.

Williams, H. (1967). Island of Newfoundland. Geol. Surv. Canada Map 1231A.

Williams, H. (1970). Relationships between Late Precambrian and Paleozoic rocks at Belle Bay, eastern Newfoundland. Geol. Soc. Amer. Abstr. Vol. 2, no. 1, pp. 40-41.

Williams, H. (1971). Mafic-Ultramafic complexes in western Newfoundland Appalachians and the evidence for their transportation. Proc. Geol. Assoc. Canada, v. 24, pp. 9-26.

Williams, H., Kennedy, M. J. and Neale, E. R. W. (1970). The Hermitage Flexure, the Cabot Fault and the disappearance of the Newfoundland Central Mobile Belt. Bull. Geol. Soc. America, v. 81, pp. 1563-1568.

Williams, H. and Stevens, R. K. (1969). Geology of Belle Isle - northern extremity of the deformed Appalachian miogeosynclinal belt. Can. Jour. Earth Sci., v. 6, pp. 1145-1157.

Reprinted from:

XXIV International Geological Congress

Montreal, Quebec, 1972

Guidebook

Excursion A63-C63

Appalachian Geotectonic Elements of the Atlantic Provinces

and Southern Quebec

W.H. Poole and John Rodgers

(parts of p. 81-97)

of dolostone and limestone, and the overlying early Middle Ordovician Table Head Formation of over 300 m (1,000 feet) of dark grey limestone. Limestone is quarried from both formations near Corner Brook for the manufacture of cement.

Stop 5-3 Top of autochthonous sequence; black phyllite (early Middle Ordovician) with some exotic blocks, Great Northern Peninsula zone.

Location: Trans Canada Highway; just north of main exit for Corner Brook.

Dark shale, phyllite and sheared, like that (Stop 4-7) at the top of the mainly carbonate early Middle Ordovician Table Head Formation, here lies just below the Humber Arm Klippe. A few blocks of greywacke quartzite are scattered through the shale, but it is not as spectacular as the "Wildflysch-type" breccia at Stop 4-7. The klippe lies to the west, structurally above the west-dipping autochthonous carbonates.

Stop 5-4 Quartzite and bank-foot limestone-conglomerate in allochthon: Irishtown Formation (Lower and ? Middle Cambrian) in lower part of Humber Arm Klippe, Great Northern Peninsula zone.

Location: Within Corner Brook at north end of Todd Street, just north of Holiday Inn.

Interbedded with typical dark shale, greywacke and white quartzite of the Lower and (?) Middle Cambrian Irishtown Formation (see Stop 5-5), are beds of limestone conglomerate (Stevens, 1970). Early Cambrian trilobites and hyolithellids have been found in some pebbles. The pebbles of limestone and quartzite were probably derived from the autochthonous Cambrian sequence. The limestone probably formed on a carbonate bank covering the eastern side of the North American craton, i.e. on the Precambrian inlier in western Newfoundland and its subsurface extension along the Great Northern Peninsula zone. Fragments of limestone and quartzite were transported with clean quartz sand derived from the Precambrian rocks into deeper water east of the carbonate bank. No obvious source for these rocks and sand is known to the east.

Stratigraphic and structural sequence along the shores of Humber Arm and Bay of Islands (Bruckner, 1966, pp. 158-176)

	Metres (approximately)	Feet (approximately)
Ultramafic, mafic, and felsic igneous rocks, mainly intrusive (in highest slices)		
Volcanics, mafic and intermediate, flows and pyroclastic rocks, some greywacke and shale (one or more separate slices)	300+	1200+
Blow-Me-Down Brook Formation (Lower Ordovician) Greywacke sandstone, arkose, red and green shale; some pebbly beds	500	1650
Middle Arm Point Formation (Lower Ordovician) Black and green shale; thin beds of dolostone, siltstone, greywacke, limestone and chert	150	500
Cooks Brook Formation (Middle Cambrian to Lower Ordovician) Black shale with many beds of thin-bedded limestone and limestone-breccia	300	1000
Irishtown Formation (Lower and ?Middle Cambrian) Dark shale, quartzite, siltstone, locally beds of limestone-conglomerate associated with quartzite	300	1000
Summerside Formation (Lower Cambrian ?) Green and purple shale, grey shale and greywacke sandstone	250	800
Total	**1800+**	**6150+**

(All contacts between sedimentary units are transitional and difficult to draw, not to mention the very considerable deformation, especially of the Middle Arm Point Formation. Furthermore, according to Williams (1973) and Williams *et al.* (1972), the volcanic and intrusive rocks shown here at the top of the sequence constitute separate tectonic slices and cannot be interpreted as the youngest (stratigraphic) units of the Humber Arm sequence. See also description for Stop 5-8.

Stop 5-5 Basal slate-greywacke unit in the allochthonous sequence (Summerside Formation) and view of east part of Humber Arm klippe and its relation to the autochthon, Humber Arm klippe of Great Northern Peninsula zone.

Location: Top of Crow Hill in west part of Corner Brook.

Greywacke and slate on Crow Hill form a small anticline of the lowest formation, the Summerside, of the allochthonous sequence in the Humber Arm klippe. The Summerside is unfossiliferous but probably Lower Cambrian, and the clastic material was probably derived from a Precambrian terrane like the detritus in the overlying Irishtown Formation (Stop 5-4). In this eastern part of the klippe, cleavage dips west and is probably related to deformation later than the klippe emplacement process.

From Crow Hill, in good weather, one can see a panorama from Mount Musgrave on the east, in the metamorphosed Fleur de Lys Supergroup, to Blow-Me-Down Mountain on the west, formed by a large ultramafic mass in the highest of the allochthonous slices of the Humber Arm klippe. Almost the entire allochthonous sequence is displayed along the shores of Bay of Islands and Humber Arm (Brückner, 1966; Stevens, 1970).

Stop 5-6 Bank-foot limestone-conglomerate in slate of allochthonous sequence; Cooks Brook Formation (late Middle Cambrian to Lower Ordovician), Humber Arm klippe, Great Northern Peninsula zone.

Location: Highway 46 along south shore of Humber Arm, over Giles Point, about 6 miles (9.6 km) west of centre of Corner Brook.

Coarse limestone-conglomerate or breccia and fine-grained limestone interbedded with dark, partly limy shale or slate characterize the Cooks Brook Formation. Good outcrops of the formation are visible at the water's edge on the shore just north of this road stop. Presumably, the blocks in this conglomerate came from the carbonate bank along the west side of the original depositional basin of the allochthonous sequence. Aside from such blocks and from quartz sand probably also derived from the craton to the west, only silt and fine mud entered this basin between the Early Cambrian (Summerside Formation) and the late Early Ordovician (base of Blow-Me-Down Brook Formation), although the provenance area then shifted from the west to the east at the beginning of deposition of the Blow-Me-Down Brook Formation (Fig. 13).

(R. K. Stevens)

Clasts in the Cooks Brook limestone-conglomerate are not as coarse and the formation is thinner bedded than the well-known Cow Head breccias (Stop 4-9), but both belong to the same general lime-conglomerate, lime-turbidite facies (Stevens, 1970). Fragments in the Giles Point exposures include mainly limestone plates that are probably locally derived and also exotic blocks of carbonate rock that are probably of shallow water origin. A few oölitic limestone blocks are also present. Rocks in the shaly zone transitional into the underlying Irishtown Formation include fine-grained sandstone, limestone and graded oölitic beds, which are interpreted as turbidites. At least two phases of deformation are discernible in the complexly folded strata at Giles Point. The latest phase of deformation was associated with the formation of the major south-plunging synclinorium, in which the klippe rocks now rest, and which was formed after the klippe was emplaced.

Stop 5 - 7 Mélange within or above the Middle Arm Point Formation (Lower Ordovician), Humber Arm klippe, Great Northern Peninsula zone (R. K. Stevens).

Location: Frenchman's Cove, south shore of Humber Arm just east of the village of Frenchman's Cove on Highway 46, 15 miles (24 km) west of Corner Brook.

A mélange zone over a mile (1.6 km) wide forms the cliffs around Frenchman's Cove. Typically it consists of carbonate, greywacke, and tough shale blocks set in a phacoidally cleaved black and green shaly matrix. Some greywacke blocks resemble slumped beds and others resemble boudins. A crude alignment of blocks of similar lithology and a gross stratification of block lithologies show that the mélange is not as chaotic as it appears at first sight. Some blocks have also been rotated parallel to the north-trending regional cleavage.

All of the blocks at Frenchman's Cove can be matched with lithologies in the Blow-Me-Down Brook, Middle Arm Point, and Cooks Brook Formations. The black and green shale matrix corresponds to shales of the Middle Arm Point Formation and contains fragments of Early Ordovician graptolites. Small flat cones of calcite (2-3 mm across) have also been found here; they are solid, slightly concave on the face opposite the apex, and occasionally articulated in pairs, point to point. Although presumably organic, they have not been identified by any paleontologist to whom they have been shown.

Elsewhere in this zone, some exotic blocks have been noted; for example, a large gabbro block forms the prominent hump on the eastern end of Woods Island, which is visible from Frenchman's Cove.

The origin and significance of this and other mélange zones in the klippe are not yet clear. Strong differential tectonic movement within the most incompetent members of the klippe sequences might be thought of as the only cause for their chaotic structure. Because of the occasional exotic inclusions and general paleogeographical considerations, however, it can be argued that tectonic deformation has not primarily created but only increased and modified the disorder in masses that had become chaotic because of terrestrial (Brückner, 1966) or submarine mass-wasting before and/or during the tectonic transport of the klippe slices. A possible explanation of the mélange zone at Frenchman's Cove is that it represents a predominantly shaly olistostrome, which was overrun and deformed by a higher slice of the allochthon, the base of which became tectonically incorporated into the upper part of the mélange (Stevens, 1970).

Stop 5 - 8 Serpentinite mélange below the slice containing the Blow-Me-Down pluton, Humber Arm klippe of Great Northern Peninsula zone (H. Williams).

Location: Highway 46 along south shore of Humber Arm, one mile (1.6 km) west of Blow-Me-Down Brook, about 18 miles (29 km) west of Corner Brook.

The serpentinite mélange consists of serpentinite and gabbro blocks in a finely comminuted serpentine matrix. This zone, commonly several tens of feet thick, separates gabbroic rocks of the Blow-Me-Down pluton (above) from unmetamorphosed, poorly indurated sandstones of the Blow-Me-Down Brook Formation at the top of the clastic terrane (Fig. 12). These clastic strata are exposed on the coast below the road and represent the eastern part of a flysch wedge that eventually transgressed westward and spread across the carbonate succession (Fig. 13). The flysch locally contains serpentinite fragments, chromite grains, and pyroxene crystals, implying that the mafic-ultramafic complexes were in an elevated position during its deposition (Stevens, 1970).

The mafic-ultramafic complexes occur in separate slices that overlie the transported clastic sedimentary rocks. Some of these, especially the Blow-Me-Down pluton of the Bay of Islands igneous complex, have all the features of a typical ophiolite suite complete with sheeted dyke complex and mafic pillow lavas at its top (Williams, 1971). More westerly coastal exposures of the mafic-ultramafic rocks are internally structurally complex and include much polyphase deformed amphibolitic gabbro and foliated granodiorite, all cut by sheeted dykes and dyke breccias and locally unconformably overlain by relatively undeformed mafic volcanic rocks.

Three miles (4.8 km) farther west along the road is the Big Nama mine adit at Mine Brook. The adit is collared in a large, reddish volcanic boulder about 15 m (50 feet) in diameter. It was driven to test the continuity at depth of a pyrite-chalcopyrite orebody that occurs in mafic rocks at a higher level in the pluton. Nearby red mélange contains large blocks of Blow-Me-Down Brook sandstone within a scaly shale matrix. All these rubbly rocks, characteristic of the basal contact of the pluton, are faulted against nearby mafic pillow lavas that occur upstream in Mine Brook. About half a mile (0.8 km) west of Mine Brook, mafic pillow lavas and agglomerates are exposed that are typical of those at the top of the Blow-Me-Down ophiolite succession. Farther west again is gabbro on the west side of the Blow-Me-Down pluton, indicating that the structure of the pluton is a broad open syncline with the ophiolite units truncated along its basal tectonic contact.

A few miles farther along, the highway crosses low land around York Harbour (underlain by greywacke sandstone of

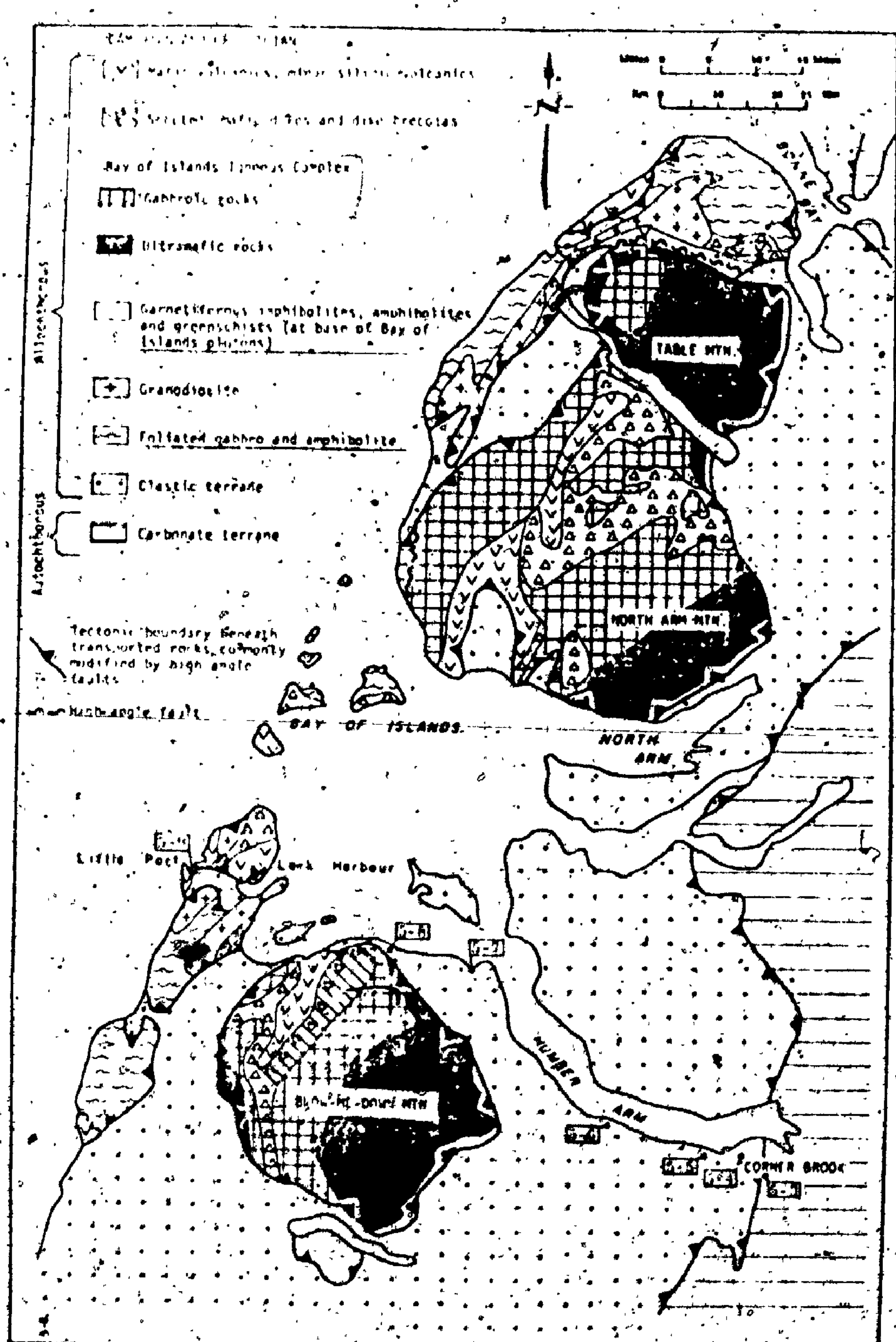


Fig. 12. Geology in the vicinity of the Bay of Islands Complex. After Williams et al. (1972, p. 15). Locations of Stops 5-3 to 5-9 are indicated.

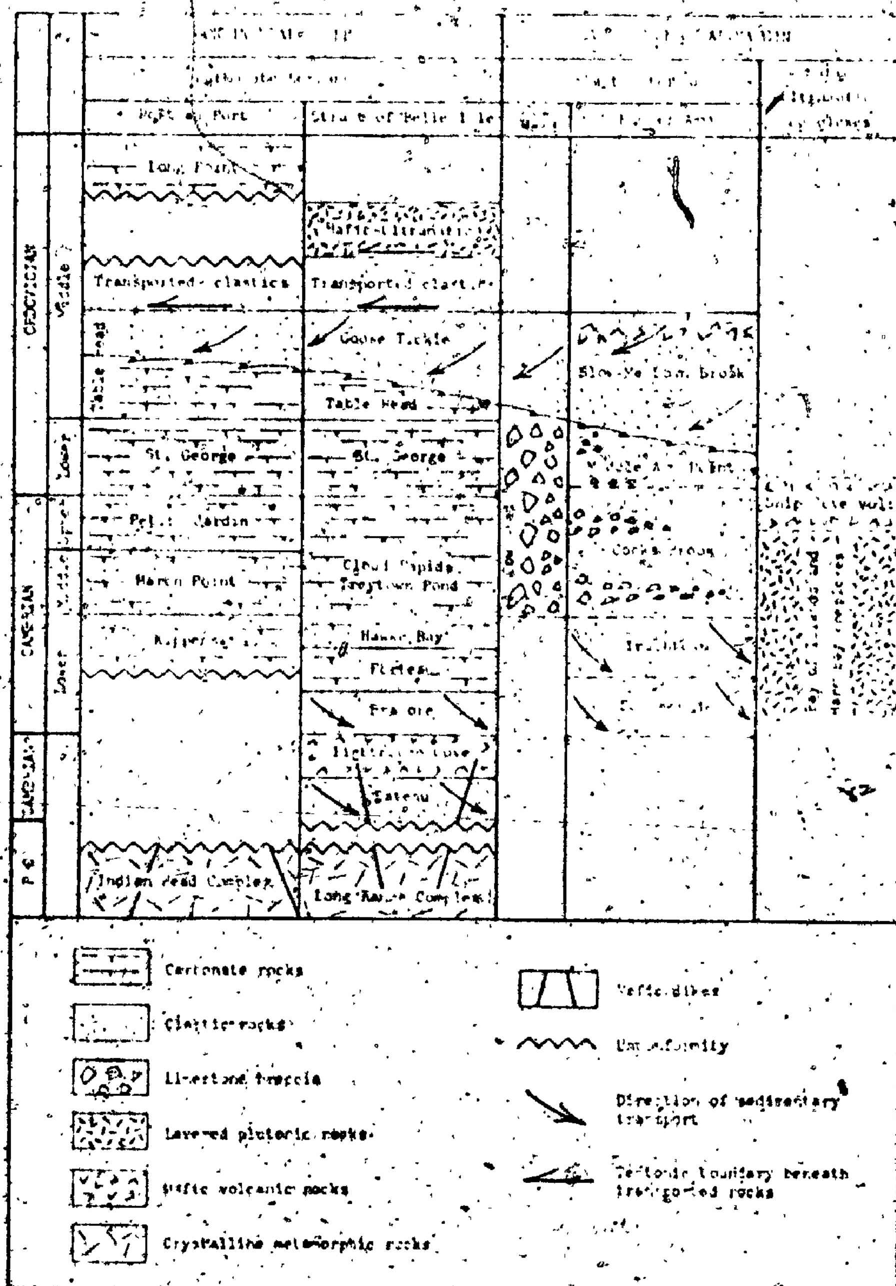


Fig. 13. Stratigraphic relationships of facies belts in western Newfoundland before tectonic transport. After Williams (1971, Fig. 4).

the Blow-Me-Down Brook Formation), and then rises to a high pass where albite granite to quartz diorite, part of the allochthonous sequence, is exposed. The rocks are massive to weakly foliated and almost everywhere are cut by veinlets of clastic, gas-brecciated, granitic material. As seen in coastal exposures the granodiorite cuts amphibolitic gabbro and is itself cut by mafic dykes and dyke breccias that pass upward into mafic pillow lavas. The dykes, dyke breccias, and mafic lavas are all similar to the rocks that occur toward and at the top of the Bay of Islands plutons. The strongly foliated amphibolitic gabbros that are cut by granites have no real correlatives among the plutonic rocks of the Bay of Islands plutons and their complex structural history suggests that they are older.

Stop 5-9 Volcanics within slices of igneous rocks of the allochthonous sequence, Humber Arm klippe of Great Northern Peninsula zone.

Location: Little Port, west end of Highway 46, on Gulf of St. Lawrence.

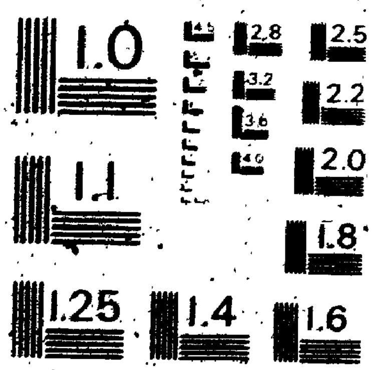
The volcanic rocks are mainly altered green and red mafic flows and pillow breccias with some silicic units. They are noticeably less deformed and less altered than the amphibolites and foliated gabbro (Williams, 1971), and indeed are believed to overlie the gabbro unconformably. Mafic dykes cut the granitic rocks and the volcanics and are probably related to the volcanism.

The outer, western coastline of the Humber Arm klippe is remarkably straight, and probably marks the present west margin of the klippe, either its original margin, or an erosional margin, or most probably the overlap of a neautochthonous sequence (Long Point and Clam Bank Formations of Stops 6-4 and 6-5) which probably lies under the gulf 8 to 16 km (5 to 10 miles) off-shore (Lilly, 1966; Ruffman and Woodside, 1970). Lilly discovered gently dipping or flat-lying Clam Bank sediments underwater in three localities off-shore from Port au Port to north of Bonne Bay, a distance of 150 km (100 miles).

DAY 6 - West coast of Newfoundland, Port au Port Peninsula; Precambrian to Devonian (?); Great Northern Peninsula zone.

Stop 6-1 Retrogressed basement: Indian Head Range complex (pre-Hadrynian); Great Northern Peninsula zone (V. S. Papezik).

3 OF/DE 4



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS - 1963

Location: Highway on east side of Indian Head Range, at intersection of Trans-Canada Highway access road and Stephenville-Stephenville Crossing road (Hansen Highway).

Gneissic rocks of granulite and amphibolite facies, minor granitic rocks and a small body of anorthosite, make up a Precambrian inlier 5 km wide and 25 km long (3 by 15 miles) in the Indian Head Range. Biotites from granitic gneiss and from pegmatite have yielded typical "Grenville" dates of 830 and 900 m.y. by K-Ar analyses. The rocks are probably continuous in the subsurface with the Precambrian rocks outcropping north of the Humber Arm klippe (Stop 4-6), and with the anorthosite and gabbro body 19 km (12 miles) to the east. The Indian Head Range complex is overlain unconformably by Cambrian, Ordovician and Carboniferous strata.

At the stop locality is crudely layered dark grey, medium-grained andesine-orthopyroxene gneiss with minor biotite; the gneiss forms layers and lenses several metres thick interlayered with thinner layers of biotite amphibolite. This "basic" gneiss grades westward into a pinkish granitic gneiss consisting chiefly of quartz, potash feldspar, plagioclase (An_{30}) and biotite. The gneiss is cut by several thin veins of pegmatite.

The high hills along the highway to the west, bounded by steep cliffs, are formed of coarse-grained porphyritic granite, grading in places into gneissic granite and granitic augen-gneiss, all characterized by large porphyroblasts of red potash feldspar.

The gneissic rocks of the Indian Head Range contain many small lenses of massive and disseminated magnetite and/or hematite with some ilmenite. Several of them were of sufficient size to warrant exploration by various mining companies over the last fifty years, and are now exposed in short adits and small open-cuts. Most of these are accessible only by long-abandoned mining roads, but a small example can be seen in a roadcut along the highway 2.4 miles (3.8 km) to the west.

A relatively small (3 by 2 km, 2 by 1.25 mile) body of anorthosite and gabbroic anorthosite in the southern tip of the Indian Head Range, consists of remnants of light grey plagioclase crystals 5 to 50 cm (2 to 20 inches) long, enclosed in a white medium-grained cataclastic feldspathic matrix. Crystals and aggregates of partly altered hyper-

[illegible] up to 1 metre (3 feet) across are irregularly distributed throughout the rock. The feldspar is calcic andesine ([illegible]); a bluish play of colours ("labradorite effect") can be seen in a few spots, but is not common. Magnetite and [illegible] are minor accessories.

Stop 6-2: View of Port au Port region from autochthonous carbonates (St. George Group, Lower Ordovician and ? Upper Cambrian), Great Northern Peninsula zone.

Location: West brow of Table Mountain along road to radar site, about 5 miles (8 km) west-northwest of Stephenville, and 3 miles (5 km) northeast of Port au Port village on Highway 47.

The autochthonous carbonate strata of the St. George Group underlie Table Mountain (Fig. 14) and dip about 25 degrees west-northwest toward Port au Port Bay; they are little deformed but lie on a long, tilted fault block. Southwestward they can be traced to the shore of the bay and across its southeast corner onto the east end of the Port au Port Peninsula, where they dip gently north and can be followed along the south shore to Cape St. George at the southwest tip. The base of the St. George Group is exposed locally along that shore and also on the east face of Table Mountain. The top is exposed on the east shore of Port au Port Bay, where it is succeeded by the early Middle Ordovician Table Head limestone and the overlying autochthonous shale. This shale is overlain by the rocks of the Humber Arm klippe, which reach the shore at Stop 6-3 and are also preserved on the peninsula across the bay, at least on Shoal Point and along the west shore of the bay; these are the southwesternmost exposures of the klippe. Long Point, the long northern extremity of the Peninsula, is formed, however, of a northwest-dipping neautochthonous sequence (Stops 6-4 and 6-5), which rests unconformably on the klippe rocks. Farther southwest it may rest directly upon the upper layers of the autochthonous sequence; according to Stevens (1970; *see* his Fig. 4), the Long Point Formation rests conformably upon the autochthonous flysch sequence that was deposited in front of the klippe and was overrun by the klippe in what is now central Port au Port Peninsula. The Carboniferous Codroy Group of sandstone, conglomerate, limestone and gypsum (equivalent of the Windsor Group, Stop 7-3) laps unconformably upon all older rocks. St. George's Bay is probably underlain by thick Carboniferous strata. Magnesia is extracted from sea water at Aguathuna near the isthmus of Port au Port Peninsula in a process utilizing limestone and dolostone from a nearby quarry in St. George and Table Head carbonate. The quarry wall displays an erosional unconformity between these two units and fossiliferous Codroy limestone rests unconformably on the Table Head. Farther north along the west coast, at Daniel's Harbour, are sphalerite deposits associated with the St. George - Table Head contact. Gypsum is quarried from the Codroy in the large Carboniferous terrane near Flat Bay on the southeast side of St. George's Bay opposite Stephenville.

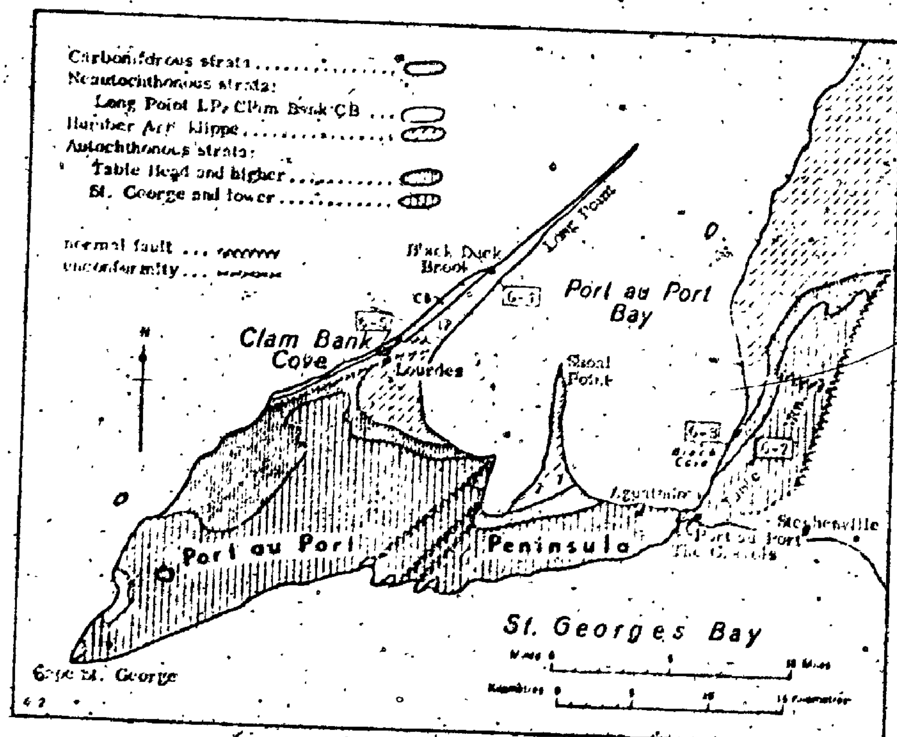


Fig 34. Geology of Port au Port Peninsula. Modified from Riley (1962). Locations of Stops 6-2 to 6-5 are indicated

Stop 6-7 "Wildflysch-type" breccia and the base of the Humber Arm klippe, Great Northern Peninsula zone.

Location: East shore of Port au Port Bay, 3 miles (5 km) north of Port au Port village along Highway 59. Take trail to shore from road at a point 2.3 miles (3.7 km) north of Port au Port village, walk north on shore, and return via trail to road at 3.4 miles (5.4 km) north of Port au Port village.

The well exposed section of the upper St. George Group and the Table Head from The Gravels north to Black Cove (south of the tanks) is described in detail by Schuchert and Dunbar (1934, pp. 46-47, 66-67). At Black Cove many paleontologists have collected graptolites from black shale generally assigned to the upper part of the Table Head Formation; the latest detailed discussion of this fauna is by Morris and Kay (1966), who gave the age as Llanvirn (Zone 6 of the Elles and Wood succession according to Morris and Kay, Zone 9 of the Berry succession according to Whittington, 1968). On the shore below the tanks, this black shale is overlain by a bed, about 15 m (50 feet) thick, of limestone-breccia. North of the tanks, the limestone-breccia is succeeded by a thin mélange zone with components from the underlying Table Head shale and breccia. The mélange in turn, is overlain by grey shale with thin green sandstone (subgreywacke) beds. All these strata dip regularly about 25 degrees northwest, the shore bevelling them obliquely.

Farther north along the shore, at the mouth of a brook, these rocks, here somewhat folded, are abruptly overlain by a wildly contorted and broken series including red and green slate, greywacke, black chert, and other rock types characteristic of the allochthonous sequence. At their base, these rocks form a "Wildflysch-type" mélange, but not far to the north they are coherent, though still highly deformed, and traversed by another mélange zone. Apparently the coherent parts of this section belong to the Middle Arm Point and Blow-Me-Down Brook Formations of the allochthonous Humber Arm sequence. Lower Ordovician (Tremadoc) graptolites have been found in similar rocks on Shoal Point, which projects into the southern part of Port au Port Bay, and also in shale interbedded with limestone and limestone-conglomerate on the west shore of the bay east of Lourdes, just south of the overlap of the neautochthonous sequence. (See also guidebook for excursion AC62; Stop 10-3).

Stop 6-4 Lower part of neautochthonous sequence, Long Point Formation (Middle Ordovician), Great Northern Peninsula zone

Location: Seacliffs along east shore of Long Point of Port au Port Peninsula, off Highway 58, either just east of Black Duck Brook village or about half a mile (0.8 km) south.

The unconformity at the base of the neautochthonous succession has been seen near the base of Long Point east of Lourdes, but the locality is not very accessible and needs to be dug out.

Stratigraphic sequence of Ordovician to (?) Devonian neautochthonous succession on Port au Port Peninsula (Rodgers, 1965).

	Metres	Feet
Clam Bank Formation (Upper Silurian and ?Lower Devonian)		
Red cross-bedded sandstone, some pebbly; red, green and brown siltstone and mudstone; limy siltstone and shale, quartzose limestone (lime-sandstone and lime-siltstone)	450	1500
Long Point Formation (Middle Ordovician)		
Shale and siltstone member		
Dark shale, with beds of limy sandstone and sandy limestone (lime-sandstone), with coarser sandstone (greywackes) at the top, grey and brown grading to maroon in the highest beds	750	2500
Basal limestone member		
Nodular shaly limestone	36	120
Nodular limestone, middle part massive	23	75
Sandy, silty and shaly limestone	23	75
Totals	1282	4270

At this stop locality, the upper two thirds of the basal limestone member is exposed in the cliffs, and the lower part of the shale and siltstone member can be found in the ditch of the road crossing the point south of Black Duck Brook village. The basal limestone member contains numerous corals and other fauna. The shelly fossils were originally assigned to the Wilderness stage of the Middle Ordovician, but more recently Kay (1969c, pp. 667-668) concluded that they are considerably older: Chazy and Porterfield. Thus, the geologic relations around Port au Port Bay prove that the Humber Arm klippe was emplaced during a relatively short span of the early Middle Ordovician, and that, almost immediately thereafter, normal shallow-water conditions returned.

Stop C-[illegible] Upper part of neautochthonous sequence: Clam Bank Formation (Upper Silurian and ?Lower Devonian), Great Northern Peninsula zone.

Location: South side of Clam Bank Cove on northwest shore of Port au Port Peninsula just west of Lourdes.

The Clam Bank Formation is well exposed along the south side of Clam Bank Cove and southwestward for over 5 km (3 miles). Most of the formation consists of redbeds, but at the cove (and again some 3 km - 2 miles - to the southwest) beds of fossiliferous limestone are intercalated. The fossils were formerly assigned to the Lower Devonian, but Boucout (1969, p. 477) recently concluded they represent the Přídolí stage at the top of the Silurian. In this area all the neautochthonous rocks are overturned, dipping southeast but facing northwest, as indicated by the abundant cross-bedding in the redbeds.

At the northeast corner of the cove, the highest exposed beds of the Long Point Formation appear along a small waterfall; the rocks are shale, siltstone, and sandstone (greywacke), mostly grey and brown but with a distinct maroon cast toward the top. Graptolites found in the greywacke just below the colour change (by E. R. W. Neale in 1961) have been identified as Middle Ordovician, suggesting that reddish sediments appeared in this region already at that time. These relations led Rodgers and Neale (1963, p. 728) to suggest a conformable sequence from the Middle Ordovician Long Point into the Silurian or Devonian Clam Bank, but because of the great age difference Rodgers (1965, p. 93) later suggested a disconformity. Alternately, the contact may be a fault. The intermediate strata are not well enough exposed along the bluffs on the southeast side of the cove to settle the question, and east-west faults are known to intersect the coast near here, notably close to the waterfall. In any case, the strata of the two formations are structurally parallel.

Reprinted from:

Geological Survey of Canada

Paper 73-1, Part A

p. 8-14

(with H. Williams and W.R. Smyth)

4. HARE BAY ALLOCHTHON, NORTHERN NEWFOUNDLAND

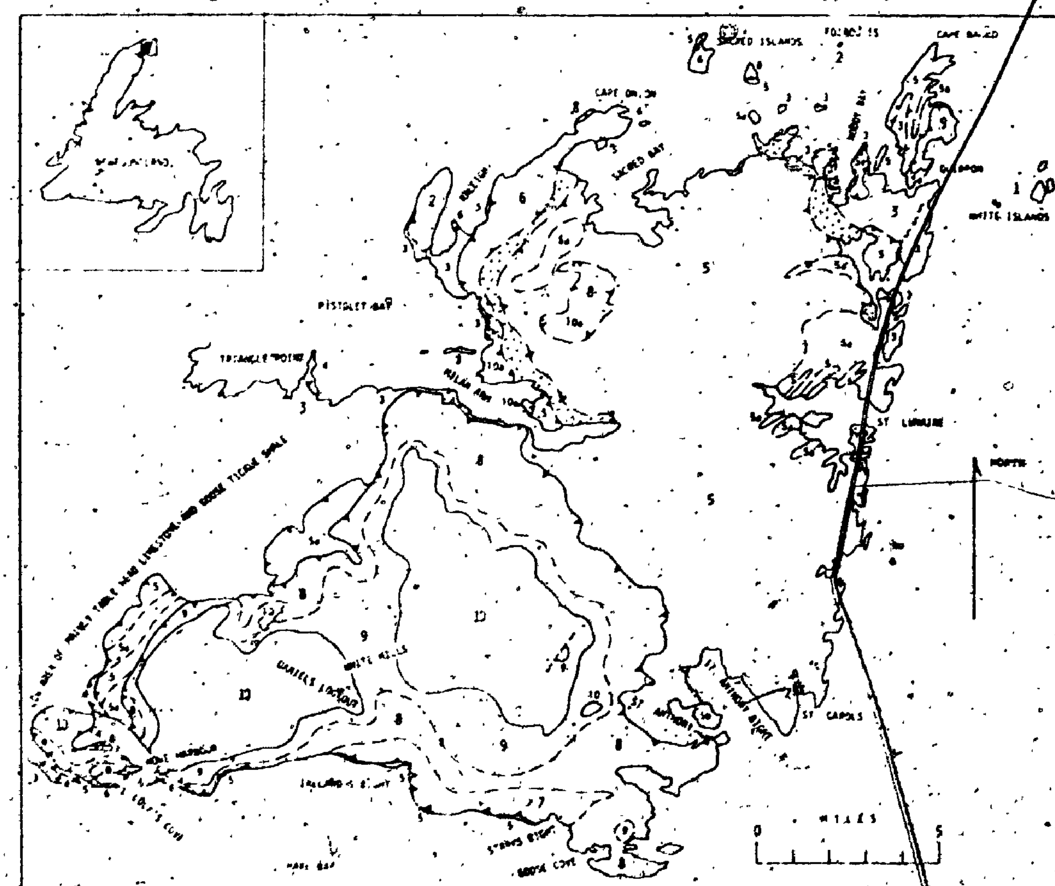
Project 720093

Harold Williams*, W.R. Smyth*, [redacted] R.K. Stevens*

Approximately 60 per cent of the Hare Bay allochthon north of Hare Bay was mapped for publication at a scale of 1 inch to 2 miles, and reconnaissance studies were carried out in the remainder of the area.

Autochthonous rocks below the allochthon are mainly Middle Ordovician flysch of the Goose Tickle Formation (3)[1,2], underlain by limestone of the Middle Ordovician Table Head Formation (2). The quartzite on White Islands is of unknown age and relationship but is correlated lithologically with the Bateau Formation (1) of Belle Isle[3].

Four lithologically distinct rock groups are recognized among the transported rocks. Each comprises one or more separate slices that occur in a definite and consistent stacking order with respect to structural slices of contrasting rock groups. Structural slices of the same rock group and at the same level within the structural succession are collectively referred to as a



*Memorial University, St. John's, Newfoundland

Legend for Figure 1 (opposite)

WHITE HILLS SLICE ASSEMBLAGE

LOWER ORDOVICIAN OR OLDER

10	Foliated peridotite and dunite; 10a, includes serpentinite, amphibolite, hornblendite, pyroxenite, and rhodingite
9	Amphibolite, garnetiferous amphibolite, and garnet-amphibole-biotite schist
8	GOOSE COVE FORMATION: green chloritic schist mainly of volcanic derivation, black phyllitic schist, grey schistose limestone, and minor psammitic schist
7	IRELAND POINT VOLCANICS: schistose to massive purple and green agglomerate, amygdaloidal (calcite) purple and green lava, and green pillow lava

CAPE ONION SLICE ASSEMBLAGE

LOWER ORDOVICIAN

6	Dark grey to black amygdaloidal (calcite) pillow lava, agglomerate, tuff, minor black graphitic shale and diorite dykes

MAIDEN POINT SLICE ASSEMBLAGE

LOWER CAMBRIAN (?) OR OLDER

5	MAIDEN POINT FORMATION: coarse greywacke to pebble conglomerate with blue quartz grains, grey siltstone and black and red argillite; 5a, green agglomerate, tuff, tuffaceous siltstone and sandstone, and pillow lava; 5b, medium- to coarse-grained massive diorite

NORTHWEST ARM SLICE ASSEMBLAGE

LOWER ORDOVICIAN

4	NORTHWEST ARM FORMATION: black and green shale with boulders and blocks of buff-weathering limy siltstone, sandstone, and limestone. Locally includes limestone breccia beds and blocks of limestone breccia.

AUTOCHTHONOUS ROCKS

MIDDLE ORDOVICIAN

3	GOOSE TICKLE FORMATION: grey to dark grey sandstone, siltstone and shale with local conglomerate beds
2	TABLE HEAD FORMATION: grey nodular-weathering limestone

LOWER CAMBRIAN OR OLDER

1	BATEAU FORMATION: white quartzite, minor grey to purple shale
...	Mélange with black and green shale matrix and mainly sandstone (5) and volcanic (6) blocks.

'slice assemblage' (Fig. 1). Individual slices within an assemblage are locally superposed but more commonly they are widely separated, either as erosional remnants of a once continuous slice or as singly transported slices.

The transported slices in most places are separated by mélange zones that vary from a few feet to several tens of feet in thickness. These zones consist of a variety of boulders and larger blocks mainly of Maiden Point sandstone and volcanic rocks surrounded by black or black and green shale. In a few places where relatively high structural slices lie directly upon autochthonous flysch, mélange is sparse or absent, and the contact is a 'hard' thrust.

The four distinct rock groups comprise four slice assemblages as defined above. No continuous vertical section exhibits all four so that the order of structural stacking must be built up from observations throughout the map-area. Each slice assemblage is in contact with every other slice assemblage at least locally, and each in some place lies upon autochthonous flysch of the Goose Tickle Formation (Fig. 2). Ommisions in the stacking order are therefore commonplace, but reversals are unknown.

The four slice assemblages of the Hare Bay allochthon and their general geological features, from the structurally lowest to the structurally highest, are as follows:

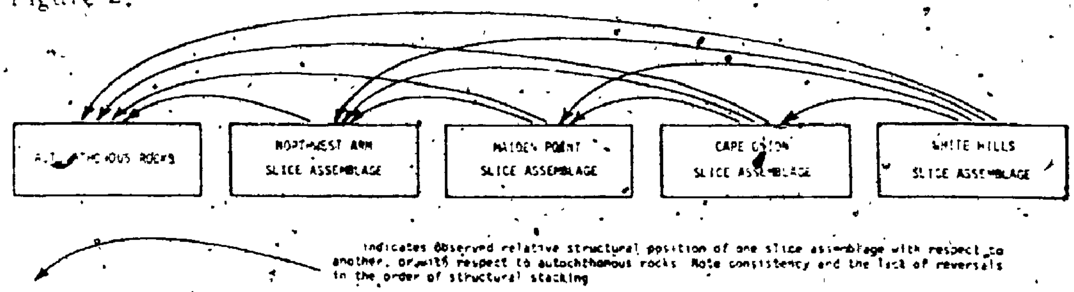
1. <u>The Northwest Arm slice assemblage</u> - composed of black and green shale with boulders and larger detached blocks of buff-weathering limy siltstone, grey sandstone, white to grey limestone, and limestone breccia (4) (the Northwest Arm Formation of Cooper)[1]. The rocks locally contain Lower Ordovician graptolites at Pistolet Bay[2, 4], and they are everywhere chaotic and rubbly. The Northwest Arm Formation (4) directly overlies the younger Goose Tickle Formation (3). Basal relationships are well exposed at Triangle Point and west of Lock's Cove, at the western extremity of the Hare Bay allochthon. The Northwest Arm Formation is of limited areal extent and occurs only at the western margin of the Hare Bay allochthon where its now widely separated occurrences may represent erosional remnants of a once much more continuous slice or slice assemblage.

2. <u>The Maiden Point slice assemblage</u> - composed of graded greywacke, pebble-conglomerate with blue quartz grains, and mainly dark grey to black shale (5). Agglomerate, tuff, and lesser pillow lava (5a) are prominent in the vicinity of St. Lunaire and Milan Arm. All these rocks are presently referred to the Maiden Point Formation[2]. Medium- to coarse-grained massive diorite (5b) also forms an integral part of the Maiden Point slice assemblage and is especially abundant in the greywacke in those places where the Maiden Point is overlain by structurally higher slice assemblages, i.e. at St. Anthony, Ireland's Bight, and Lock's Cove.

Black shaly mélange zones locally separate continuous sections of Maiden Point sandstone and suggest that the Maiden Point Formation is represented in several slices separated by mélange (e.g. Croque Head south of Hare Bay[5]). Other narrow outcrop belts of mélange within the Maiden Point terrane probably represent a basal mélange beneath a continuous slice that has been eroded across anticlinal crests to expose the basal mélange in elongate fold cores, e.g. St. Carols.

The Maiden Point slice assemblage is by far the most extensive within the Hare Bay allochthon. In general the Maiden Point slices lie directly upon autochthonous Goose Tickle flysch (3). Basal relations are well exposed at

Figure 2.



Noddy Cove, eastern Sacred Bay, Little Sacred Island, and Quirpon, all north of Hare Bay, and at Springs Inlet on the south side of Hare Bay. Locally at Lock's Cove and Howe Harbour, the Maiden Point overlies rubbly shale of the Northwest Arm slice assemblage.

3. The Cape Onion slice assemblage – composed mainly of basaltic pillowed lava and agglomerate with local black pyritic shale interlayers that contain Tremadocian graptolites at Onion Cove[6]. These rocks are informally referred to as the Cape Onion volcanics. The largest segment of the Cape Onion slice assemblage forms the Cape Onion Peninsula but similar rocks comprise the Sacred Islands and a small detached mass at Raleigh. These may be the remnants of a single slice or else represent several separate slices. Lithologically similar volcanic rocks above the Maiden Point Formation at Lock's Cove and two miles to the east may be correlatives. The Cape Onion volcanics directly overlie the Goose Tickle Formation (3) at Raleigh and lithologically similar rocks overlie minor unseparated Goose Tickle near the southern entrance to Lock's Cove. In addition a small slice of volcanic rocks, possibly correlative with the Cape Onion volcanics, overlies the Northwest Arm Formation (4) north of Lock's Cove on the west side of Howe Harbour. Elsewhere the Cape Onion slice assemblage overlies the Maiden Point slice assemblage. Clear relationships are evident on Sacred Islands, along the west shore of Sacred Bay, at the coast one mile north of Raleigh, and possibly east of Lock's Cove where amygdaloidal (calcite) pillowed lavas overlie the Maiden Point greywackes (5).

4. The White Hills slice assemblage – composed of mixed schistose volcanic rocks, greenschist, amphibolite, and ultramafic rocks north of Hare Bay; and including similar metamorphic rocks at Fishot Islands and Croque Head, south of Hare Bay[5]. Polymictic conglomerate and arenaceous limestone at St. Julien Island, south of Hare Bay, are also considered part of the slice assemblage. The mixed volcanic rocks, greenschist, and amphibolite north of Hare Bay have been referred to the Goose Cove Formation (8)[2] and the ultramafic rocks are known as the White Hills Peridotite Sheet[1]. North of Hare Bay, these rocks constitute the White Hills in a large continuous slice. Similar greenschist and amphibolite occur at Quirpon above the Maiden Point Formation (5), and also south of Cape Onion where they overlie the Cape Onion volcanics. Other occurrences north of Hare Bay are along the north shore of Milan Arm and at the network of large ponds east of Raleigh. South of Hare Bay, similar greenschist and amphibolite, locally including psammitic units and conglomerate and arenaceous limestone have been referred to the Hare Bay Schist Group[5].

All of these rocks have a complex structural history that predates their final emplacement. The structural contrast with either allochthonous or autochthonous underlying rocks is everywhere pronounced and locally east of Ireland's Bight, boulders of foliated greenschist occur in black shale mélange below the White Hills slice assemblage.

Mixed volcanic rocks along the north shore of Hare Bay (Ireland Point Volcanics[1]) are gradational and infolded with Goose Cove greenschist at Starks Bight, although in places they are surprisingly unaltered and undeformed compared to the greenschists. The greenschist in turn grades into black amphibolite that is concordant and overlain in the White Hills by ultramafic rock. The ultramafic rock contains thin hard, amphibolite layers at its base overlain by mylonitized ultramafic rock, in turn overlain by banded cherzolite, hartzburgite and minor dunite. All contain a strong tectonic fabric that is generally parallel to the mineralogical banding. Orthopyroxenite bands of two generations are contained in the peridotites. The older are pre-tectonic and form the most conspicuous primary bands. The younger are post-tectonic and crosscut the banding and tectonic fabric in the peridotites.

Amphibolite and peridotite occur in isolated exposures and in superposed slices north of Milan Arm and east of Raleigh. In places the amphibolite has associated exceedingly coarse grained pyroxenite and hornblendite with single crystals up to one foot in length. Many of the amphibolite occurrences at Milan Arm are surrounded by a 1- to 2-foot thick, hard, massive, light grey alteration halo followed outward by a thin 1-inch rind of serpentinite. The relationship indicates that these amphibolites were once surrounded by serpentinite and that the presently exposed surface is coincident with the tough alteration rind that formed as an alteration halo at an amphibolite-serpentinite contact.

The White Hills slice assemblage overlies each of the preceding slice assemblages and locally rests upon the Goose Tickle autochthonous flysch (3). In most places it rests upon the Maiden Point Formation (5) but locally south of Cape Onion it overlies the Cape Onion volcanics (6) and at Howe Harbour it locally overlies the Northwest Arm Formation (4).

Structural features related to at least three deformational episodes are recognized in the transported rocks of the Hare Bay allochthon. The earliest is represented only in the metamorphic rocks of the White Hills slice assemblage where the Goose Cove Formation (8) exhibits a penetrative schistosity and minor tectonic slides[5]. The second is evidenced by subhorizontal schistosity or cleavage and associated recumbent folds that are especially evident in the higher structural slices, e.g. Maiden Point and White Hills slice assemblages. Both early deformations are interpreted as penecontemporaneous with earliest transport of the allochthonous rocks. The latest penetrative deformational episode affects the transported rocks and underlying autochthonous rocks alike and is clearly post-emplacement. It increases in intensity from west to east across the map-area and it is expressed by a single steeply southeast-dipping cleavage and associated tight to open upright folds. It is probably Devonian (Acadian) in age and its effects are most apparent in the lowest structural slices, e.g. the Northwest Arm and Maiden Point slice assemblages. Higher structural slices are for the most part unaffected, except for mild warping and open folding. Mélange zones between structural slices are in most places cleaved as a result of post-emplacement deformation. Near the western extremity of the allochthon, westward directed low-angle thrusts along which have been emplaced Table Head limestone (2) above Goose Tickle shale (3) at Raleigh and Table Head limestone (2) above the Northwest Arm Formation (4) at Hare Island, are either related to or post-date the third deformational episode.

The Northwest Arm Formation (4) is everywhere dismembered and chaotic indicating emplacement in only a semi-consolidated condition. It has been deformed by post-emplacement deformation and its cleavage and intensity of deformation are analagous to those displayed in nearby outcrops of the underlying Goose Tickle Formation (3).

The Maiden Point Formation (5) is in places characterized by early recumbent folds with subhorizontal to gently-dipping axial plane cleavage. Excellent examples are apparent at St. Anthony Bight and their presence is inferred in other places by bedding-cleavage relationships. The early recumbent folds are clearly the result of deformation in well-indurated, competent rocks and their presence indicates that the Maiden Point Formation (5) was finally emplaced as a rigid and hard slice or slice assemblage. South of Hare Bay the early recumbent folds are upward-facing toward the northwest whereas north of Hare Bay they are of variable attitude with the best examples at St. Anthony Bight facing slightly downward toward the southwest. East of St. Anthony Bight the early recumbent folds are involved in post-emplacement steep upright structures near St. Carols.

The Cape Onion volcanics (6) for the most part consist of massive and relatively undeformed pillow lavas that show no indication of pre-emplacement deformation and most everywhere they have been only slightly affected by post-emplacement (Acadian) deformation. Where the Cape Onion volcanics (6) overlie the Goose Tickle slates (3) northeast of Raleigh, cleavage in the slates locally continues upward into the volcanic rocks, but nearby at Raleigh the the cleavage does not appear to penetrate the more competent overlying slice. Similarly at Cape Onion, fossiliferous black graphitic shales interlayered with the volcanic rocks are essentially uncleaved. The lack of post-emplacement deformation in the Cape Onion volcanics (6) is also in part due to their position at the western margin of the allochthon where the competent volcanic rocks are effectively outside the zone of intense Acadian deformation.

The White Hills slice assemblage is characterized by polyphase deformation that predated its final emplacement. The Goose Cove Formation (8) possesses a strong early schistose fabric that was refolded by flat-lying recumbent folds. The intensity of these deformations and grade of accompanying metamorphism increases structurally upwards within the formation towards the contact with the White Hills Peridotite Sheet.

The ultramafic rocks of the White Hills Peridotite Sheet exhibit a strong tectonic fabric defined by flattened orthopyroxene crystals. This fabric is axial planar to recumbent isoclinal folds that fold the primary lithologic banding. The folds are sparse, so that in most cases the tectonic fabric and the lithologic banding are parallel.

Late open upright folds and warps refold the earlier recumbent structures in the Goose Cove Formation (8) and in the White Hills Peridotite Sheet and are probably of post-emplacement age (Acadian). The base of the Peridotite Sheet in the vicinity of Daniels' Lookout, northwest of Ireland's Bight, is cataclastically deformed. The tectonic fabric is brecciated and locally refolded on minor discontinuous flat-lying folds. The cataclastic effects die out upwards in about 250 feet from the base of the Peridotite Sheet. This cataclasis is interpreted as a late detachment feature that post-dated the main emplacement of the allochthon.

The stratigraphic and structural evolution of the map-area is interpreted to relate to the development of a continental margin that reached a climax by the obduction of oceanic crust and mantle westward upon the continent. This model fits well with the lithologies represented among the transported rocks and also the order of structural stacking of the slice assemblages, which indirectly suggests that the highest slices are the farthest travelled. The White Hills Peridotite Sheet is interpreted as oceanic mantle and its underlying metamorphic rocks, which now form an integral part of the same slice, are thought to represent supracrustal rocks that were deformed, metamorphosed, and structurally attached to the sole of the peridotite sheet at the time of its initial expulsion from an oceanic domain. The Cape Onion volcanics (6) probably originated in the same oceanic domain where at deposition they represented the upper volcanic layer of oceanic crust. The Maiden Point clastic sedimentary rocks (5) were derived from a metamorphic Precambrian terrane and the formation was probably deposited along a continental margin. Volcanic rocks within the Maiden Point possibly relate to rifting during the formation of such a margin. Finally, the Northwest Arm Formation (4), in the lowest slice assemblage, lay at a shelf edge immediately east of an evolving carbonate bank. There it represented a shaly deeper water facies of the Lower Ordovician carbonate bank that is so prominent and well developed in western Newfoundland[7]. Conglomerates in the autochthonous Middle Ordovician Goose Tickle Formation (3) consist mainly of Northwest Arm Formation detritus and the deposition of the Goose Tickle Formation is thought to be related to the emplacement of the Hare Bay allochthon.

[1]Cooper, J.R.: Geology and mineral deposits of the Hare Bay area; Newfoundland Dept. Nat. Res., Geol. Soc., Bull. no. 9, 36 p. (1937).

[2]Tuke, M.F.: Autochthonous and allochthonous rocks in the Pistolet Bay area in northernmost Newfoundland; Can. J. Earth Sci., v. 5, p. 501-513 (1968).

[3]Williams, Harold, and Stevens, R.K.: Geology of Belle Isle northern extremity of the deformed Appalachian miogeosynclinal belt; Can. J. Sci., v. 6, p. 1145-1157 (1969).

[4]Kay, Marshall: Thrust sheets and gravity slides of western Newfoundland; in Kay, Marshall (editor) North Atlantic – Geology and Continental Drift; Amer. Assoc. Petrol. Geol., Mem. 12, p. 665-669 (1969).

[5]Smyth, W.R.: Stratigraphy and structure of part of the Hare Bay Allochthon, Newfoundland, Geol. Assoc. Can. Proc., v. 24, p. 47-57 (1971).

[6]Williams, Harold: Mafic-ultramafic complexes in western Newfoundland Appalachians and the evidence for their transportation: A review and interim report, Geol. Assoc. Can. Proc., v. 24, p. 9-25 (1971).

[7]Stevens, R.K.: Cambro-Ordovician flysch sedimentation and tectonics in west Newfoundland and their possible bearing on a proto-Atlantic ocean, Geol. Assoc. Can., Spec. Paper No. 7, p. 165-177 (1970).

Reprinted from:

Province of Newfoundland,

Department of Mines and Energy,

Mineral Development Division.

Report of Activities for 1973,

p. 50-51.

(with I. Knight)

ECONOMIC GEOLOGY OF WEST NEWFOUNDLAND

R.K. Stevens* and I. Knight*

West Newfoundland is defined, for the purpose of this report, as that part of Newfoundland that is west of the Cabot fault. Much of the area formed part of a Lower Paleozoic continental terrace wedge marginal to the Proto-Atlantic ocean. The continental margin and the Proto-Atlantic ocean were destroyed during the Taconic orogeny. The area was later deformed during the Acadian orogeny, the last stages of which produced block faulting that continued intermittently into Carboniferous times. A complex of marine and nonmarine Carboniferous rocks were deposited in the resultant fault-bound basins.

The Precambrian basement of west Newfoundland crops out in the northern Long Range and in the Indian Head range. It is characterized by high grade granulites, gneisses, granites and anorthosites. Its economic potential is considered low at the present time.

Locally the Grenville is cut by mafic dykes that feed basalt flows in the north of the area. The flows immediately underlie Lower Cambrian deposits. This mafic activity is thought to have taken place during the initiation of the Proto-Atlantic ocean. If this is so, mineralization associated with rifted margins elsewhere might be found in these rocks.

The overlying Lower and Middle Cambrian rocks comprise a transgressive series of arkoses, quartzites, shales and limestones. The shales often show up to 13% K_2O and form a potential source of agricultural potash.

From Middle Cambrian to Middle Ordovician times a carbonate bank covered west Newfoundland. Base metal mineralization has been reported from low in the bank sequence but is mostly concentrated at a disconformity of latest Canadian age between the St. George and Table Head formations. Pale coloured sphalerite is the predominant ore mineral.

Minor veins of sphalerite, galena, fluorite and chalcopyrite cut limestones of the Table Head Formation north of St. Anthony.

*Department of Geology, Memorial University of Newfoundland

A complex of clastic rocks and ophiolites have been thrust into the upper parts of the Table Head Formation. These rocks are of Cambro-Ordovician age but formed to the east of the Cabot fault and represent former continental rise sediments and oceanic lithosphere. Petroleum and minor chalcopyrite are the only shows in the sediments but chalcopyrite, asbestos, chromite and gold are known from the ophiolites and associated rocks.

During Siluro-Devonian times the eastern margin of west Newfoundland was invaded by granitic rocks. These are presently exposed at a very high level and are associated with intrusive and extrusive rhyolite. Hydrothermal alteration is common in the country rocks and traces of chalcopyrite are widely dispersed. The area seems favourable for porphyry copper type mineralization.

During Carboniferous times a great thickness of predominantly clastic rocks formed in two fault bounded basins. No volcanic rocks have yet been recognized. The southwestern Codroy-Bay St. George Basin was formed in late Devonian times and was infilled first by marine sediments derived from the south. Later, detritus was locally derived and deposited in a marine to fluviatile environment and forms the Anguille Group. The overlying Codroy and Barachois Groups represent a locally derived, mixed-marine and nonmarine, molasse sequence.

The northeastern Deer Lake-White Bay Basin consists of a lower, narrow rift controlled sequence of rocks that range from axial turbidites to marginal conglomerates. These rocks are separated by a marked unconformity from the overlying [illegible] Group, which comprises a sequence of fluviatile and alluvial fan deposits with local marine inclusions.

Barite and chalcopyrite mineralization occurs in the Codroy-Bay St. George area within the Ship Cove Limestone, which can be probably correlated with the Windsor Group limestones of Nova Scotia. The Snakes Bight Formation contains copper-zinc mineralization at Cape Anguille. The potential of the area seems high.

Reprinted from:

Province of Newfoundland

Department of Mines and Energy,

Mineral Development Division

Preliminary Report, 1973

18 p.

(on open file)

ECONOMIC GEOLOGY OF WEST NEWFOUNDLAND

Preliminary Report 1973

R. K. Stevens, Department of Geology, M.U.N

Introduction

For the purposes of this report, west Newfoundland is defined as that part of Newfoundland to the west of the Cabot Fault as defined by Wilson. Geologically, it consists of a core of Grenville basement unconformably overlain by shallow water Cambrian and Ordovician sediments. Onto these are thrust slabs of deeper water Cambrian and Ordovician sedimentary rocks and two disected masses of igneous and metamorphic rocks of early Ordovician age. Locally Middle Ordovician to Lower Devonian shallow water and terrestrial deposits unconformably overlie the transported sequences. Carboniferous sedimentary rocks unconformably overlie all of the older rocks. The relationship between the rocks of west Newfoundland and the metamorphic rocks to the east is problematic. That is to say the true nature of the Cabot Fault is not understood.

History of Investigation

My final report will include a brief outline of the development of geological concepts in west Newfoundland as well as a history of economic development. Unfortunately, much work done in west Newfoundland remains unpublished. As a first recommendation I suggest an attempt be made to obtain from H. Johnson, a former government geologist, any unpublished material concerning west Newfoundland and also to ask him the locations of irreplaceable fossil material he collected while in government employ.

Strangely enough, my field work this summer accidentally discovered evidence that the earliest inhabitants of the west coast might have been attracted to the area by economic minerals. Whilst working on Fox Island several filled caves were found well above sea level. One of these yielded numerous shells and bones from stratified deposits. The Anthropology Department at Memorial thinks that the caves might be Dorset Eskimo dwellings. Economic minerals of interest to stone age man occur all around the site. There are good chert and pyrite deposits for firemaking, oil for heat and light, native copper and talc all within a few miles of Fox Island. It is hoped that detailed investigations of these caves will be started next season.

The rest of this preliminary report outlines the main areas of economic interest in west Newfoundland and suggests some projects that might be attempted by the government in the future. From the point of view of economic potential, west Newfoundland can be divided into the following regimes:

1) The Grenville basement complex
2) Late Hadrynian/Early Cambrian volcanic rocks
3) Early Cambrian clastic sediments
4) St. George Formation
5) The Table Head - St. George disconformity
6) The Table Head Formation and younger rocks
7) The Humber Arm Supergroup

8) The Cow Head Group

9) The Bay of Islands/Hare Bay Complexes

10) The Ordovician-Devonian cover rocks

11) The Northwest Brook Granite

12) The Plutonic-volcanic complexes of White Bay

13) The Carboniferous Rocks

14) The Pleistocene cover

Any one of these divisions could form the basis of a separate project.

(1) The Grenville Basement

Rocks of radiometric age 900-1100 m.y. form the basement of west Newfoundland. These are equivalent to rocks in Labrador South of the Grenville Front. The Grenville gneisses, migmatites and intrusions belong to a tectonic system that predates the Appalachian system by about 500 m.y. There is not, as yet, a good geologic model to explain the formation of the Grenville system.

Recommendation: Since the Grenville rocks of west Newfoundland form a detached part of the Canadian Shield it would seem logical that they should be the responsibility of the Labrador geologist. If this is not done the economic potential of the rocks will be neglected or investigated by geologists who are not familiar with the assemblage. Close co-operation between the Newfoundland Government and the Governments of Quebec and Ontario during the evaluation of the Grenville rocks is recommended since these Governments have had long experience with the Grenville. It should be noted, however, that mineral production from the Grenville is low so that a correspondingly low priority should be assigned to any Grenville project, at least until satisfactory models of the Grenville cycle are evolved.

(2) Hadrynian/Early Cambrian volcanic rocks

Flood basalts and related dykes are amongst the first rocks formed during the Appalachian cycle in west Newfoundland. The volcanic rocks are thin but northeast trending dykes are numerous in the northern part of the Long Range and southern Labrador. It is thought that the mafic volcanism accompanied an early rifting phase of the Appalachian just as dyking and flood basalts accompanied the breakup of Europe, Greenland and North America during the Mesozoic. If this analogy is correct, mineralization associated with rifting might be associated with the Newfoundland flood basalts and dykes. Examples of mineralization at rifted margins include the fluorite deposits of the Kenya rift, the Greenland cryolite deposit, kimberlites and alkaline complexes. Several of these deposits are associated with differentiated intrusions that fed the flood basalts and dykes. Such intrusions have not yet been reported from west Newfoundland, but if they occur they would be confined to the Grenville of the Indian Head Range, the Long Range and Southern Labrador and would probably be interpreted as Grenville rocks. Such intrusions would doubtlessly show as magnetic and gravity highs.

Recommendation: The Department should regard these rocks as a unit from Stephenville to Labrador and evaluate their economic potential with an eye on mineral deposits known to have formed in rift environments elsewhere. Eventually, a search for layered intrusions should be made in the Grenville after the geophysical data has been evaluated. Special attention should be paid the literature of the African Rift valleys and also the publication of the Danish Survey in Greenland where economic deposits related to rifted margins of three different ages occur.

(3) Early Cambrian Clastic Sediments

After the mafic volcanism, early Cambrian seas transgressed onto the old Grenville continent. At first the arkoses, sandstones and shales of the Bradore were deposited and later the shales, limestones and archeocyathid reefs of the Forteau Formation. Pure quartzites occur at several horizons and are locally separated as formations.

The Bradore seems to show a transition from terrestrial to beach and tidal environments reflecting the transgression of the Cambrian sea. Heavy mineral concentrations might have been preserved by fluke; especially where the basement nearby is a Grenville anorthosite but the chances are very poor.

The Archeocyathid reefs are potential sites of lead/zinc mineralization but their small size suggests that any deposits found will never be any more than an academic curiosity.

Some of the Forteau shales are marly and might prove to be natural cement stones. This should be investigated along with a geochemical survey of the whole Forteau. In 1969, the writer confirmed a suggestion of Dr. Dearnly of the G.S.C. that potassium rich shales existed in the Cambrian of west Newfoundland. Grab samples assayed up to 13% K_2O. The main potassium bearing mineral is orthoclase. These shales, even untreated, are a potential fertilizer for areas underlain by limestone with potassium deficient soils, a fact recognized by the local populance at Plum Point who have extensive potato gardens on the nearby Forteau shale.

Recommendation: A ground mapping project using a scintilometer should attempt to estimate grade and reserves of potassium rich shale in the Plum Point-Brig Bay area. At the same time a geochemical survey should determine the detailed composition of the shale. Is there, for example, any chance that some of the radioactivity of the shale is due to uranium rather than potassium? Similar beds in Scotland, the so-called "fucoid beds" have been extensively investigated by the U.K. geological survey and it might be as well to ask them for their economic evolution of their beds. These beds were discovered during a geophysical search for uranium.

(4) St. George Formation

The St. George Formation ranges in age from Middle Cambrian to youngest Lower Ordovician. The base of the formation seems to be oldest towards the north and east and carbonate bank conditions seem to have migrated to the west and south. A bulk of the formation consists of dolomite and minor limestone and shale. Deposition on a very shallow intermittently emergent bank behind a seaward limestone "reef" under arid, hot conditions seem probable. As yet no regionally mappable subdivisions have been recognized and mapped but using modern techniques of carbonate petrology, a detailed account of the history of the bank could be worked out. This would be a very long task.

The lead/zinc potential is under active investigation by the department and is not discussed further here and the use of the dolomite as a magnesium source is also well known. Nevertheless, should the geochemical survey indicate high lead/zinc values over the lower part of the St. George Formation, the department should initiate a detailed mapping program with aim of understanding the conditions of deposition and hence mineralization.

(5) The Table Head - St. George Disconformity

It is well known that zinc mineralization occurs associated with solution features under the disconformity between the Table Head and St. George Formations. Although at most localities the disconformity seems a minor feature, it has been estimated that relative sea level dropped by about 300 feet. In view of the economic importance of the disconformity, a brief summary of its possible origin is included.

The very latest Lower Ordovician was a critical time in west Newfoundland. At this time about 120 m.y. of stability came to an end. At first there was relative uplift of the shelf recorded by the disconformity and then a rapid sinking, perhaps to oceanic depths. The disconformity seems to have been synchronous all along the Appalachians from Newfoundland to Alabama. The sinking, however, seems to have been diachronous, earlier in Newfoundland than further south. At this same time flysch deposits were being generated further to the east marking the onset of tectonic activity that was later to destroy the old continental margin. Given these data, it seems reasonable to interpret the disconformity as a result of tectonic forces. However, the paradox of uplift followed by rapid sinking is difficult to explain.

The first stage of the destruction of the old continental margin was the subduction of the margin under oceanic lithosphere (the ophiolites) along an east dipping subduction zone. It can be postulated that during subduction of the margin, buckling due to compression uplifted the western platform to give rise to the disconformity. On the other hand, if the eastern margin of the bank was an emergent "reef" fringing the continent, any subsidence of the continent due to the weight of the obducted ophiolite further to the east, would cause a western migration of all the shelf facies. As the emergent "reef" facies passed through any area it would leave, as its record, a disconformity. A disconformity formed in this way would be diachronous from east to west and there is some limited conodont data suggesting that this is the case in west Newfoundland. In both the foregoing explanations, disconformity due to buckling and disconformity due to sinking, the motive force is the obduction of ophiolite onto the continental margin, now the Fleur de Lys. The compressive effects of the subduction could have squeezed pore fluids from the marginal rocks into the carbonate rocks of the platform to give rise to the mineralization.

Nevertheless, it is difficult to explain how a random event such as the collision of a continental margin with a trench should be synchronous over the entire length of the Appalachians. Perhaps other mechanisms in combination with tectonics were at work. It has long been known that the Ordovician was a time of glaciation in Africa. A recent account shows a glacial maximum exactly at the lower to middle Ordovician boundary. It was suggested that a large ice cap formed at this time. This would mean a drastic drop in sea level due to withdrawal of water into the ice cap. A disconformity would develop on a world wide basis in shallow water marine sediments. A fall of sea level of 300 feet would not be unreasonable.

(6) The Table Head Formation and Younger Rocks

The Table Head Formation was deposited under conditions of progressively deepening water depths reflecting the collapse of the old continental margin. At first, relatively pure, rubbly bioclastic limestone was deposited followed locally by coarse limestone breccia, thin bedded lime turbidites with shale, pure shale and finally clastic flysch-like rocks derived from the east. The transported rocks of west Newfoundland are thrust onto the flysch.

Economically, the lower Table Head has provided limestone for several industries, its rubbly nature making for easy extraction. It has also been suggested that the Table Head was the source of the petroleum seeps in west Newfoundland, the predominantly shaley rocks of the transported rocks forming the cap.

The Table Head is not usually thought of as a potential base metal host. Nevertheless, interesting base metal showings occur in small Table Head outcrops that poke out as windows through the thrust sheets north of St. Anthony. Minerals include galena, sphalerite, chalcopyrite and fluorite in veins up to a foot wide. These showings close to the old continental margin should be investigated further but unfortunately, short of drilling, they will be difficult to evaluate.

(7) The Humber Arm Supergroup

Much of the transported sequences of west Newfoundland are clastic sedimentary rocks referred to the Humber Arm Supergroup. These range in age from early Cambrian to latest Lower Ordovician. The oldest rocks are impure greywackes derived from the Grenville Shield and its volcanic cover. Above these are relatively pure quartzite turbidites derived from a shallow water quartzite source such as the March Point. When the St. George carbonate bank established itself on the shelf the turbidites in the Humber Arm changed in composition from quartz rich to carbonate rich. The lower part of the Humber Arm reflects exactly the condition prevalent on the adjacent shallow water shelf. The upper part of the Humber Arm is a coarse flysch derived from tectonic lands to the east. The onset of flysch sedimentation is coeval with the Table Head/St. George disconformity.

No economic prospects have been developed in the Humber Arm rocks with the exception of shale which is locally quarried near Corner Brook. The potential of these rocks is considered low except as a source of construction material.

Several petroleum shows are known in Humber Arm rocks. These usually occur in predominantly shaley rocks. It is not known if the oil originates within the Humber Arm rocks or if it is merely trapped in the Humber Arm from a source in the underlying carbonates. Later folding and faulting seems to have dissipated much oil; many fractures in the Humber Arm are lined with bitumen. Perhaps the best oil potential is to be found in areas where the Grenville basement has been thrust over the Humber Arm to form an extra seal.

Volcanic rocks intercalated in the upper units of the

Humber Arm sporadically contain native copper. These have been investigated on an off for many years but seem best suited for providing museum samples rather than commercial production.

There are several small base metal showings in the Humber Arm but none seem important. Asbestos was formerly produced in small quantities from large ultramafic blocks in the basal melange and this horizon might yield new asbestos showings on further investigation but none are likely to be important.

(8) The Cow Head Group

The Cow Head Group of carbonate conglomerates, thin limestones and shale occurs in a restricted area north of Bonne Bay. They are geologically important since they formed as bank edge breccias and, in fact, mark the most westerly facies of the Humber Arm yet recognized. They have no economic importance except as a possible source of very pure limestone. However, it would be a pity to destroy such valuable and famous geological outcrops when other good limestone prospects exist.

(9) The Bay of Islands/Hare Bay Complexes

The top slices in both allochtons in west Newfoundland consist of complexes of igneous, metamorphic and sedimentary rocks which at one time formed the floor of an old ocean basin or were generated when this floor was thrust or obducted onto the continental margin of the time. Three main elements can be recognized within the complex. These are:

(1) Ophiolites.

(2) Metamorphosed ophiolites under the ophiolites.

(3) The Coastal Complex in the Bay of Islands Area.

The ophiolites are economically the most important element of the complexes. They are layered bodies ranging from the base up through lherzolite, hartzburgite, dunite, gabbro sheeted dykes, basalt and sediment of deep water origin. The west Newfoundland ophiolites are the largest Lower Paleozoic example known and have been preserved from intense later deformation by their allochthonous position on the western platform. Furthermore they are amongst the best exposed ophiolites in the world and of relatively easy access. All of these factors combine to make the ophiolites extremely attractive exploration areas. As yet, however, their production record has been, to say the least, sporadic.

Briefly, the economic potential of the ophiolites is as follows. The lower lherzolite and hartzburgite levels are usually barren unless zones of platinum metal enrichment occur. These have not been looked for in west Newfoundland. At Baie Verte and Thetford the main asbestos bearing horizons occur in the hartzburgite horizon but asbestos formation is related to deformation and alteration during the Acadian orogeny when conditions seem to have been particularly favourable. Since west Newfoundland in the region of the ophiolites was not strongly effected by the Acadian orogeny, it is not likely that large asbestos deposits of the Advocate/Thetford type exist there. The best place to look would be along the very eastern edge of the Hare Bay allochthon where ultramafic rocks have been strongly folded into a vertical attitude. Unfortunately, this prime area is underwater in White Bay. Nevertheless, west Newfoundland is not without hope since some asbestos seems to have formed during emplacement of the ophiolite. This is found in the lower hydrated parts of the ultramafic section. Numerous small showings are known. Several have been drilled and some minor production has been recorded. Exploration for asbestos should first be concentrated in the lower parts of the complexes.

During thrusting, the hot ultramafic rock seems to have absorbed material from the country rock. Water was the most important constituent absorbed, giving rise to amphibole and biotite-bearing ultramafic rocks. It is in this basal zone of hot metasomatism that conditions favourable for the formation of pentlandite seem to have occurred. All nickel showings seem to be confined to this zone and exploration should, therefore, be concentrated there. Nickel is usually dispersed in ophiolites, hidden in olivine, and only such processes as metasomatism or lateritic weathering concentrate it.

Other potentially economic material that might be expected at the base of the ophiolite include decorative serpentine, talc and soapstone. It is unlikely that any of these will have more than local economic importance.

Chromite concentrations occur near the contact between the depleted residual hartzburgite and the overlying cumulate dunite. Sporadic production has been recorded from this level in the Bay of Islands Ophiolite which has the best chromite potential.

Perhaps the most attractive prospect in the ophiolites is the horizon low in the pillow lava sequence just above the sheeted dyke complex. It is here that the massive sulphides of the Cyprus type occur and this is the location of the old mines and showing in the York Harbour area. In general, the ores have a simple pyrite-chalcopyrite mineralogy and consist of two components, a lower stockwork of dessiminated sulphide and an upper massive sulphide horizon. The occurrences tend to be of small to moderate size. Little Long Lac has recently made a discovery at this horizon in the Gregory River area and further discoveries can be expected. This horizon does not seem to be present at Hare Bay.

A sheet of metamorphic rock occurs immediately beneath the ophiolites in Hare Bay and the Bay of Islands areas. The ophiolites are welded to the metamorphic rock and, at the contact the two approach each other in general field aspect. The ultramafic rock becomes amphibolitized and serpentinized and is hard to distinguish from the amphibolite beneath. Only the presence of chromite in thin section obviously relates the banded amphibolite rock to the ultramafic proper. The metamorphic grade drops sharply away from the ultramafic contact through greenschist to little deformed or metamorphosed rock. There the main components of the upper part of an ophiolite suite can be recognized in the Hare Bay area, pillow lava, gabbro and cherty pelagic sediment. Some sediment resembles that of the lower part of the Hare Bay allochthon suggesting that the metamorphic rock represents old ocean floor in front of the old continental rise that has been overrun by the ophiolite. If this is so then a large area is opened up as a potential host to massive sulphide mineralization. In the company of Dr. D. F. Strong the old Goose Cove Mine was visited and a conclusion reached that the ore body was of the Cyprus type but metamorphosed. This supports the interpretation of the metamorphic rocks as ophiolites. Since the deformational history of the schists is easy to work out, any discovery of a massive sulphide showings in the schists would be traceable.

The most problematic rocks in west Newfoundland belong to the so-called Coastal Complex of the Bay of Islands area. The complex consists of mafic schists and gneisses with associated fresh volcanic rock and large trondhjemite plutons. The complex has been overridden by the ophiolites and some, but not all, of the deformation and metamorphism can be attributed to this. In turn the complex is thrust onto the upper flysch of the Humber Arm. Shales inject several metres into the complex which is strongly granulated in its lower levels. An age of about 500 m.y. has been obtained from the trondhjemite (W. R. Church, per. comm.)

From an economic standpoint, the complex is likewise little understood. A few scattered platiniferous pyrite, chalcopyrite showings have been reported along with a trace of gold. In general, the coastal complex resemble the basement complexes of some currently active island arcs but, at present, there are no guidelines for its exploration except that it seems favourable for gold mineralization.

(10) The Ordovician-Devonian Cover Rocks

Rocks above the Table Head pass probably conformably, up into the shallow water limestones of the Long Point Formation of late Middle Ordovician age. These overstep unconformably eastwards onto the transported rocks dating the transportation. A disconformity separates the Long Point from the overlying red beds of the Siluro-Devonian Clam Bank red beds. The whole sequence has been faulted and folded presumably in the Acadian orogeny. No mineral showings have been reported from these rocks.

(11) The North West Brook Granite

One object of the present investigation is to outline areas of mineralization analogous to the copper deposits of the Gaspe Peninsula. A prime area for this type of mineralization occurs west of Gallants along the course of North West Brook. Here Walthier reports an intrusive granite cutting the Humber Arm. The writer failed to confirm this relationship but the area should be closely investigated in view of the clear parallel with the Gaspe situation. The granite might have originated in any of the following ways:

1) The granite represents an upfaulted block of Grenville basement along the strike of the Indian Head Range.

2) The granite is of pre-Acadian age, intruded into the Humber Arm prior to the emplacement of the thrust sheets.

3) The granite is of Acadian age and the most western of the massive Acadian granite intrustions of central Newfoundland. The Quebec deposits are related to granites of this type. It is recommended that a small project be initiated to test the above hypotheses.

(12) The White Bay Area

White Bay hides the Cabot fault. The metamorphic rocks of the Fleur de Lys and its cover of ophiolites and Silurian clastic and volcanic rocks lie to the east. To the west Cambro-Ordovician clastic and carbonate rocks are in contact with Silurian conglomerates, volcanic and intrusive rocks. The main economic interest in western White Bay is in the volcanic and related intrusive rocks. Wherever the contact between these and the carbonate rocks of the Doucers formation is seen, it is faulted. The faults dip steeply eastwards but if the overlying Carboniferous rocks are rotated back to horizontal the faults become low angle thrust faults bringing Silurian and possibly later rocks westward over the Cambro-Ordovician sequence. Of prime importance, however, is the fact that the silicic intrusions are barely unroofed in the Sops Arm area. Indeed several of the previously mapped granites are in fact extrusive porphyries and rhyolites. Sericitization, pyrophyllite alteration and ultramafic alteration are common and sporadic disseminated chalcopyrite mineralization occurs in the granite, porphyry and rhyolite units. The setting bears all of the marks of a porphyry copper province. However, the shattering often associated with poprhyry copper deposits was not observed. Nevertheless the area shows promise and a geological survey of the silicic rocks of the area perhaps with a geochemical survey should be attempted next year. Previous exploration seems to have been confined to small showings such as the Simms Ridge gold prospects with little or no economic potential. This area has the best chance of yielding copper deposits of the Gaspe type of anywhere in west Newfoundland.

(13) The Carboniferous Rocks

These rocks are the subject of a separate report by I. Knight.

(14) Pleistocene Deposits

The Pleistocene glaciation stripped west Newfoundland down to bed rock removing any residual mineral deposits that might have accumulated especially over and around the ultramafic rocks. The Federal Survey and Universities have been actively investigating the Pleistocene deposits for several years and a fair amount of data have been accumulated. However, much of the data are of a general nature and construction engineers and consulting geologists invariably have to perform an on site investigation of the surficial deposits before starting a construction project. The department could perform a valuable service by initiating a detailed program of surficial geology mapping in the Corner Brook area.

Two other projects merit consideration if and when the department feels it has the resources available. The first, the compilation of an inventory of clays of ceramic quality has already been proposed to the department by the writer so no further details will be given. A good source of ceramic clay could be the making of a small pottery industry in Newfoundland. The second is a project that might be carried out in cooperation with the department of tourism.

Tourism is a major industry in west Newfoundland, its main assets being scenic and cultural attractions. Throughout North American and Europe caves and caverns are major tourist attractions, the most famous drawing many thousands of tourists a year. The carbonate terrains of west Newfoundland must contain many caves and caverns presently undiscovered. There are numerous examples of streams plunging underground and traversing some areas in carbonate terraines is rather hazardous because of hidden solution holes. The first stage in the exploitation of caves and caverns is to find and explore them. For this reason it is suggested that a small team of competent speleologists be hired to hunt for spectacular caves and caverns. This project could have two objectives. 1) To locate areas where caves and caverns occur so that the area could be promoted as a recreation area for amateur speleologists who could further knowledge. 2) To carry out geochemical and usual exploration for lead/zinc deposits. Exploration is conventially carried out only on the surface or by drilling. However, areas cut by underground drainage offer a unique opportunity for underground sampling and observation at low cost. This is especially important in west Newfoundland where surface exposures in the carbonate terrain are often poor and the known zinc deposits are associated with fossil caverns. A good area to start would be between Hare Bay and Canada Bay where both mineralization and underground drainage are known. With both professional and directed amateur searching, the discovery of a major cavern system with its tourist potential may not be long delayed.

Reprinted from:

Program for Geological Society of America
Northeastern Section, 8th Annual Meeting,
Allentown, Pennsylvania
p. 192
(with J. Malpas and D.F. Strong)
p. 222
(with H. Williams)

THE EMPLACEMENT OF THE HUMBER ARM ALLOCHTHON, WESTERN NEWFOUNDLAND

Stevens, R.K., and Williams, Harold, Department of Geology,
Memorial University of Newfoundland, St. John's, Newfoundland.

The Humber Arm Allochthon consists of a stack of structural slices derived from various parts of an ancient continental margin and adjacent oceanic lithosphere. During emplacement of the allochthon, the continental margin fractured and subsided, perhaps to oceanic depths, and island arc volcanism and tectonism were active in the oceanic area of central Newfoundland.

The first stage of emplacement involved overthrusting or obduction of oceanic lithosphere and mantle onto the sediments marginal to the continent. An inverted metamorphic zonation developed beneath the obducted mantle and oceanic lithosphere during this phase of thrusting. It ranges from pyroxene granulite through amphibolite and greenschists into unmetamorphosed sediments over a few hundred feet. Although no blueschists have been recognized, the zone of early thrusting might be a fossil Benioff zone that dipped eastward beneath oceanic lithosphere.

A transported series of predominantly sedimentary slices occurs under the igneous and metamorphic rocks. Each sedimentary slice is separated from the next by mélange zones, and in general, the structurally lowest slices are the least travelled. The local occurrence of large ultramafic, gabbroic, and volcanic blocks in mélange zones between lower sedimentary slices indicates that the higher igneous slices were already emplaced and provided a nearby source of ophiolite blocks during this phase of movement.

The last stages of emplacement seem to have been by gravity sliding of an already assembled allochthon. During this phase of emplacement the Humber Arm Allochthon might have been a migrating island like Cyprus in the present day Mediterranean Sea.

THE ORIGIN AND SIGNIFICANCE OF OPHIOLITE-AMPHIBOLITE ASSOCIATIONS

Malpas, J., Stevens, R.K., Strong, D.F., Department of Geology,
Memorial University of Newfoundland, St. John's, Newfoundland.

Ophiolite suites are thought to represent oceanic crust and mantle incorporated in mountain belts during orogenesis. Rock types which comprise the ophiolite suite are lherzolites, harzburgites and dunites, gabbros, diabases and low potash-tholeiitic pillow lavas. Investigation of such suites in Newfoundland has suggested that another important rock type-amphibolite-is invariably associated with ophiolites to such an extent that one might often consider an ophiolite/amphibolite couple.

In Newfoundland, amphibole bearing rocks in and associated with ophiolites might be classified in the following way:

I. Primary amphibole: a) <u>Mantle</u>, amphibole in lherzolites
  b) <u>Magmatic</u>, amphibole associated with gabbros.

II. Metamorphic amphibole: a) <u>Produced in the oceanic environment</u>
  i) Burial metamorphism
  ii) Tectonic amphibolites on faults
  iii) Contact metamorphism at gabbro/dyke interface.
  b) <u>Produced at Destructive Plate Margins</u>
  i) Amphibolite 'basement' to island arcs.
  ii) Amphibolite associated with ophiolite obduction.
  c) <u>Later regional metamorphism.</u>

Reprinted from:

Geology

Volume 1, Number 3

p. 45-47

(with J. Malpas and D.F. Strong)

Amphibolite Associated with Newfoundland Ophiolite: Its Classification and Tectonic Significance

J. Malpas, R. K. Stevens and D. F. Strong

[illegible]

ABSTRACT

[illegible]

INTRODUCTION

[illegible]

ROCKS WITH PRIMARY AMPHIBOLE

Mantle Derived Amphibole

[illegible]

Magmatic Amphibole

[illegible]

ROCKS WITH METAMORPHIC AMPHIBOLE

Produced in Oceanic Environments

By Burial Metamorphism. [illegible]

[illegible]

[illegible]

By Contact Metamorphism during Sea Floor Spreading and Intrusion in Island Arcs. [illegible] Notre Dame Bay [illegible] Dewey, 1970 [illegible]

By Dynamic Metamorphism along Faults in Ocean Basins. [illegible]

Produced at Destructive Plate Margins

Dynamothermal Metamorphism during Obduction of Ophiolites. [illegible] Bay and Bay of Islands Complexes [illegible] Stevens, 1973 [illegible]

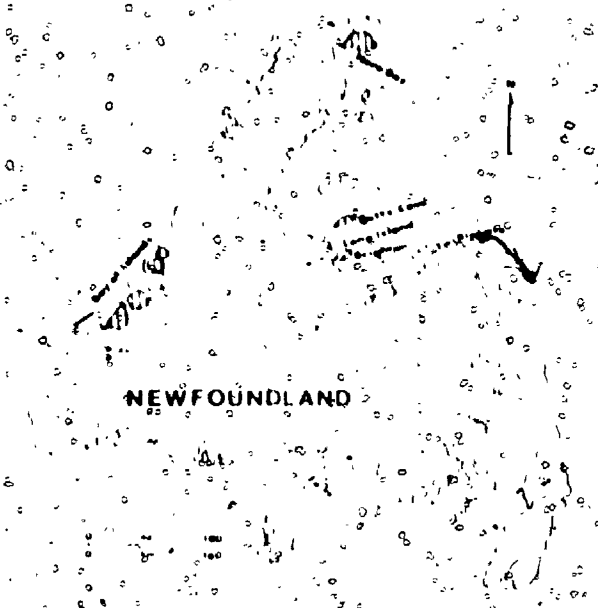


Figure 1. Newfoundland with place names (locations [illegible])

[illegible]

Amphibolite Associated with Island Arc Volcanic Rocks. [illegible]

[illegible]

DISCUSSION

[illegible]

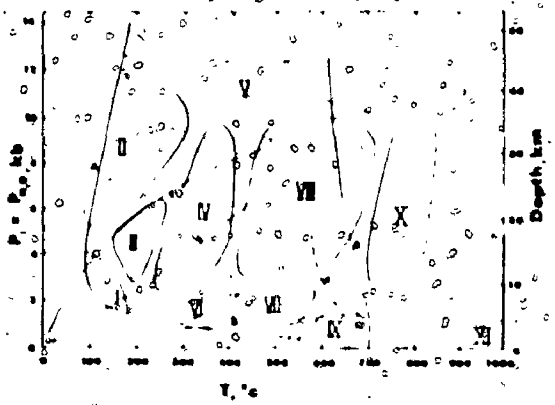


Figure 2. Metamorphic facies diagram [illegible]

[illegible]

REFERENCES CITED

[illegible]

ACKNOWLEDGMENTS

[illegible]

Reprinted from:

Program of the Annual General Meeting of
the Geological Association of Canada,
Newfoundland Section
Spring Meeting, 1983
(with J. Hodych and A. Frew).

Abstract for Geological Society of Canada

Newfoundland Section

Spring 1973

MAGNETICALLY ANOMALOUS, FIBRE-BEARING KNOCKERS IN WEST NEWFOUNDLAND

by

R.K. Stevens, J. Hodych and A. Frew

Two positive aeromagnetic anomalies of about 3,000 gammas occur near Gallants and Spruce Brook, two settlements situated between Stephenville and Corner Brook, west Newfoundland. The anomalies cover small areas and are bounded by steep gradients. They stand out sharply from the otherwise magnetically bland terraine. Geologically, the anomalies are situated at or near the contact between the transported Humber Arm rocks and the underlying untransported shales and carbonates but the area is one of exceptionally poor exposure. An old asbestos working in serpentine, the Bond Mine, is sited on the northern anomaly and there is evidence that the southern anomaly is also caused by a mass of serpentine. Other serpentine masses occur at the same geological horizon but do not produce aeromagnetic anomalies. Some of these also contain traces of asbestos fibre.

The Bond property was drilled in 1967 and cores containing serpentine, serpentine talc schist, peridotite, altered gabbro and other rocks were obtained. Of particular interest is the occurrence in the cores of dark shale with fragments of limestone, sandstone and serpentine. This rock resembles the tectonic melanges produced at the contact between transported and untransported rocks in other areas of west Newfoundland.

It seems, then, as if the magnetic anomalies are caused by large knockers of ultramafic rock, some of which contain asbestos, in melange at the base of the Humber Arm allochthon. The basal melange might therefore have asbestos potential.

Most probably the serpentine was derived from the Bay of Islands Igneous Complex which forms the upper slice of the Humber Arm allochthon. If this is so, the allochthon must have arrived in west Newfoundland as a single mass of thrust slices and not as a set of serially emplaced slices, the lowest one first. It must have arrived as an already assembled mass for it to be possible for knockers of the uppermost ophiolite slice to occur in the basal melange, since the two are now separated by a thick screen of sedimentary slices.

The apparent lack of [illegible] Spruce Brook - Gallants area suggests that during emplacement of the allochthon the [illegible] concentration of ultramafic knockers in the area.

Reprinted from:

Nature

Volume 249, Number 5457

p. 545-546

(with D.F. Strong)

(Reprinted from Nature, Vol. 249, No. 5457, pp. 545–546, June 7, 1974)

Possible thermal explanation of contrasting Archean and Proterozoic geological regimes

The Earth underwent a remarkable change of behaviour at the Archean–Proterozoic boundary. Greenstone belts intruded by granites dominate the geological record before about 2.5 × 10^9 yr ago. After that time essentially no such greenstone belts were formed and long linear orogens characterised by high grade metamorphic rocks made their first appearance.

A typical Archean greenstone belt has the following characteristics. Early volcanic activity commonly ranges from ultramafic to mafic implying high and variable degrees of partial melting of the underlying mantle. Series of volcanic rocks becoming progressively more silicic along calc-alkaline differentiation trends overlie the ultramafic flows. Clastic sedimentary rocks are sporadically interbedded with the volcanic rocks but predominate towards the top of the pile which can reach a thickness of about 100,000 feet (ref. 1). Diapiric granitic plutons cut the greenstone belts which are often preserved only as deep keels between the plutons. Structures within the greenstone belts and granitic rocks indicate that they were deformed by vertically acting forces. The rocks show only low grade metamorphism typically in the greenschist facies although locally amphibolite and granulite grades are reached. Large areas of platformal sediments are lacking on Archean terrains.

In contrast the Proterozoic terrains show a clear division into mobile belts and platforms. The mobile belts are long linear features characterised by high grade reworking of pre-existing rocks as well as of newly deposited rocks. Deformation is intense and complex with flow folding predominating. Transcurrent dislocations characterise many Proterozoic mobile belts. In short the Proterozoic mobile belts are more similar to Phanerozoic orogens than are the Archean greenstone belts.

The contrasts between the Archean and Proterozoic regimes are commonly attributed to a thin Archean sialic crust[1,2]. But there is evidence to show that the Archean crust may have been as thick as that of the present day[3]. Large areas of continental crust are underlain by rocks 2.5 × 10^9 yr old or older, yet today many of these areas have sialic crust of normal thickness. Either this was the Archean thickness or sial has been added to the base of the crust since Archean times. Sial added to the base of the crust would cause isostatic rise of the continent and subsequent erosion, so that the gain in thickness of the crust would be substantially less than the amount of underplated sial. Furthermore post-Archean isostatic uplift and subsequent erosion would expose rocks with lower K–Ar mica ages, so that Archean ages should not be preserved. We consider it much more likely that the continents have grown by lateral accretion since the Archean, possibly with their thickness being controlled essentially by sea level.

Nevertheless, the differences between Archean and Proterozoic geologic regimes outlined above require an explanation, one which is consistent with the relative sharpness and worldwide nature of the change between the two. We suggest that an explanation lies in the thermal behaviour of the Earth.

There is ample evidence to show that the Earth is cooling[4], presumably because of a decrease in heat production by radioactive decay and also degassing to form the oceans and atmosphere. The supposedly continuous nature of this cooling has perhaps obscured its potential in causing discontinuous geologic behaviour such as the Archean–Proterozoic transition. But a simple possible explanation lies in the intersection of phase boundaries and the geotherm.

Figure 1 shows schematically the relations between geotherms which, as a result of cooling, would migrate downwards with time, and a hypothetical peridotite solidus which would be progressively higher with lower water pressure, that is, would migrate upwards because of mantle degassing. Partial melting occurs only when the geotherm and solidus intersect and the degree of partial melting will be proportional chiefly to the excess heat involved. Thus during the Archean, with a high geothermal gradient and high P_{H_2O}, there would be melting over a wide P_{H_2O} interval with adiabatic rise of numerous mantle diapirs probably in a random geological pattern though perhaps locally controlled by crustal fracture systems. This, along with lower pressure differentiation under high P_{H_2O}, would account for the wide range of both extrusive and intrusive magma compositions as well as the geological patterns of the Archean greenstone belts.

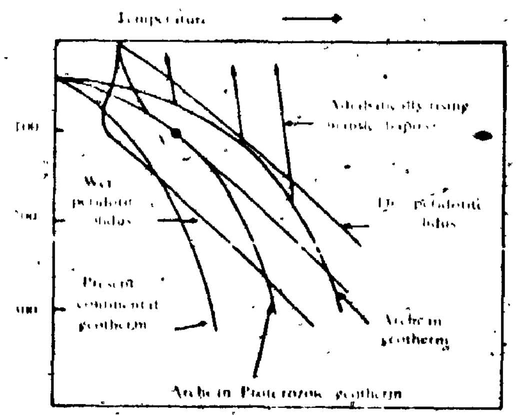


Fig. 1 Schematic relations between peridotite solidus at different water pressures and geotherms at different times in a cooling Earth. Designed to show the nature of these effects but not precise temperatures or water pressures. See text for further explanation. (Modelled after Fig. 4 of ref. 5)

As the extent of intersection of the geotherm and the solidus is decreased as a result of cooling and mantle degassing, the degree of partial melting should decrease. One might thus expect to see a gradual change in magma compositions (a more restricted range and less hydrous nature) with time in the Archean. But as this process continues there would be a rapid change of behaviour at the point where the geotherm and solidus no longer intersect, such as at point A in Fig. 1. Magma at this point would have a very restricted composition and with further cooling melting would cease. This situation is suitable to explain the nature of the Archean–Proterozoic transition. After this condition obtained there would be no further world-wide magmatism, since it would be restricted to local areas of perturbation of the geotherm or to pockets of high water content. Geothermal perturbations could result from adjustments of the lithosphere (possibly an early form of plate tectonics), thus accounting for the linear patterns of Proterozoic magmatism and tectonics, or possibly in zones of concentrated heat flux (deep mantle plumes) for which there seems to be little Proterozoic evidence. We suggest the former process and further suggest this as an explanation for the relatively constant tholeiitic composition of Proterozoic magmas.

This paper arose from discussion with J. G. Thurlow, S. Swinden, and P. L. Dean.

D. F. STRONG
R. K. STEVENS

Department of Geology,
Memorial University of Newfoundland,
St John's, Newfoundland

Received January 21; revised March 5, 1974.

Anhaeusser, C. R., Mason, M. J., and Viljoen, R. P., *Bull. geol. Soc. Am.*, 80, 2175–2200 (1969).
Cloud, P., *Am. J. Sci.*, 272, 537–548 (1972).
Condie, K. C., *Bull. geol. Soc. Am.*, 84, 2981–2992 (1973).
Ernst, W. G., *Am. J. Sci.*, 272, 657–668 (1972).
Naldrett, A. J., *Bull. Can. Inst. Min. Metall.*, 66, 45–63 (1973).

Printed in Great Britain by Henry Ling Ltd., at the Dorset Press, Dorchester, Dorset

Reprinted from:

Nature

Volume 248, Number 5443

p. 37-39

(with D.F. Strong, W.L. Dickson,
C.F. O'Driscoll and B.F. Kean)

(Reprinted from Nature, Vol. 248, No. 5444, pp. 17–19, March 1, 1974)

Geochemical evidence for an east-dipping Appalachian subduction zone in Newfoundland

THE concept of plate tectonics explains the present behaviour of the Earth better than any rival hypothesis. Modern plate motion can be observed and measured, but unfortunately much of the evidence is ephemeral. Spreading ridges, trenches, oceanic magnetic lineaments, zones of seismic activity dipping under orogenic belts, and areas of anomalous heat flow are all destroyed or decay as the plate regime evolves. Applicability of the plate tectonic concept to the ancient past must therefore be determined by more indirect geological observations which are often open to more than one interpretation. For example, it can be inferred that mélanges should develop in trenches associated with subduction[1] but not all mélanges originate in this way and there is presently no easy way of typifying mélanges. Thus, if the great variety of presently observed plate interactions existed in the past, geologic data may not be subtle enough to distinguish them and the record may be blurred beyond reasonable interpretation.

Given the limitations of geological data, it seems most reasonable to use the gross regional information rather than the details of local areas as a first basis for evaluating ancient plate tectonics. It also seems more reasonable to accept, at least temporarily, the simplest model suggested by the regional data rather than construct complex models to explain variations in local detail.

There are several gross geochemical trends observed across presently active subduction zones. The potassium content of igneous rocks varies systematically across both island arcs[2,3] and Cordilleran mountain chains[4,5] with increasing distance from the trench; the potassium content of igneous [illegible] eral deposits across several active orogenic zones with progressively more lithophile elements being concentrated away from the trench above the subduction zones[6–8]. Although these geochemical trends have not been clearly observed across all presently active subduction zones, there are no substantiated cases where a reverse zonation has been established.

Other geological features which may be systematically related to subduction zones include paired metamorphic belts[9], ophiolite emplacement[10], mélange zones[1], and belts of calc-alkaline volcanic rock. But these features by themselves are not yet unambiguous indicators of the reality or nature of plate movement in the Palaeozoic and are especially difficult to interpret for directions of dip of palaeosubduction zones.

The various plate tectonic models that have been proposed for the Appalachian-Caledonian mountain system are summarized in Fig. 1. Most of the models presuppose plate tectonics and support the assumption with local geological data of varying reliability and significance. It is noteworthy that all the models based on empirical geochemical data are consistent and all indicate an ancient subduction zone dipping away from the proto-North American continent in a present easterly or [illegible]erly direction. The models for Great Britain and Norway (ref. 15 and G. H. Gale and F. M. Vokes, unpublished) are based on the chemical composition of igneous rocks and/or the general zonation of mineral deposits; these geochemical patterns strongly resemble those over presently active subduction zones and they represent the most direct non-palaeomagnetic evidence for Palaeozoic plate movements.

Our data suggesting an easterly dipping Appalachian subduction zone in Newfoundland are derived from a study of both the geochemistry of igneous rocks and the present distribution of mineral deposits. They are supported by other geological data.

More than 1,200 samples of granitic rocks from thirty-three plutons in Newfoundland have recently analysed in detail[16]. These analyses show that, irrespective of geological

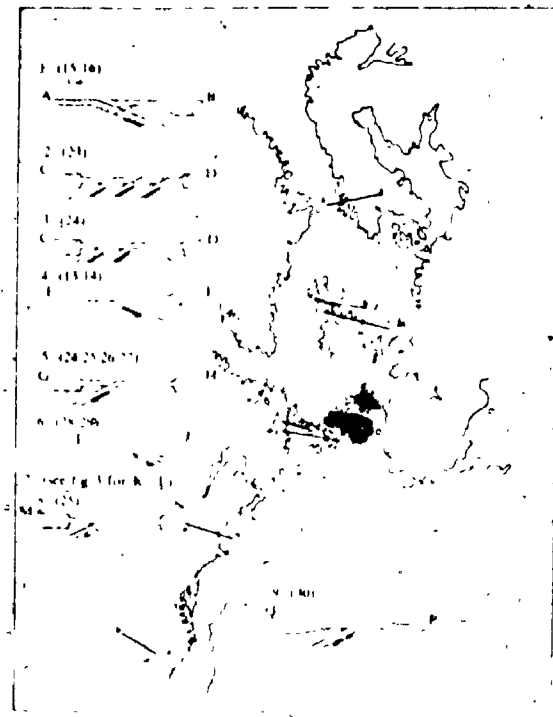


Fig. 1 Summary of plate tectonic models suggested for different sections of the Appalachians-Caledonides. Numbers in brackets next to each model refer to references. Stippled areas represent oceanic island arc crust and lined areas represent continental crust. Map drawn from reconstruction by Bullard et al.[21]. Note that only models 1, 4 and 6 are supported by chemical data. *Unpublished results of G. H. Gale and F. M. Vokes.

age, there is a definite eastwards increase in the average potassium content of the plutons in the Central and Gander zones of eastern Newfoundland (Fig. 2). The plutons of the eastern Avalon zone do not seem to follow this trend and are therefore anomalous. This distribution of potassium is similar to that described from western North America and explained by derivation of magmas from an east-dipping subduction zone. The Avalon anomaly is comparable with the disparity observed by Lipman et al. and interpreted by them as indicating a second subduction zone. Further data may substantiate such an interpretation in Newfoundland but our present data allow us only to make a very tentative postulation of a second subduction zone responsible for the Avalon plutonic rock. Preliminary inspection of our data suggests that the main subduction zone dipped at a rather steep angle, perhaps at more than 60°, eastwards. A steep dip would also explain the relative narrowness of the Appalachians as compared to the Cordillera.

The zonation of Newfoundland mineral deposits[22] also indicates an eastward-dipping subduction zone (Fig. 3). The observed distribution is like that described by Sillitoe[7] in western North and South America, Mitchell[6] and Garson[8] for the southwest Pacific and G. H. Gale and F. M. Vokes (unpublished) for Norway. Several other features of Newfoundland geology are also satisfactorily explained by a long lived east-dipping subduction zone.

The ophiolites of west Newfoundland and the Burlington Peninsula represent obducted oceanic lithosphere. Their westward emplacement is most simply explained by an over-

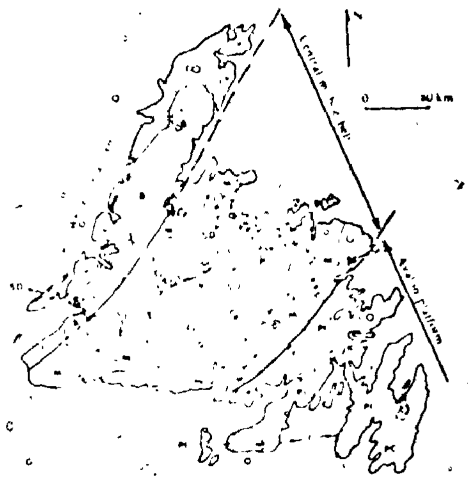


FIG. 2. Simplified geological map of the island of Newfoundland. [illegible] C. Carboniferous [illegible] SD. Silurian and Devonian subaerial sandstones, conglomerates and shale. V. Ordovician pillow lavas and [illegible] sediments. CO. Cambrian and Ordovician sandstones, limestones and shale. M. Pre-Ordovician schists and gneiss. PC. Precambrian sediments and lavas. B. Grenville basement gneisses, granites and anorthosites.

thrusting of oceanic lithosphere onto the proto-North American continent above an east-dipping subduction zone, [illegible] continental margin sediments under the ophiolites, all of which now form the west coast allochthons.

TABLE 1. Points of geological comparison between eastern and western Newfoundland

Western	Eastern
1. Grenville Basement	None definitely known except possibly in the Gander Lake zone
2. Hadrynian plateau basalt volcanism	Hadrynian acid ignimbrite volcanism
3. Fleur de Lys metamorphic zone	Gander Lake metamorphic zone
4. Cambro-Ordovician shelf limestone	Cambro-Ordovician Mn-Fe oxides
5. Ophiolites obducted onto western platform	Ophiolites not obducted, just deformed and intrusive ultramafics
6. No post-Grenville granitoid rock present	Granitoid rocks possibly ranging from Hadrynian to Devonian in age

The calc-alkaline piles of early and middle Ordovician volcanic rock with associated sediment of Notre Dame Bay would represent the volcanic island arcs associated with such eastward subduction.

The Gander Lake metamorphic belt would result from metamorphism along a continental margin above the subduction zone. The zone passes eastwards into the Avalon Platform continental crust, which was then a Basin and Range type regime marked by strong faulting and bimodal basalt-ignimbrite eruptions. This Cordilleran type mountain chain might have been the long lived New Brunswick geanticline of Schuchert. Its existence might also explain the inferred long age span of granites of the Gander Lake zone[19].

The western Fleur de Lys metamorphic and plutonic zone would be explained according to the model of an east-dipping subduction zone as being the result of the overriding effect of oceanic lithosphere, that is, subduction under oceanic lithosphere with resulting sinking, deformation and melting at the base of the continental crust.

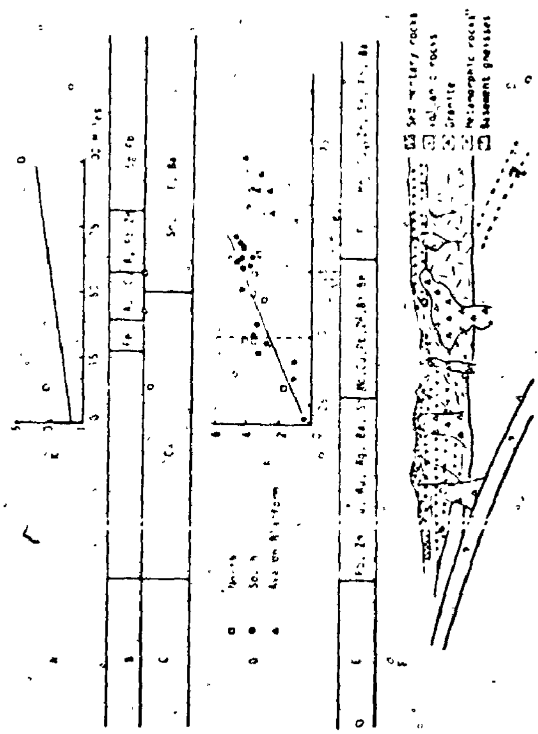


FIG. 3. Summary of geochemical and metallogenic evidence supporting an eastward-dipping Appalachian subduction zone in Newfoundland as compared to analogous areas elsewhere. A. Variation in K_2O across the Central Sierra Nevada Batholith (after Bateman and Dodge[3]). B. Metal zoning of western North and South America (after Sillitoe[?]). C. Metal zoning across Circum-Pacific island arcs (after Mitchell and Garson[?]). D. Variations in K across eastern Newfoundland. The K data points are means for individual plutons (≥1 200 analyses in total), the positions of which are plotted as distance of pluton centres from the western margin of the Gander Lake metamorphic belt, which is taken as the eastern Appalachian continental margin. E. Metal zoning in eastern Newfoundland. F. Schematic plate tectonic interpretation of the data described above.

Although the gross geological symmetry of Newfoundland[20] can be explained by the bringing together of two continental margins[21] we emphasise that there is a fundamental asymmetry evident on a finer scale (Table 1, Fig. 2). It can be explained as the result of an east-dipping subduction zone. The most striking aspect of this asymmetry is that there are no post-Grenville granitoid rocks on the western platform; that is, they seem to terminate abruptly at a line approximately along the Cabot fault. This line is taken as the westward limit of subduction.

The inferred existence of a subduction zone active for more than 250 m.y. suggests that the proto-Atlantic was a rather large ocean basin.

The chemical analyses of granitoid rocks on which this paper is based were obtained during a study for the Newfoundland Department of Mines and Energy under their DREE program and they are published with the permission of the Department. It was also supported by the National Research Council of Canada.

D. F. STRONG
W. L. DICKSON
C. F. O'DRISCOLL
B. F. KEAN
R. K. STEVENS

Department of Geology,
Memorial University of Newfoundland,
St John's, Newfoundland, Canada

Received August 6; revised September 12, 1973.

1 [illegible] 78, [illegible] (1973).
2 Dickinson, W. R., and Hatherton, T., *Science, N.Y.*, 157, 801-803 (1967).
3 Hatherton, T., and Dickinson, W. R., *J. geophys. Res.*, 74, 5301-5310 (1969).
4 Jakeš, P., and White, A. J. R., *Tectonophysics*, 8, 223-236 (1970).
5 Bateman, P. C., and Dodge, F. C. W., *Bull. geol. Soc. Am.*, 81, 409-420 (1970).
6 Christiansen, R. L., and Lipman, P. W., *Phil. Trans. R. Soc.*, A271, 249-284 (1972).
7 Lipman, P. W., Prostka, H. J., and Christiansen, R. L., *Phil. Trans. R. Soc.*, A271, 217-248 (1972).
8 Sillitoe, R. H., *Geol. Soc. Am. Bull.*, 83, 813-833 (1972).
9 Sillitoe, R. H., *Econ. Geol.*, 67, 184-197 (1972).
10 Mitchell, A. H. G., and Garson, M. S., *Trans. Sect. B, Inst. Min. Metall.*, 81, B10-B25 (1972).
11 Miyashiro, A., *Am. J. Sci.*, 272, 629-656 (1972).
12 Coleman, R. G., *J. geophys. Res.*, 76, 1212-1222 (1971).
13 Fitton, J. G., and Hughes, D. J., *Earth planet. Sci. Lett.*, 8, 223-228 (1970).
14 Thorpe, R. S., *Bull. geol. Soc. Am.*, 83, 3663-3668 (1972).
15 Gale, G. H., and Roberts, D., *Nature phys. Sci.*, 238, 60-61 (1972).
16 Strong, D. F., Dickson, W. L., O'Driscoll, C. F., and Kean, B. F., *Reconnaissance geochemistry of Eastern Nfld granitoid rocks* (Nfld Dept Mines and Energy, 1973).
17 Strong, D. F., [illegible] (in the press).
18 Schuchert, C., *Bull. Geol. Soc. Am.*, 41, 701-724 (1930).
19 Kennedy, M. J., and McGonigal, M. H., *Can. J. Earth Sci.*, 9, 452-459 (1972).
20 Williams, H., *Am. J. Sci.*, 262, 1137-1158 (1964).
21 Wilson, J. T., *Nature*, 211, 676-681 (1966).
22 Garson, M. S., and Plant, J., *Nature phys. Sci.*, 242, 34-38 (1973).
23 Church, W. R., and Gayer, R. A., *Geol. Mag.* (in the press).
24 Bird, J. M., and Dewey, J. F., *Bull. Geol. Soc. Am.*, 81, 1031-1060 (1970).
25 Dewey, J. F., and Bird, J. M., *J. geophys. Res.*, 76, 3179-3207 (1971).
26 Kennedy, M. J., *Geol. Soc. Am. Northeastern Sec. Eighth A. Mtg Abstract* 5, 183 (1973).
27 Church, W. R., and Stevens, R. K., *J. geophys. Res.*, 76, 1460-1466 (1971).
28 Kay, M., *Twenty-fourth int. geol. Cong.*, Sec. 3, 122-133 (1972).
29 Hatcher, R. D., *Geol. Soc. Am. Bull.*, 83, 2735-2760 (1972).
30 Bullard, E., Everett, J. E., and Smith, A. G., *Phil. Trans. R. Soc.*, A258, 41-51 (1965).

Please note that the correct references to cross-sections in Fig. 1 are as follows:

Fig.	Correct Ref.
1-1	15
1-2	22
1-3	23
1-4	13, 14
1-5	24, 25, 26, 28
1-6	27
1-8	25
1-9	29

Reprinted from:

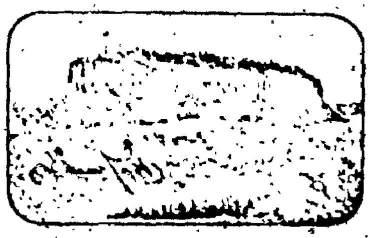
Geoscience Canada

Volume 1, Number 4

p. 40-44

Features

SIR WILLIAM LOGAN AND THE TACONIC PROBLEM



History of Canadian Geology

R. K. Stevens
Department of Geology
Memorial University of Newfoundland
St. John's, Newfoundland

The Taconic Problem has taken several different forms during the last hundred years or more and the attempts made to resolve it have had a major influence on the evolution of geological thought. Geologists attempting to come to grips with the Taconic Problem have been likened to blind men trying to describe an elephant but only randomly touching various parts of it (Zen 1967). Of course they all came up with different descriptions depending on the part of the animal they happened to touch. It is not generally realized however that Sir William Logan came close to our present understanding of the whole animal and in so doing introduced many novel concepts to the science of geology.

In Canada the Taconic Problem is ... the ... Appalachian ... Gaspé ... Newfoundland ... New England. The ... Appalachian ... of ... metamorphic and igneous rocks that ... between the little deformed rocks of the platform and the highly deformed and metamorphic core of the Appalachian system.

Logan (1863, p. viii) admitted in his introduction to the Geology of Canada that "The age of those rocks which are now termed the Quebec Group was ... an early period of the Survey a subject of considerable difficulty." Even when the age problem was resolved there still remained the knotty problems of field relationships and palaeogeography. What is the present relationship of the Quebec Group to other units in the Appalachians and what was its original nature ...?

The way in which Logan and his coworkers faced these problems of palaeontology, correlation, structure and paleogeography is of some historic interest for it involved one of the first discussions of tectonics and sedimentation at an ancient continental margin.

We are fortunate that Logan recorded the evolution of his thoughts in his correspondence as well as in the introduction to his Geology of Canada.

First Impressions

Logan was not the first geologist to study the rocks of the Quebec City area. Earlier work had been done by J. J. Bigsby (1828). He had concluded that the rocks later to be called the Quebec Group rested conformably on the underlying Trenton Limestones. At first Logan disagreed with this view when he investigated the rocks in ... 1840 ... that the ... of the rocks of the Quebec Group were much more deformed than the Trenton and ... them to be older and ... until ... the Trenton ... 1845 ... he was forced to develop this interpretation when he found that there was no ... apparent stratigraphic break between the two sequences. A section of dark coloured shales, the Utica and Hudson River formations linked the Trenton to the overlying Quebec Group. Logan reverted to Bigsby's interpretation and recorded his change of mind in a footnote to the 1845 report. This ... was emphasized in several later reports.

For over 17 years Logan held to this view and believed that the structural, stratigraphic and palaeontological evidence supported it.

Colonies and the Reformation 1860

Nevertheless ... some parts of the Quebec Group. Bigsby (1828) obtained many fossils from limestone conglomerates at Levis but since these came from clasts he naturally thought that they had been derived from the underlying Trenton ... collected graptolites ... at Levis in 1854 and ... obtained ... from the ... From 1856 to 1860 substantial fossil collections were made at ... by various members of the Survey (Logan, 1863, p. 349) but ... their significance was not realized. Even so the ... to be taken to collect ... overworked ... survey ... at least a residual ... stratigraphy that placed ... deformed rocks on top of undeformed rocks.

... the Survey ... responsible for ... the Levis fauna ... was directed towards ... the Levis section with ... sections, which were ... increasingly ... the endeavours of the French [illegible] Barrande. Gradually [illegible] came to realize that the Levis fauna was much more primitive than expected. Not only did it look older than that of the underlying shales, but it seemed older even than the Trenton fauna and to correlate best with faunas at the base of Barrande's second fauna or at about the level of the [illegible] of [illegible] Formation [illegible] that is low in the Ordovician. This conclusion could not be reconciled with the stratigraphy worked out [illegible] by Logan and was a matter of great concern to the Survey [illegible] were not an [illegible]

Barrande had encountered similar problems during his work in Bohemia. In places he found fossils well out of their normal stratigraphic order. [illegible] graptolites [illegible] somewhat [illegible] in the middle of a [illegible] sequence ([illegible] p. [illegible]). To explain these anomalies Barrande devised his theory of colonies in 1852. According to this theory [illegible] did not reach the same degree of development [illegible] that their entire [illegible] Ordovician graptolites gave way upward to [illegible] this did not happen at the same time all over the world so that an influx of certain forms could temporarily [illegible] an area inhabited by [illegible] forms. Colonies of [illegible] might pass [illegible] in an area occupied by Ordovician forms [illegible] in this way [illegible] the faunal [illegible] be [illegible].

At first [illegible] Barrande's theory of colonies [illegible] that colonies of primitive [illegible] might have survived [illegible] [illegible]

were no theoretical objections to colonies, and field relationships seemed to support the hypothesis.

In May 1860, however, Logan and [illegible] made new fossil discoveries at Levis. Although I have not been able to find out what the new fossils were, they were important enough to wreck the theory of colonies and destroy Logan's field interpretation. By June 12, 1860, [illegible] was convinced that the Levis faunas were truly of Lower Ordovician age corresponding with the faunas at the base of Barrande's second fauna and so informed Barrande. Billings saw that the theory of colonies could not explain the Levis faunas because of its exclusively primitive aspect. It was not a case of a few primitive forms associated with younger forms but one in which 137 species showed a uniform primitive aspect (Logan, 1860, p. 474). [illegible] of this fauna not one species [illegible] the [illegible] group, where we have a gradual passage from the fauna of the Hudson River formation to that of the [illegible] (Logan, 1860, p. 474). Not a single fossil could be found in [illegible] found in rocks that appeared to occupy the same stratigraphic position elsewhere.

[illegible] Billings, with [illegible] and a certain amount of [illegible] (Bailey et al., 1928, p. [illegible]) transferred the Levis Formation from a position high in the Ordovician to one low in the Ordovician. Bailey et al. (1928) called this revision "The 1860 Reformation". It presented a considerable challenge to the Survey: in the light of the new paleontological data how could the Levis Formation, and hence the great mass of the Quebec [illegible] [illegible] [illegible] paleontological methods were [illegible] Whatever the outcome, much of the Survey's [illegible] work would have to be [illegible] with a consequent loss of [illegible]

After Logan [illegible] James Hall [illegible] [illegible] [illegible] of these [illegible] other

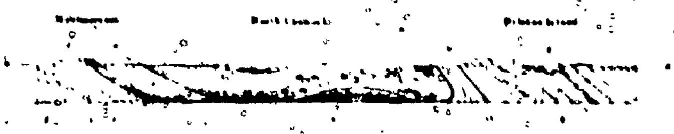
condition that could in the least interfere with his conclusions that these were one and the same group. In November I had the same assurances from him after he had [illegible] and re-examined Quebec, and it was not until late in December that he wrote me that there must be a break upon paleontological grounds, but that it did not affect his stratigraphical results of generally [illegible]. Now I cannot see but both Logan and Hall must give up their mode of working and their results amount to nothing.

[illegible] cannot see that by these admissions he [illegible] taken out his props to his physical and topographical [illegible] everywhere in Canada and renders it as worthless as he confesses the actual work on the Green Mountain range to be — and not only this, confesses the worthlessness of his chemical geology, but leaves his enemies, if he has any, to take advantage of these circumstances. (Letter from J. [illegible] to J. P. Lesley, 1861, quoted in Marcou, 1934, p. [illegible])

Marcou offered another explanation of the fossils, differing somewhat from that of Logan's [illegible] [illegible] held the [illegible] that the fossils described by Mr. Billings and the so-called outcrops A[1] A[2] A[3], etc., of Mr. Logan were collected and observed in a very careless way without regard [illegible] [illegible] [illegible] [illegible] 1862 [illegible] Marcou [illegible] [illegible]

The Great Dislocation

[illegible] [illegible] [illegible] [illegible] [illegible] of overthrust [illegible] had [illegible] December,



Horizontal and vertical scale, one inch two mile.

- g, Laurentian gneiss.
- l, Trenton limestone
- u, Utica and Hudson River formations.
- q, Quebec group
- F, Fault
- O, Overlap
- S, Level of the sea

Figure 1

[illegible] such [illegible] and the [illegible] was only a few years [illegible] incorporated [illegible] paleontology [illegible] should be judged [illegible] background

Paleogeography

[illegible]

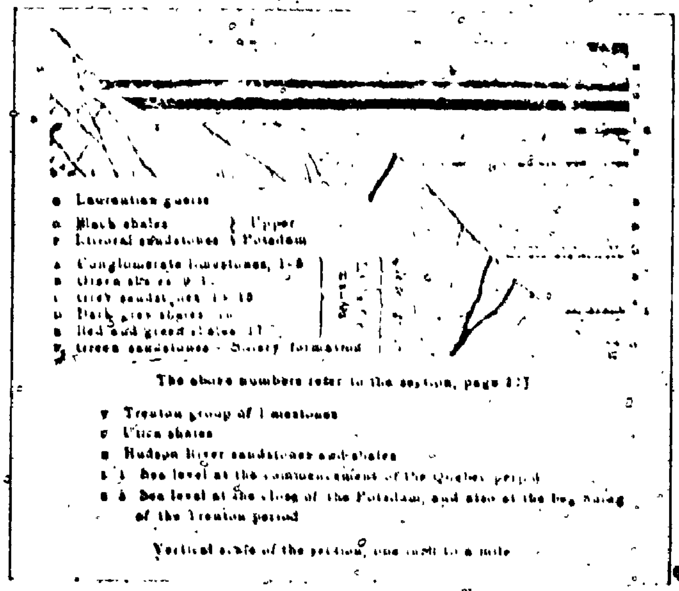


Figure 2

[illegible]

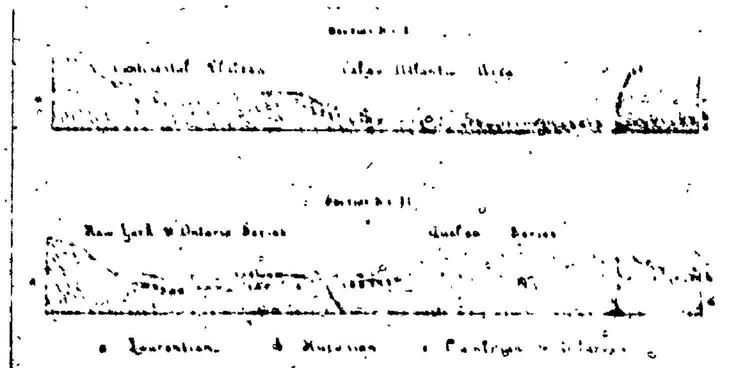


Figure 3

[illegible]

Influence and Legacy

The most rec[illegible] tectonic map of Canada shows [illegible] as the Great [illegible] line to be known running through Quebec City and then under the St. Lawrence River well north of where Logan showed it and where it actually [illegible] (Fig. 4). Much of Logan's hypothesis was either [illegible] ignored or [illegible] understood in the same way that [illegible] treated [illegible] elephant. The [illegible] better. The [illegible] several [illegible] reasons [illegible] misunderstanding of Logan's hypothesis. To start with, it is demonstrably wrong [illegible] respects. Logan's [illegible] the Quebec [illegible] reversed. Neither has his [illegible] of the Quebec Group with the Proterozoic rocks of [illegible].

Perhaps the most [illegible] of Logan's [illegible] was the assertion that the [illegible] was a relatively [illegible] fault (Figs. [illegible]) [illegible] calculated that the dislocation [illegible] [illegible] it has been [illegible] so that [illegible] much of [illegible] A [illegible] Logan's [illegible] the Appalachians [illegible] and undeformed rocks. The [illegible] map of Canada [illegible] assumption [illegible] as [illegible] North [illegible] [illegible] research.

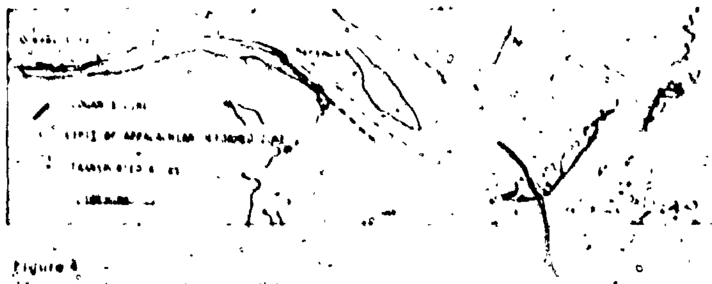


Figure 4
[illegible]

Acknowledgements

Research for this study was partially financed by a NRC grant to W. H. Church. Thanks are extended to [illegible] Strong and H. Williams for critically reading the manuscript and [illegible] Jackson for drafting Figure 4.

References

A[illegible] 18[illegible] The Geological Survey of Newfoundland: Nature, v. 14, p. 2[illegible]

Bailey, E. B., [illegible] W. Collet and R. M. Field, 19[illegible] [illegible] v. 36, p. 577-614.

[illegible] J. J., 18[illegible] On the [illegible] Proc. Geol. Soc. London, v. 1, p. [illegible]

Geikie, A., 18[illegible] The crystalline rocks of the Scottish Highlands: Nature, v. 24, p. 29-[illegible]

Harrington, B. J., 1883, Life of Sir W. E. Logan: Montreal, Dawson Bros., 432 p.

[illegible] and [illegible] W. [illegible] 1950, The [illegible] overthrust fault [illegible] v. 2[illegible], p. 1[illegible]

Logan, W. E., 184[illegible] Progress report [illegible] 1844: Montreal, Geol. Surv. Can.

Logan, W. E., 186[illegible] Remarks on the fauna of the Quebec group of rocks [illegible] Nat. and Geologist, v. 5, p. 4[illegible]

Logan, W. E., 18[illegible] Geology of Canada: Montreal, Dawson Bros., 983 p.

Logan, W. E., 186[illegible] On the rocks of the Quebec [illegible] (Letter addressed [illegible] March [illegible]): Can. Nat. and Geologist, v. 8, p. [illegible]

Merrill, G. P., 192[illegible] The First One Hundred Years of American Geology: New York, Hafner, [illegible] p. (reprinted 1969)

[illegible] The Moine Thrust: its discovery, age and tectonic significance: Proc. Geol. Assoc. London, v. [illegible], p. [illegible]-220

[illegible] Mountain View, Ca., [illegible] Pacific Press, [illegible] p.

Rogers, W. B. and H. D. Rogers, 1843, On the physical structure of the Appalachian chain, as exemplifying the laws which have regulated the elevation of great mountain chains generally: Assoc. Am. Geol. Rept., p. 474-531.

Safford, J. M., 185[illegible] A Geological Reconnaissance of the State of Tennessee: Nashville, Meigs, [illegible] p.

• Ms received February [illegible] 197[illegible]

Reprinted from:

Geology

Volume 2, Number 4

p. 175-178

(with D.F. Strong and B.F. Kean)

Do Some Eastern Appalachian Ultramafic Rocks Represent Mantle Diapirs Produced above a Subduction Zone?

R. K. Stevens, D. F. Strong
Department of Geology, Memorial University of Newfoundland
St. John's, Newfoundland, Canada
B. F. Kean
Newfoundland Department of Mines and Energy
St. John's, Newfoundland, Canada

Benson (1926) and Hess (1939, 1955) drew attention to the common occurrence of ultramafic rocks in mountain belts, and Hess (1955) suggested that [illegible] flanks of orogens, taking the Appalachians as a particular example. Since then there have been numerous attempts to explain the origin of these supposedly particular ultramafic belts, and most recent papers interpret a range of such ultramafic rocks as ophiolites representing oceanic lithosphere (Coleman 1977; Moores 1970; Dewey and Bird 1971; Smith 1971; Dietz 1963), an interpretation endorsed by a recent international conference (Penrose Field Conference 1972). We find it curious that, although most plate tectonics models predict the existence of peridotite diapirs rising above subduction zones, there are apparently few of these ultramafic rocks which have been inter[illegible] pirs. Of these, some, such as the Bay of Islands area of western Newfoundland (Dewey 1969; Bird and Dewey 1970) are now generally considered to be well defined ophiolites, that is, obducted oceanic lithosphere (Stevens 1970; Church and Stevens 1971; Dewey and Bird 1971). Perhaps the closest approach to such an interpretation is that of Murray (1972) for the Alaskan zoned ultramafic rocks. This note suggests the possible existence of such rocks in the Appalachians and describes some characteristics that may lead to their general recognition.

Although Hess's suggestion that there were two ultramafic belts in the Appalachians has been repeated often, recent new data and interpretations require a revision and refinement of this view. Two areas at the northern and southern ends of the Appalachians can be used for illustration. In Newfoundland there are a variety of ultramafic rocks (Fig. 1), and these have a number of different characteristics (summarized in Table 1). The largest and best known are the large allochthonous ophiolite suites at Hare Bay and the Bay of Islands in western Newfoundland, and at Baie Verte and Betts Cove on the Burlington Peninsula. The latter three have a clearly recognizable ophiolite stratigraphy (lowermost [illegible] passing upward through [illegible] gabbro, sheeted diabase, pillow lava, and sediment), which supports their interpretation as fragments of oceanic crust (Stevens 1970; Church and Stevens 1971; Dewey and Bird 1971; [illegible] and others 1976).

Mafic volcanic rocks, sheeted dikes, small exposures of gabbro, and very minor occurrences of [illegible] and serpentinite occur in the Notre Dame Bay area of north-central Newfoundland. These are thought to represent the upper levels of an ophiolite sequence (Strong [illegible]). These pass upward into rocks of an island arc complex of Notre Dame Bay (Kean 1973; Strong 1973; Strong and Payne 1973), which is sporadically intruded by mafic sills that have a lower cumulus peridotite zone (Harris 1973). Other than these rocks, the crust under the island arc complex is not exposed, but geophysical data (Weaver 1967; Miller and Deutsch 1973) suggest that an ultramafic layer exists at no great depth, possibly representing the ocean mantle upon which the island arc was constructed.

The third main area of ultramafic rocks is in the southeastern part of the central mobile belt and [illegible] of the Gander Lake zone to the east and southeast of Notre Dame Bay. Although these ultramafic rocks have generally been interpreted as [illegible] oceanic crust, they display significant differences from those described above. First, although they are commonly bounded by faults and in some cases occur as blocks in a melange (Kennedy and McGonigal 1972), in many cases, such as at Great Bend (Table 1), they appear to be intrusive into the surrounding rocks. Second, they do not show the ophiolite stratigraphy from peridotite through gabbro, sheeted diabase, pillow lava, and abyssal sediment, although gabbro and diabase are present in some cases. In fact, these ultramafic rocks are commonly associated with clastic and pyroclastic rocks rather than with the cherts and pillow lavas of ophiolite terrains. The third and perhaps most important difference is that they are composed predominantly of clinopyroxenite rather than peridotite.

Proceeding southward, we still recognize one of the ultramafic belts proposed by Hess (1955) that is the equivalent of our western allochthonous fragments of oceanic lithosphere, clearly exposed in Quebec, for example, Thetford Mines (St. Julien 1972; Laurent 1975), although we do note the alternative interpretations of Chidester and Cady (1972). Although the Mt. Albert body is generally taken as one of the few "hot" peridotite intrusions (Smith and MacGregor 1960), the regional setting compels us to suggest that it is also an obducted ophiolite, the "aureole" being explained by dynamothermal metamorphism as in the Bay of Islands complex (Malpas 1973; Williams and Smyth 1973). East of this zone, however, Hess's second belt does not stand up to detailed examination. The ultramafic rocks of eastern Maine appear to be younger cumulates in mafic sills (for example, see Espenshade 1972), although it is possible that they

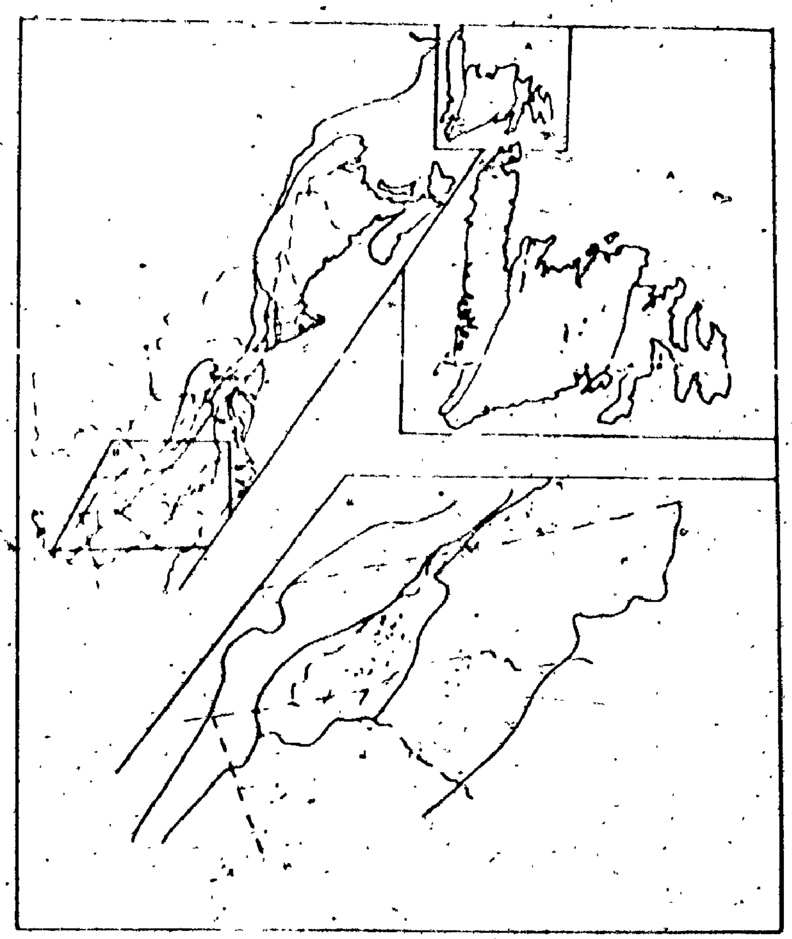


Figure 1. Sketch map showing locations of ultramafic rocks in Newfoundland (A) and the northern Appalachians (B) indicated by black areas. Solid lines show major tectonic divisions.

are related to the diapirs (J. S. Dickey, 1973, personal commun.) whereas farther south they are apparently absent until well into the Southern Appalachians.

The ultramafic rocks of the eastern parts of the southern Appalachians occur as numerous small isolated bodies which do not appear to occupy a distinct belt but are irregularly distributed throughout the Piedmont zone (Fig. 1). These rocks seem to show all the characteristics of those in the Gander Lake zone of Newfoundland, with intrusive contacts into clastic sedimentary rocks and a dominantly clinopyroxenite mineralogy, the type websterite in North Carolina being the best known example.

These eastern Appalachian ultramafic rocks can be explained as diapirs rising above a subduction zone, according to predictions of plate tectonics models (see, for example, Karig, 1971). The following additional evidence supports this interpretation. Available geochemical, geologic, and metallogenic data strongly suggest that Appalachian-Caledonian tectonics from Norway to Alabama can be explained as resulting from long-lived eastward-dipping subduction at an Andean Cordilleran-type continental margin to the east, represented by the Avalon platform of Newfoundland and the Suwannee basin and other areas of Florida, Georgia, and [illegible] 1974; Strong, 1974; Wolchowsky and Gilbert, 1974). If this model is correct, the eastern ultramafic rocks occur in precisely the correct position expected for diapiric bodies (see Fig. 2).

Nicholls and Ringwood (1973) have recently produced experimental evidence suggesting that clinopyroxenites can be produced by partial melting and recrystallization [illegible] diapirs. This gives the first satisfactory explanation of the mineralogical differences between these bodies and the ophiolites of the western belt: their large volumes of clinopyroxenite. The partial melting during ascent also produces quartz tholeiites, which might be represented by the gabbro and diabase associated with these bodies. However, [illegible] test such hypotheses. (We might also

TABLE 1. CONTRASTING FEATURES OF ULTRAMAFIC AND ASSOCIATED ROCKS OF WESTERN AND EASTERN NEWFOUNDLAND

Name	Size and shape	Rock types	Geologic relations
Western Newfoundland			
Bay of Islands Complex	Four detached slices of circular outline, largest, 40 km diam, smallest, 16 km diam	Full ophiolite suite (see text)	Thrust upon western platform with transported Cambrian [illegible] clastic sediments. Basal thrust contact aureole of garnetiferous amphibolite
Hare Bay	Irregular outline, 20 km diam	Ultramafic member of ophiolite suite	Part of the Hare Bay Allochthon. Basal thrust contact aureole with reversed metamorphic zoning from lower greenschist upward into garnetiferous amphibolite
Baie Verte	Elongated bodies, discontinuous over 80 km	Ultramafic member of ophiolite suite, some sheeted diabase	Obducted onto and deformed with Cambrian Fleur de Lys Supergroup
Ming's Bight	Oval body, 8 km diam	Full ophiolite suite	Disrupted into fault-bounded blocks
Betts Cove	Elongated body, 8 km long	Full ophiolite suite	Thrust contact with polyphase deformed rocks of the Fleur de Lys Supergroup
Pilley's Island	Extensive pillow lava, elongate zone of sheeted diabase 3 km long	Upper ophiolite: gabbro, dikes, pillow lava	Overlain by island arc volcanic suite
Eastern Newfoundland			
Pipestone Pond	Narrow, elongated body, 18 km long, 5 km wide	(Dunite?) pyroxenite, gabbro, diorite, diabase	Fault contacts with metasedimentary and metavolcanic rocks
Great Bend	Circular, 8 km diam	Dunite, peridotite (pyroxenite), gabbro	Intrusive into clastic sedimentary (volcaniclastic) rocks
Gander Lake Zone (north and south of Gander Lake)	Numerous circular, oval, and elongated bodies ranging from 1 km diam to an elongate belt 80 km long	Pyroxenite (minor peridotite), gabbro	Intrusive into volcanic and sedimentary rocks of Gander Lake Group; some disrupted with fault contacts

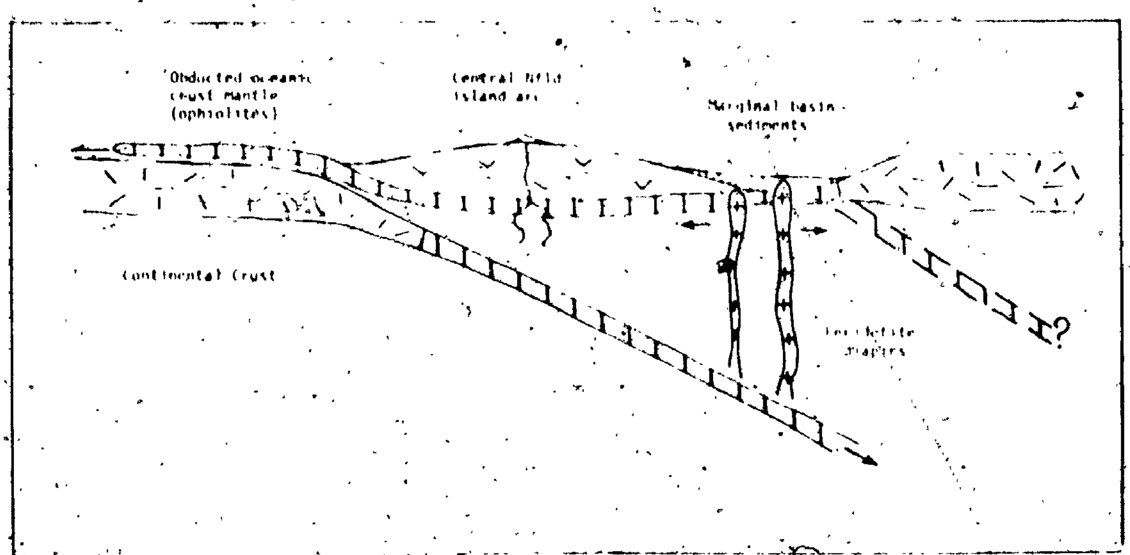


Figure 2. Schematic cross section across Newfoundland indicating different postulated origins of ultramafic rocks of western Newfoundland (obducted ophiolite) and eastern Newfoundland (peridotite mantle diapirs). Modified from Strong and others (1974).

point out that such an explanation may also be valid for the zoned ultramafic rocks of Alaska, which are likewise in approximately the right position and rich in clinopyroxenite, although Murray [1972] presents an elegant explanation of their origin as crystal cumulates. Such an explanation of some Appalachian ultramafics was in fact advanced by Church [1971], although magnetite hornblende rocks so common in the Alaskan ultramafics are notably absent from them.)

The preservation of these diapirs as well as of obducted and trapped ophiolites depends on the efficiency of erosion and the degree of suturing. In areas of strong erosion and tight suturing, only a thin and highly deformed zone of ultramafic rocks associated with metamorphosed clastic rocks might remain. The actual recognition of specific ultramafic types within an orogenic belt obviously depends not only on their original development but also on later tectonic events such as erosion. Hypotheses based on the apparent absence of obducted ultramafic rocks (see, for example, Chidester and Cady, 1972) should therefore be treated with caution. Evidence of obducted ophiolites might remain only in the [illegible] chromite in the Ordovician and Silurian sedimentary rocks on the north and western margins of the central Appalachians.

In summary, Appalachian ultramafic rocks are considered [illegible] of four main types: obducted ophiolites derived from oceanic lithosphere, oceanic lithosphere trapped beneath island arcs, [illegible] differentiated mafic sills and pyroxenite rich plutons derived from upwelling mantle diapirs above an east dipping subduction zone.

REFERENCES CITED

Benson, W. N., 1926, [illegible] ultrabasic igneous rocks: Natl. Acad. Sci. Mem., [illegible].

Bird, J. M., and Dewey, J. F., 1970, Lithosphere plate–continental margin tectonics and the evolution of the Appalachian orogen: Geol. Soc. America Bull., v. 81, p. 1031–1060.

Chidester, A. H., and Cady, W. M., 1972, Origin and emplacement of alpine-type ultramafic rocks: Nature Phys. Sci., v. 240, p. [illegible].

Church, W. R., 1972, Ophiolite: its definition, origin as oceanic crust, and mode of emplacement in orogenic belts, with special reference to the Appalachians: Canada Dept. Energy, Mines and Resources Earth Physics Br. Pub. 42, no. 3, p. [illegible].

Church, W. R., and Stevens, R. K., 1971, Early Paleozoic ophiolite complexes of the Newfoundland Appalachians as mantle-oceanic crust sequences: Jour. Geophys. Research, v. 76, p. 1460–1466.

Coleman, R. G., 1971, Plate tectonic emplacement of upper mantle peridotites along continental edges: Jour. Geophys. Research, v. 76, p. 1212–1222.

Dewey, J. F., 1969, Evolution of the Appalachian/Caledonian orogen: Nature, v. 222, p. 124–129.

Dewey, J. F., and Bird, J. M., 1971, Origin and emplacement of the ophiolite suite: Appalachian ophiolites in Newfoundland: Jour. Geophys. Research, v. 76, p. 3179–3206.

Dietz, R. S., 1963, Alpine serpentinites as oceanic rind fragments: Geol. Soc. America Bull., v. 74, p. 947–952.

Espenshade, G. H., 1972, Geology of the Moxie pluton in the Moosehead Lake–Jo Mary Mountain area, Piscataquis County, Maine: U.S. Geol. Survey Bull. 1340, 40 p.

Harris, A., 1973, Geology of the Osmonton Arm, Gibsons Harbour area, central Notre Dame Bay, Newfoundland [M.Sc. thesis]: St. John's, Memorial Univ. Newfoundland, 115 p.

Hess, H. H., 1938, Island arcs, gravity anomalies and serpentinite intrusions: Internat. Geol. Cong., 17th, Moscow 1937, Rept., v. 2, p. 263–283.

——— 1955, Serpentines, orogeny and epeirogeny: Geol. Soc. America Spec. Paper 62, p. 391–408.

Karig, D. E., 1971, Origin and development of marginal basins in the western Pacific: Jour. Geophys. Research, v. [illegible], p. 2542–[illegible].

Kean, B. F., 1973, Stratigraphy, petrology and geochemistry of volcanic rocks of Long Island, Newfoundland [M.Sc. thesis]: St. John's, Memorial Univ. Newfoundland, 155 p.

Kennedy, M. J., and McGonigal, M., 1972, The Gander Lake and Davidsville Groups of northeastern Newfoundland: New data and geotectonic implications: Canadian Jour. Earth Sci., v. 9, p. 452–459.

Laurent, R., 1973, The Thetford Mines ophiolite, Paleozoic [illegible] of oceanic lithosphere in the northern Appalachians of Quebec: Geol. Soc. America Abs. with Programs (Northeastern Sec.), v. 5, no. 2, p. 188.

Malpas, J., 1973, A restored section of oceanic crust and mantle in western Newfoundland: Geol. Soc. America Abs. with Programs (Northeastern Sec.), v. 5, p. 191.

Miller, H. G., and Deutsch, E. R., 1973, A gravity survey of eastern Notre Dame Bay: in Earth science symposium on offshore eastern Canada: Canada Geol. Survey Paper 71-23, p. [illegible].

Moores, E. M., 1970, Ultramafics and orogeny, with models of the U.S. Cordillera and the Tethys: Nature, v. 228, p. 837–842.

Murray, C. G., 1972, Zoned ultramafic complexes of the Alaskan type: feeder pipes of andesitic volcanoes: Geol. Soc. America Mem. 132, p. 313–335.

Nicholls, G. A., and Ringwood, A. E., 1973, Effect of water on olivine stability in tholeiites and the production of silica-saturated magmas in the island-arc environment: Jour. Geology, v. 81, p. 285–300.

Penrose Field Conference, 1972, Ophiolites: Geotimes, v. 17, no. 12, p. 24–25.

Smith, A. G., 1971, Alpine deformation and the oceanic areas of the Tethys, Mediterranean and Atlantic: Geol. Soc. America Bull., v. 82, p. 2039–2070.

Smith, C. H., and MacGregor, I. D., 1960, Ultrabasic intrusive conditions illustrated by the Mount Albert ultrabasic pluton, Gaspé, Quebec [abs.]: Geol. Soc. America Bull., v. 71, p. 1978.

Smitheringale, W. G., 1972, Low-potash Lushs Bight tholeiites: Ancient oceanic crust in Newfoundland?: Canadian Jour. Earth Sci., v. 9, p. 574–588.

Stevens, R. K., 1970, Cambro-Ordovician flysch sedimentation and tectonics in west Newfoundland and their possible bearing on a proto-Atlantic ocean: Geol. Assoc. Canada Spec. Paper 7, p. 165–177.

St. Julien, P., 1972, Structural setting of the Thetford Mines ophiolite complex: Geol. Soc. America Abs. with Programs (Northeastern Sec.), v. 5, no. 2, p. 218.

Strong, D. F., 1972, Sheeted diabases of central Newfoundland: New evidence for Ordovician sea-floor spreading: Nature, v. 235, p. 102–104.

——— 1973, Lushs Bight and Roberts Arm Groups of Central Nfld.: Possible juxtaposed oceanic and island-arc volcanic suites: Geol. Soc. America Bull., v. 84, p. 3917–3928.

——— 1974, Plate tectonic setting of Appalachian-Caledonian mineral deposits as indicated by Newfoundland examples: Soc. Mining Engineers Trans. (in press).

Strong, D. F., and Payne, J. G., 1973, Early Paleozoic volcanism and metamorphism of the Moreton's Harbour area, Newfoundland: Canadian Jour. Earth Sci., [illegible].

Strong, D. F., Dickson, W. L., O'Driscoll, C. F., Kean, B. F., and Stevens, R. K., 1974, Geochemical evidence for eastward Appalachian subduction in Newfoundland: Nature (in press).

Upadhyay, H. D., Dewey, J. F., and Neale, E. R. W., 1971, The Betts Cove ophiolite complex, Newfoundland: Appalachian oceanic crust and mantle: Geol. Assoc. Canada Proc., v. 24, p. 27–34.

Weaver, D. F., 1967, A geological interpretation of the Bouguer anomaly field of Newfoundland: Dominion Observatory Ottawa Pubs., v. 35, no. 5, p. 223–251.

Wyckoff, [illegible], and Gilbert, [illegible], 1973, The pre-Mesozoic rocks of the southeastern Atlantic and Gulf Coastal Plain: Florida subsurface and their bearing on the origin of the southernmost Appalachians: Geol. Soc. America Abs. with Programs (Southeastern Sec.), v. 5, no. 5, p. 452.

Williams, Harold, and Smyth, W. R., 1973, Metamorphic aureoles beneath ophiolite suites and alpine peridotites: Tectonic implications with west Newfoundland examples: Am. Jour. Sci., v. 273, p. 594–621.

ACKNOWLEDGMENTS

Reviewed by [illegible].

Supported by the National Research Council of Canada and the Newfoundland Department of Mines and Energy.

MANUSCRIPT RECEIVED JAN. 2[illegible], 1974

MANUSCRIPT ACCEPTED JAN. 28, 1974

Reprinted from:

Program of the Annual General Meeting of
the Geological Association of Canada,
Newfoundland Section
Fall Meeting, 1974

A REGURGITATION MODEL FOR THE EVOLUTION OF THE BURLINGTON PENINSULA.

R. K. Stevens
Department of Geology
Memorial University of Newfoundland

The proposed evolution of the peninsula is as follows:

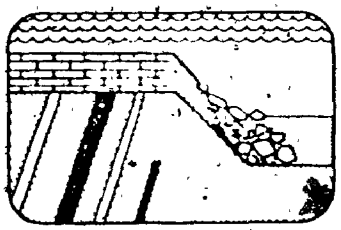
1. Deposition of the older part of the Fleur de Lys Supergroup with associated volcanic rocks.

2. Obduction of a thick ophiolite and island arc slab during Arenigian time producing deformation and metamorphism of the Fleur de Lys.

3. Strong vertical adjustments involving the sinking of the oceanic slab and the regurgitation of sial, both in solid and liquid form, along the lines suggested by Ramberg's centrifuge studies. Results include the formation of the Cape St. John volcanic and associated intrusive rocks, sinking of rocks along the Baie Verte "suture", deformation and metamorphism of the Fleur de Lys.

Reprinted from:

Geoscience Canada,
Volume 1, Number 4
p. 31-33
(with H. Williams)



Taconic Orogeny and the Development of the Ancient Continental Margin of Eastern North America in Newfoundland

Harold Williams and R. K. Stevens
Department of Geology
Memorial University of Newfoundland
St. John's, Newfoundland

For about 150 million years since the beginning of the Paleozoic, the western part of Newfoundland formed a segment of the ancient continental margin of eastern North America. The margin was initiated in the late Precambrian by rifting with accompanying thick clastic deposition and tholeiitic volcanism (Fig. 1). Possibly as much as 10 km of deep water turbidites accumulated locally at the thickest part of the continental rise prism.

A thinner sequence of rocks deposited in shallow water, locally supratidal, formed on the continental shelf from Lower Cambrian to latest Lower Ordovician (Fig. 2). These sediments thicken eastward and record an upward transition from immature arkosic sandstones to mature quartz sandstones and by limestones and dolomites.

Rocks deposited at the morphological margin between the shelf sequence and the thicker parts of the continental rise prism are now preserved above the shelf within the Humber Arm and Hare Bay Allochthons. These consist of turbidites, lime breccia beds with distinctive shelf edge faunas (Fig. 3), and interbedded pelagic shales.

A reconstruction of the ancient continental margin in Newfoundland, compared with the present Atlantic margin of North America at Cape May, is shown in Figure 4.

The uppermost slices of the Humber Arm and Hare Bay Allochthons consist of ophiolite suites up to six km thick that are interpreted as oceanic crust and mantle. As such, they provide direct evidence that the Appalachian System evolved during a cycle of oceanic growth and destruction rather than one of ensialic rifting. Similar ophiolites, in a more easterly belt above the now metamorphosed continental rise prism, may be deformed and [illegible] erosional remnants of this same sheet. If so, then it was obducted across the ancient continental margin in the same way as the Semail Nappe of Oman and the Papuan Nappe of New Guinea. This simplistic view is contrasted with an alternate interpretation that relates each ophiolite belt to an equal number of small ocean basins at the ancient margin.

The width of the ancient ocean is unknown but the 150 million years between initiation and destruction of the ancient continental margin would suffice for the generation of a major ocean comparable in size with the present North Atlantic Ocean initiated 150 million years ago in the Jurassic. The eastern margin of the Appalachians, on the eastern side of the inferred ancient ocean, may have evolved independently so that its present proximity to rocks of the ancient North American margin is due to the random interaction of wandering continents. It is also possible that the late Precambrian volcanism and rifting in the eastern Avalon Zone related to the initiation of the continental rise prism in western Newfoundland, and that the ancient proto-Atlantic formed only a small ocean behind a migrating micro-continent. Nonetheless, the evidence for an ocean basin to the east of a continental shelf is especially strong and the destruction of this

Figure 1
Late Precambrian [illegible] the rifted ancient continental margin

Figure 2
[illegible] the ancient continental margin

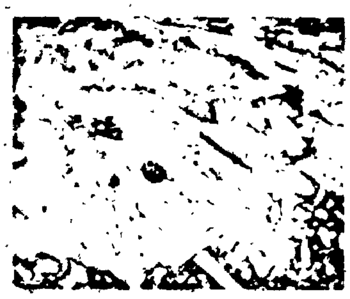


Figure 3
[illegible] of the [illegible] bank at the ancient continental margin

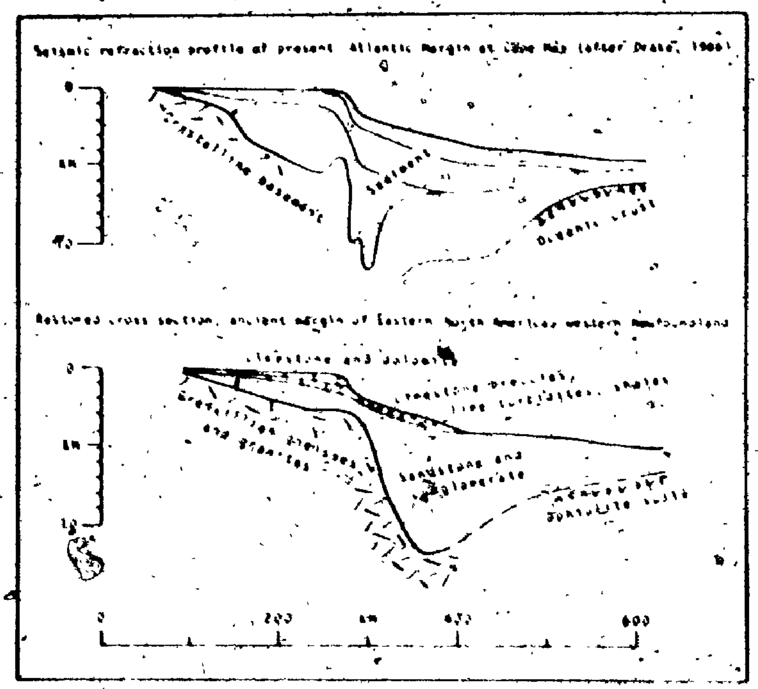


Figure 4

Figure 5

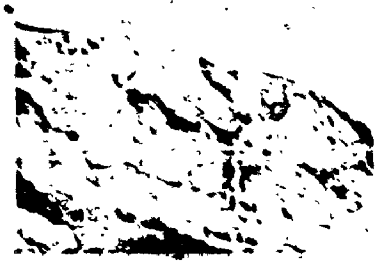


Figure 6

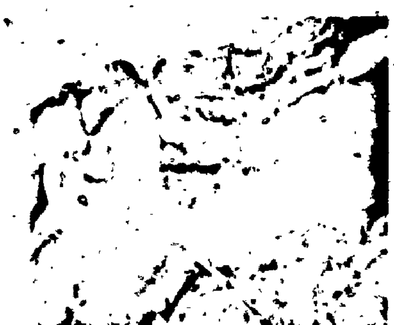


Figure 7

[illegible]

Newfoundland ... assembled from the east ... Polyphase deformation ...

metamorphism in the ... [illegible]

[illegible]

Figure 8

[illegible]

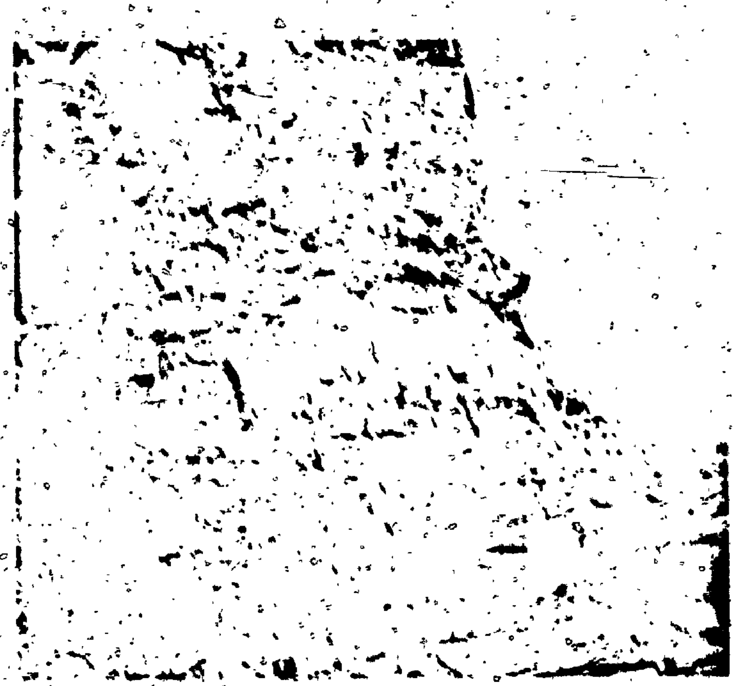


Figure 9

[illegible]

MS received [illegible]

Reprinted from

The Geology of Continental Margins

edited by C.A. Burk and C.L. Drake

Published by Springer-Verlag, New York

p. 81-96

(with H. Williams)

The Ancient Continental Margin of Eastern North America

Harold Williams and R. K. Stevens

INTRODUCTION

Continental Margins and the Siting of Orogens

It has long been recognized in North America that orogens represent the sites of ancient continental margins, although the basic concepts have changed greatly from the early views of Hall, Dana, and Schuchert to later ones of Kay, Drake, and Dietz. This North American view stemmed from the fact that on this continent all the Phanerozoic orogens are at or near the present edge of the continent. The doctrine that geosynclines are open toward the ocean (one sided) and that continents grow by the outward addition of younger orogenic belts was popular in North America in the 1950s and early 1960s, and it was enhanced by the interpretation of Paleozoic volcanic belts as island arc complexes (Kay, 1951). The doctrine was further supported by early oceanographic studies of the present Atlantic margin, e.g., Drake et al. (1959), and by the models of [illegible] actual comparisons between ancient and modern continental margins.

These concepts were not popular outside North America, for in many other parts of the world orogens appear to be intracratonic, e.g., the Alps and the Urals. Even in North America there were growing suspicions in some circles that the Appalachian Orogen, North America's type Mountain System, is in fact two sided, and that the [illegible] related Paleozoic [illegible] (Williams, 1964). How then can orogens be former continental margins if they are bounded by older basement and found inside some continental blocks?

Of course there can be no reconciliation of these concepts without accepting some form of continental drift. Wilson (1966) was most instrumental in solving this dilemma when he utilized the theory of continental drift to postulate a proto-Atlantic Ocean that separated the opposite sides and [illegible] Paleozoic [illegible] of the Appalachian [illegible]. Wilson thus suggested continental drift or [illegible] [illegible] with the [illegible] orogens within continental blocks. The concepts of plate tectonics fully [illegible] Wilson's views, so that geosynclines are interpreted now as [illegible] [illegible] and those geosynclines that [illegible] within continental [illegible] sutures where oceans closed and where continents collided. This model not only explains the siting of orogens at continental margins but also provides a mechanism for mountain building through subduction and continental collision.

The conclusion that orogens are a continental margin phenomenon can also be deduced by comparing some special rock assemblages found in them, such as exceptionally coarse [illegible] flysch sequences, calc-alkaline volcanic assemblages, and the ophiolite rock suite, with similar rocks at present continental margins or accreting oceanic ridges. Furthermore, the structural styles developed at young active margins have counterparts in ancient orogens. An understanding of present continental margins is therefore a key to the understanding and delineation of ancient margins. Conversely, an understanding of ancient continental margins, their depositional and structural evolution, and the position and nature of the transition between continental and oceanic crust aids in understanding recent margins. Exactly how then is the ancient continental [illegible] It is not possible to delineate the edge of the continental crust, to restore sedimentary facies during [illegible] phases of the continental margin, and to interpret its structural development during subsequent destructional stages?

Probably the most characteristic overall feature of any ancient continental margin is that it represents a zone where things change. The change may be the presence of crystalline basement rocks on one side of the zone and their absence on the other, or there may be marked facies changes, a lack of stratigraphic continuity between contrasting rock groups, or the zone may represent a marked change in structural style or metamorphic facies. Compounding the difficulties in locating and interpreting ancient continental margins are local problems of structural and metamorphic style and erosional level, for in some cases where the sedimentary record is obliterated or removed, juxtaposed ancient [illegible] may be represented only by a narrow mélange zone that separates contrasting basement complexes.

Definition of the Ancient Continental Margin of Eastern North America

All orogens must necessarily embrace at least one continental margin if, as stated, they originate at continental margins. Some orogens that involve continental collision and repeated opening and closing of ocean basins (Harry Hildreth [illegible] after the wall.

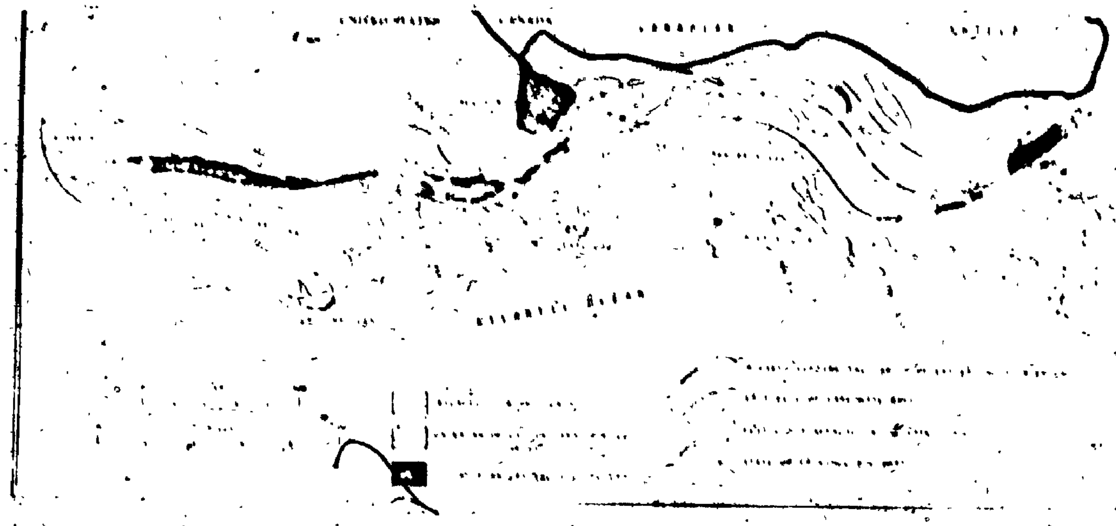


Fig. 1. Salient features of the ancient continental margin of eastern North America.

known Newfoundland, [illegible] may embrace two or more continental margins, all structurally telescoped and [illegible]. It is not enough to say that the early Paleozoic continental margin of eastern North America [illegible] the Appalachian orogen; this is but a half truth, for the Appalachian System contains stratigraphic-tectonic zones in its eastern parts that had no connection with North America during much of their development. Recent views on the development of the Appalachians in the north indicate that at least two margins are represented on opposite sides of the system in Newfoundland, each bordered by a Precambrian crystalline basement, and with the opposing margins separated by a [illegible] sequence of [illegible] and [illegible]. Possibly a third continental margin is represented in Nova Scotia, where the southeasterly derived Meguma Group forms a [illegible] easterly disposed part of the system.

The ancient continental margin of eastern North America is defined as that belt of deformed rocks along the western side of the Appalachian System that was evidently an integral part of North America in the Early Paleozoic. The eastern limit of this [illegible] coincides [illegible] with several significant geologic and geophysical changes, as follows: (1) it is the eastern limit of Precambrian basement [illegible], which in the northeast [illegible] eastward [illegible] at least locally built upon the [illegible] of rock units; (2) it is a zone of thick clastic sedimentary rocks of late Precambrian to Early Cambrian age with associated mafic [illegible] volcanics; (3) it is close to the eastern limit of exposure of the early Paleozoic carbonate sequence that is so well developed along the western border of the Appalachian System; (4) it is a zone of [illegible] contrasts; (5) it is a zone of faulting, contrasting structural style and contrasting metamorphic facies; (6) the zone is broadly coincident with a regional gravity gradient from positive Bouguer anomalies on the ocean side to negative [illegible] continental seismic refraction profiles that reflect deep structural contrasts. The eastern edge of the carbonate bank and the east limit of continental crust are depicted in Figure 1.

The northeastern extension of the same ancient margin is found along the northwest flank of the Caledonides in Ireland and Scotland and along the easterly seaboard of Greenland, and it once continued beyond Spitsbergen. Its southern extension must trend westward along the Ouachita System and continue southwestward to southern Mexico where it is truncated by the present Pacific ocean.

The ancient margin of eastern North America is sharply truncated by the present Atlantic margin in northeast Newfoundland, but throughout the 2,000-mile length of the Appalachian System and westward through the Ouachitas, the ancient and modern margins of eastern North America are essentially parallel. The same parallelism of ancient and modern continental margins is evident in the Caledonides of east Greenland and Scandinavia. Furthermore, the early Paleozoic margin of eastern North America parallels the older Grenville Structural Province. This pattern suggests that the opening of oceans and the establishment of successively younger continental margins is at least partly controlled by zones of weakness within existing orogens.

Purpose and Scope

The purpose of this paper is to summarize the most salient geologic features of the western part of the Appalachian System and to interpret their signif [illegible] and origin in terms of the development of an ancient continental margin. Many of these features have been summarized and interpreted in this way already, especially by Rodgers (1968, 1972), Stevens (1970), Bird and Dewey (1970), Rose and Isachsen (1970), Strong and Williams (1972), Hatcher (1972), Burke and Dewey (1973), Williams et al. (1972, 1974) and several others. The present paper is intended as a general overall appraisal. It is based mainly upon the authors' field experience in the Canadian Appalachians and a review of the literature, but it includes as well first-hand data collected over the past 10 field seasons in western Newfoundland. Attempts are made to extend some of the conclusions drawn in the north to southern parts of the Appalachian System of which the authors have no direct knowledge. These extrapolations are offered only as debatable suggestions in the hope that they will stimulate further work and direct attention toward remaining problems.

CONSTRUCTIONAL FEATURES OF THE ANCIENT CONTINENTAL MARGIN

Some features of the ancient continental margin of eastern North America are recognized all the way along the western side of the Appalachian System, [illegible] separated areas, and still others are confined to certain unique areas. In general, those tectonic, sedimentologic, or igneous features that are associated with continental rifting and the construction of the continental margin are most widely recognized. These are (1) the east limit of crystalline Precambrian inliers that represent easternmost exposures of North American basement; (2) a thick prism of clastic sediments that intervenes between the crystalline basement and an overlying Cambrian and later mainly carbonate succession; (3) mafic extrusions and dike intrusions that are related in space and time to the clastic sequences; and (4) an east-thickening carbonate sequence that overlies the clastic sequences and disappears eastward where rock of equivalent age are lime breccias and shales with interbedded lime breccia units.

Eastern Limit of Crystalline Precambrian Inliers

Precambrian crystalline rocks characterized by isotopic dates of [illegible] appear as basement inliers along the western margin of the Appalachian Orogen. The crystalline rocks clearly represent exposures of the Grenville Structural Province of the nearby Canadian Shield, and in the Appalachians the largest massifs are exposed in uplifted hoists or anticlines, e.g., the Long Range and Indian Head Range of Newfoundland, the Green Mountains of Vermont, the Berkshire Highlands, New Milford and Hudson Highlands massifs from Massachusetts to eastern Pennsylvania, and the Blue Ridge from Maryland through Virginia to North Carolina (Fig. 1).

Most of these Precambrian massifs are faulted along their western boundaries and some have moved westward along east-dipping thrusts, e.g., the Blue Ridge, Berkshire, and Hudson massifs. Grenvillian rocks also occupy the cores of gneiss domes east of the anticlines of transported massifs where they are deformed and retrograded so that in places the basement is difficult to distinguish from the cover sequences. Examples are known in the Burlington Peninsula of Newfoundland, in at least some of the gneiss domes in western New England, in the Baltimore gneiss domes in Maryland, and probably in domes still farther southwest.

These inliers mark the eastern limit of identifiable Grenvillian basement. In Newfoundland, the Burlington domes are bordered to the east by ophiolites of the Baie Verte Lineament and the Betts Cove Complex of Notre Dame Bay. In this northern area, then, the eastern edge of continental basement can be delineated within relatively narrow limits.

The presence of transported ophiolites in Quebec and the occurrence of ophiolite detritus in the easterly derived Normanskill of New York and Martinsburg of Pennsylvania indicate that oceanic crust and mantle lay to the east of these southern areas as well.

Farther south in the Appalachian Piedmont, the eastern edge of the ancient North American continent [illegible]. However, this former continental margin probably lies to the west of the Carolina Slate Belt, because the late Precambrian rocks and a local occurrence of fossiliferous Cambrian rocks in that belt correlate best with the Avalon Zone that lay on the eastern side of the proto-Atlantic in the Northern Appalachians (Williams et al., 1972, 1974). If there is no suture between the Blue Ridge and Carolina Slate Belt, the opening of the system in the north is but a local phenomenon (Cholestof and Eady, 1972). Yet the western margin of the Appalachian System is similar throughout, which implies that if it evolved as a continental margin bordered by an ocean in the north, it was probably bordered by an ocean in the south as well.

Clastic Sequences at the Ancient Continental Margin

Thick clastic sequences that postdate the metamorphism and intrusion of the billion year old Grenville rocks overlie the crystalline inliers along the western margin of the Appalachians with profound unconformity. The oldest of these clastic cover rocks increase in age from Upper Cambrian in the west to Late Precambrian in the east, for in the east, upper parts of the thick clastic successions are locally dated as Lower Cambrian. The clastic rocks now exhibit a pronounced metamorphic gradient across strike from little deformed and metamorphosed in the west to multideformed rocks of greenschist or amphibolite metamorphic facies in the east.

The rocks are of variable thickness both across and along strike. The thickest successions occur in the [illegible] foremost and now more [illegible] exposed parts of the sequences (e.g. [illegible] Supergroup (30,000 ft) in Newfoundland, [illegible] and Caldwell Groups of Quebec, [illegible] Group (4,000 ft) and [illegible] Formations of Vermont, [illegible] Series of Maryland, [illegible] Formation (10,000 ft) of Virginia, [illegible] (25,000 ft) in the Great Smoky Mountains of eastern Tennessee and northern Georgia). Other [illegible] sequences are found in [illegible] of [illegible] Newfoundland (Maiden Point and [illegible] Formations), Quebec ([illegible] Group), and New York ([illegible] Formation).

[illegible] clastic rocks are mostly quartzites in the upper part of the sequences or [illegible] exposures [illegible] the sequences are thin (e.g. Bradore [illegible] and [illegible] Formations of Newfoundland, Potsdam Formation, New York, [illegible] Quartzite (1,000 ft) of Vermont, and Chilhowee Group of Virginia). These are well sorted with well-rounded grains and thin [illegible] are common and the sediment [illegible] water deposits in [illegible] low relief.

Where thick, the clastic sequences are monotonous and poorly sorted with conglomerate, graywacke, siltstone, shale, feldspathic sandstone and arkose; [illegible] graded beds are common. [illegible] Blue quartz [illegible] the [illegible] Grenvillian [illegible] metamorphic rocks [illegible] places. Many of these rocks are interpreted as typical [illegible] deposited in deep water.

The [illegible] of the late Precambrian sequences from [illegible] east to west [illegible] with sediment accumulation in deep water at the onset of deposition followed by gradual erosion and infilling of the depositional troughs, concluding with the deposition of Lower Cambrian mature beach sands.

The surface onto which the Cambrian seas transgressed cannot everywhere be described as a peneplain, for there is considerable local relief (Ambrose, 1964). Since an Early Paleozoic marine transgression is a worldwide phenomenon and most likely the result of a prolonged eustatic rise in sea level (Russell, 1968; Hallam and Hayes, 1973), it is difficult to separate the local tectonic and regional eustatic influences on sedimentation during this early development of the ancient continental margin.

A lack of directional features in the lower clastic units precludes accurate paleo basin analyses, but where such studies have been made in the higher quartzitic parts of the sequences, currents are from the west, locally with addition of components along the trend of the depositional trough (e.g. Chilhowee Group of Virginia and Tennessee (Brown, 1970); Weverton Formation in Maryland (Whitaker, 1955)).

The distribution, thickness variation, provenance and directional features all indicate that the clastic sedimentary sequences were deposited in a continuous, although irregular, trough that can be [illegible]. The sediments were derived from the Grenvillian basement and transported eastward toward the ocean, probably with local redistribution by bottom contour currents and longshore currents. The rough coincidence of the regional belt of clastic rocks with the foremost exposures of Precambrian basement (Fig. 1) strongly suggests this model, and locally where the clastics are followed eastward by well-defined ophiolite sequences, a continental margin is demanded. Comparisons between the sedimentary records at the modern and restored ancient margins of eastern North America (Fig. 2) further support this interpretation.

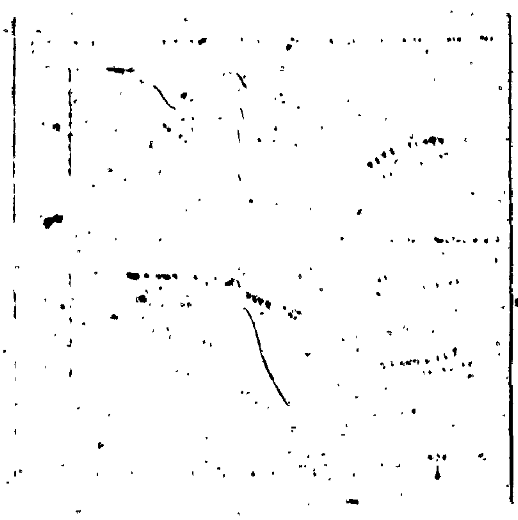


Fig. [illegible] Comparison showing the sedimentary records at the modern and restored ancient margins of eastern North America.

Mafic Volcanism and Dike Intrusion at the Ancient Continental Margin

Volcanic rocks and mafic dikes are intimately associated with late Precambrian to Early Cambrian clastic sequences along the western border of the Appalachians. In the extreme northeast, mafic flows of the Lighthouse Cove Formation (500 ft) are fed by a ramifying network of mafic dikes that cut the Grenvillian basement in Newfoundland. A bimodal volcanic assemblage occurs in the Blue Ridge of Virginia, where the much thicker Catoctin Formation (2,000-12,000 ft) overlies Precambrian basement or is interlayered with clastic sedimentary rocks. Probable correlatives of these volcanics are the mafic pyroclastics and flows of the transported Maiden Point Formation in Newfoundland, the Tibbit Hill Volcanics of Quebec, the volcanic rocks of the Bull Formation in the transported Taconic sequence of New York, and the Mount Rogers volcanics of southwest Virginia.

The volcanic rocks are chiefly mafic flows in Newfoundland with well developed columnar structures and local amygdules. The Catoctin Formation includes rhyolite flows and ignimbrites. All these rocks are altered in the greenschist facies in the southern example. A lack of pillow structures suggests that most are terrestrial, particularly in western exposures. Others are marine, as they include pillow lavas interlayered with deep water graywackes, e.g., Maiden Point Formation.

Locally in Newfoundland the mafic flows are separated from Grenvillian basement in eastern exposures by a thick quartzite conglomerate unit (Bateau Formation). The Bateau is cut by vertical mafic dikes that feed subhorizontal flows, and variable attitudes of the quartzite conglomerate beds compared with consistently vertical attitudes of mafic dikes indicate tilting of the sediments in fault blocks either before or during mafic dike intrusion (Bostock, 19[illegible]).

The mafic volcanic rocks of the Lighthouse Cove and Catoctin Formations are tholeiitic basalts of similar petrochemical characteristics, and all are chemically similar to coeval mafic dikes. Mafic volcanic rocks of the Maiden Point Formation in northern Newfoundland, although lithologically distinct, are chemically similar to the Lighthouse Cove Formation [illegible].

Strong and Williams (1972) interpreted the Lighthouse Cove Formation, and by analogy the Catoctin Formation, as plateau volcanics formed in an environment of continental rifting, distension and separation. This interpretation is based mainly on the tholeiitic nature of the volcanic rocks, which resemble tholeiites so widely distributed at continental margins along which substantial crustal separation has taken place, e.g., Karroo basalts of East Africa, Deccan traps of India, Ferrar dolerites of Antarctica, Serra Geral lavas of Brazil, and Tertiary basalts of west Greenland. In contrast, alkaline volcanic rocks characterize rifted zones within continental blocks that have not undergone extensive separation, e.g., east African rifts, Benue trough, and the Scottish Midland Valley.

This interpretation of the volcanic rocks fits well with that of the clastic sedimentary rocks with which the volcanics are interlayered. The age of the volcanics further indicates the time of continental rifting.

Zircons from the Catoctin Formation and related rocks yield an age of 820 m.y. (Rankin et al., 19[illegible]). The Newfoundland examples have yielded a wide range of potassium-argon ages, but recent determinations of 805 m.y. for dikes that are possibly related to the Lighthouse Cove Formation (Pringle et al., 1971) suggest correlation with the Catoctin Formation.

These ages are embarrassingly old for volcanic rocks that form basal parts of continuous stratigraphic sections that include fossiliferous Cambrian beds. Furthermore, they imply the existence of a continental margin shortly following the completion of the latest orogenic events in the Grenville Structural Province. They therefore present the problem of establishing a continental terrace wedge in the Early Cambrian 200 million years after the first indications of rifting.

Recent ^{40}Ar-^{39}Ar age determinations of 600 m.y. for the Lighthouse Cove Formation, and the recognition of excess argon in all specimens studied, imply that in Newfoundland the rifting was initiated probably in latest Precambrian time (Peter Reynolds and Vidas Stukas, personal communication, 1974). Similarly, ^{40}Ar-^{39}Ar studies of basement gneisses in the Central Blue Ridge indicate a long cooling history before the deposition of unconformable cover sequences, so that a more favorable age for the Catoctin Formation is 650-700 m.y. (R. D. Dallmeyer, personal communication, 1974).

A supporting age for the time of initial rifting and continental separation is provided by carbonatites and lamprophyres in widely separated areas along the St. Lawrence River and Labrador coast that are isotopically dated at 565 m.y. (Doig, 1970). These North American examples have been correlated with alkaline intrusions of similar age in coastal Greenland and Scandinavia, and all have been interpreted as the result of rifting during initiation of the proto-Atlantic (Doig, 1970). The St. Lawrence occurrences mark the failed arm of a triple rift junction (Burke and Dewey, 1973), and the persistent alkaline [illegible] to a subsequent abortive attempt toward separation during the opening of the present Atlantic Ocean.

Geophysical Changes Across the Ancient Continental Margin

The deformed and metamorphosed parts of the Appalachians are underlain in most places by a thick, dense, presumably mafic crust, whereas the western, less deformed zone is underlain by continental crust comparable to that of the nearby Canadian Shield (Ewing et al., 1966; Dainty et al., 1966; Sheridan and Drake, 1968). The change between the two types of crust roughly corresponds with a pronounced gravity gradient (King, 1964) on which local gravity highs are superposed (Innes and Argun-Weston, 1967). The gravity highs are interpreted as mafic or ultramafic intrusions within the continental crust (Diment, 1953; Fitzpatrick, 1953). These hypothetical intrusions are presumably deep seated and associated with mafic volcanism controlled by initial rifting. The presence of mafic intrusions and ramifying dike swarms at or near the ancient continental edge might explain the difficulty in the seismic delineation of the boundary between continental and oceanic crust at present continental margins.

Carbonate Bank at the Ancient Continental Margin

A thick sequence of carbonate rocks that ranges in age from Early Cambrian to Middle Ordovician occurs in most places along the western side of the

Appalachians from Newfoundland to Alabama. Its lithology, thickness, and relationships have been well documented by Rodgers (1968), and only its main features are summarized here. The rocks are best exposed in the Valley and Ridge Province of the south, in the Hudson and Champlain valleys in central parts of the system, and in western Newfoundland in the north. Their absence or nonexposure in the Quebec City-Gaspe segment of the system may be partly because of erosion, although the carbonate sequence may be hidden by overlying transported rocks south of the St. Lawrence River. The sequence thins rapidly to the west of the deformed Appalachian belt and thickens eastward from 1,000 to 10,000 ft across its exposures in the deformed zone.

The carbonate sequence rests conformably above Cambrian clastic rocks, and its Middle Ordovician top grades upward and eastward into black graptolite shales overlain in turn by westward transgressive clastic wedges. In most places an erosional disconformity is recorded at the Lower Ordovician-Middle Ordovician contact, but the Ordovician-Cambrian boundary is not marked by a lithological or structural break.

Algal mounds, desiccation cracks, and local [illegible] ding in interlayered mature sands all indicate that the carbonate rocks accumulated in shallow water. Cloud and Barnes (1948) and Rodgers (1968) suggested that the carbonates formed on a bank not unlike the present Great Bahama Bank. Cambrian shallow-water carbonates pass westward into shales, sandstones, and conglomerates, and within the bank there seems to have been a central zone of dolomite flanked by limestones at the inner and outer bank margins (Palmer, 1971). The thickness of the carbonates across the western Appalachians indicate that the continental margin subsided much more rapidly in the east, although shallow water conditions were also maintained there.

Rodgers (1968) delineated the eastern edge of the carbonate bank and interpreted it as an abrupt declivity like the margin of the present Bahama Bank. He explains the marked facies change and the lack of interfingering between eastern exposures of the carbonate sequence and clastic sediments or volcanic rocks farther east in the Appalachians. Possibly the bank edge outcrops as an abrupt lithological boundary in northwestern Vermont and in Lancaster County, Pennsylvania (Rodgers, 1968), but in most places the eastern exposures of the carbonates are in a zone of metamorphism and thrusting so that original relationships are obscured.

Transported sequences in the western Appalachians that originated east of the bank but that now structurally overlie the carbonates exhibit Middle Cambrian to Lower Ordovician shales with limestone breccia units that most likely built up off-shore just beyond the bank edge. The spectacularly coarse limestone breccias of the Cow Head Group in western Newfoundland form part of a thin (1,000 ft)

condensed sequence that spans the same interval as the carbonate sequence. Thinner, finer, and shalier units of the same age within the transported Humber Arm Supergroup (Cooks Brook Formation) are interpreted as sediments formed in deeper water and away from the bank edge. Similar lime breccias and shales are known in transported sequences in Quebec, in the Taconic sequence of Vermont and eastern New York, and in the Hamburg klippe of Pennsylvania.

Rodgers (1968) pointed out that the eastern edge of the carbonate bank closely follows the locus of Precambrian inliers along the western margin of the Appalachians, so the edge of the carbonate bank may itself have been localized by the original eastern extent of Grenvillian basement. Rodgers also suggested that the drop-off from bank to deep water approximates the ancient edge of the North American continent. However, the bank is slightly west of the easternmost exposures of Grenvillian basement in gneiss domes, and the clastic sequences previously described extend well east of the bank edge, where they are still underlain in most places by continental crust. We therefore delineate the continental edge as somewhat east of the bank edge (Fig. 1).

Most graphic attempts to reconstruct a continen [illegible] Ocean assume that the continental margins coincide with the drop-off from shallow to deep water, or the 1,000 ft bathymetric contour. There is no assurance, however, that the present continental margins exactly match this morphological feature, and comparison with the ancient margin of eastern North America suggests that continental crust extends seaward beyond the continental slope. A lack of coincidence between the continental slope and the limit of continental crust like that in the ancient example may explain apparent gaps and overlaps in present continental reconstructions (e.g., Bullard et al., 1965).

Faunal Changes at the Ancient Continental Margin

The most prominent faunal change at the Lower Paleozoic continental margin is the change from shelly faunas of the carbonate bank to offshore graptolite and related faunas of the shale, turbidite, and volcanic sequences. During Cambrian time, two faunal realms were concentric around North America: the cratonic realm and the extracratonic intermediate realm (Lochman-Balk and Wilson, 1958). These are correlated with a restricted shelf sea and a shelf margin open ocean environment, respectively (Palmer, 1971).

More subtle changes involve provincialism across the bank itself. The Whiterock genera of brachiopods and trilobites, referred to the Toquima-Table Head faunal Realm, are allied environmentally to the continental shelf or slope so that they were interpreted to mark a transitional bank edge facies (Ross and Ingham, 1970). The Table Head Formation of Newfoundland, however, overlies Lower Ordovi cian shallow water carbonates with erosional disconformity across the former bank and conglomerates in its upper part are overlain by graptolite bearing shales and graywackes. This formation therefore more likely represents a facies that migrated westward across a subsiding bank during early stages of Taconic orogeny. The Middle Ordovician Toquima-Table Head Faunal Realm in Newfoundland seems to represent the tectonically disturbed migrating bank edge rather than the traditional offshore stable bank edge that existed from Cambrian to Early Ordovician. In fact, the stable bank edge facies is difficult to locate, although it appears to have been the main source for fossiliferous blocks in bank foot breccias such as the Cow Head (Stevens, 1970). Possibly it is represented in Lancaster County, Pennsylvania, and in northwestern Vermont.

Epstein et al. (1972) suggested that limestone slide blocks in the Hamburg klippe of Pennsylvania, which contain a North Atlantic province conodont fauna, originated at a northwest facing bank that was far removed from the ancient margin of eastern North America. However, the Cow Head Group and the Table Head Formation of Newfoundland both contain a distinctive North Atlantic conodont assemblage (J. Fåhraeus, personal communication, 1974) which, like the Whiterock genera, seems to be an environmentally controlled continental margin assemblage. This removes the basis for suggesting that contrasting faunas in Pennsylvania imply distant transport.

DESTRUCTION OF THE ANCIENT CONTINENTAL MARGIN: TACONIC OROGENY

The events that led to the destruction of the continental margin are those that are attributed to Taconic orogeny (Rodgers, 1971). The earliest movements are recorded in the east and at the edge of the continental margin. Regional metamorphism that accompanied ophiolite obduction predated the emplacement of allochthonous sequences upon the carbonate bank. Certain of the allochthonous masses have early west facing recumbent folds that relate to the displacement of the sequences. Flysch wedges progressed across the carbonate bank as forerunners of the allochthons and locally autochthonous rocks in upper parts of the stratigraphic sequences display recumbent folds that resulted from invading beneath the structurally overriding slices. Following klippe emplacement the rocks were further telescoped by westward thrusting accompanied by penetrative deformation and this event locally involved the crystalline Precambrian basement.

Clastic Wedges

The first intimation of Taconic orogeny and destruction of the continental margin is the pre Middle Ordovician unconformity and the appearance of black shales and then siltstones and graywackes above the carbonates. The pre Middle Ordovician unconformity reflects uplift and warping of the shelf that resulted in a regional break in sedimentation along the entire western side of the Appalachian System. In Newfoundland the carbonate bank probably rose as much as 300 ft locally with the development of a karst topography (Collins and Smith, 1972). In New England the uplift was irregular and apparently reflects the formation of a horst and graben topography. Residual iron deposits locally occur at the top of the carbonate succession there, and erosion has cut down to the Precambrian basement in some horsts. In nearby grabens continuous sections are preserved (Zen, 1968). Following fragmentation the bank subsided rapidly so that deeper water facies migrated landward in response to its collapse. The amount of subsidence is difficult to estimate, but where transported rocks above the carbonate bank in Newfoundland are unconformably overlain by Middle Ordovician shallow water carbonates the subsidence may have been as much as the total structural thickness of the allochthon. This implies that the former bank sank to oceanic depths.

Contemporaneous with the breakup and collapse of the bank flysch wedges were built out from tectonic lands in the east. These are first recognized in the Lower Ordovician parts of transported sequences in western Newfoundland and transgress westward across the Cow Head breccias. Farther west they are of early Middle Ordovician age where they overlie the carbonate bank sequence. Elsewhere in the western Appalachians there are significant time differences in the first appearance of flysch. In Quebec the Cloridorme Formation is mainly of late Middle Ordovician age, and in New York and Pennsylvania the Normanskill and Martinsburg clastics are of comparable age (Trenton).

The flysch wedges vary greatly in thickness and may exceed 10,000 ft in Pennsylvania. Thicknesses decrease westward where the graywackes grade out into shaley beds. Paleocurrent analyses show that the sediments were derived from sources that lay generally to the east, although longitudinal transport directions are common (McBride, 1962; Stevens, 1970; Enos, 1969). The provenance seems to be much the same for all the flysch wedges: sedimentary rocks of the continental margin, Precambrian basement, mafic volcanic rocks, and possibly Paleozoic intrusive rocks. Chromite grains and serpentine fragments are locally common, suggesting that ophiolites had already been obducted onto the continental margin and had been uplifted above sea level. A few occurrences of shallow water limestone clasts even in the earliest flysch suggest that the tectonic lands that supplied detritus were ringed by local carbonate banks. In Newfoundland the flysch becomes coarser upward, probably reflecting the gradual encroachment of the Humber Arm allochthon. Similarly, in New York progressively larger pieces of the Taconic sequence slid into the sedi-

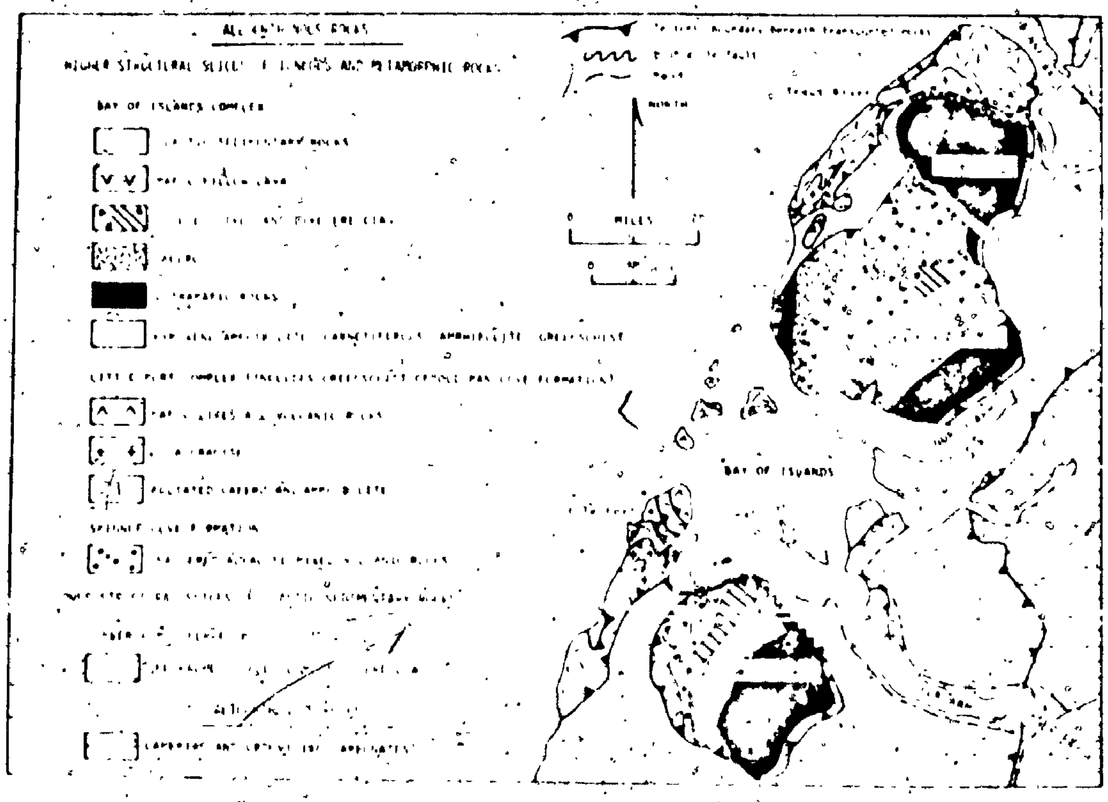


Fig. 3 Geology of part of the Humber Arm Allochthon, western Newfoundland.

mentary basin during Trenton time, thus heralding the impending emplacement of the Taconic allochthon (Zen, 1968).

Emplacement of Allochthons

Transported Cambrian-Ordovician clastic sequences that comprise the lowest structural slices above the autochthonous flysch wedges and carbonate bank represent large undigested masses embedded in the flysch wedges, e.g., parts of the Hare Bay and Humber Arm allochthons (Fig. 3) of western Newfoundland, parts of the Taconic allochthon of Vermont and east New York, the Hamburg klippe of Pennsylvania, and a large area of transported rocks between Quebec City and Gaspé Peninsula that is probably more extensive than all the others combined (Fig. 1). The transported clastic sequences, such as the Humber Arm sequence of western Newfoundland and the Taconic sequence of New York, have been interpreted as continental margin deposits. Lower clastic units that contain detritus from the crystalline basement were derived from the west; overlying condensed shale and lime breccia units reflect the development of the carbonate bank; and upper clastic units signal uplift and instability toward the east that eventually resulted in the transport of the sequences.

Ophiolite suites that are interpreted as oceanic crust and mantle overlie the transported clastic sequences. The clearest examples are found in Hare Bay and Bay of Islands in western Newfoundland and the Thetford Mines serpentinite belt of Quebec. Other examples may be represented at Mount Albert of Gaspé Peninsula and possibly the Baltimore Gabbro in Maryland (Crowley, 1969; Ina Alterman, personal communication, 1973). It is not yet clear whether or not these transported ophiolites originated in a series of small marginal ocean basins (Dewey and Bird, 1971; Kennedy, 1973) or else represent the crust of a major ocean comparable in size to the present Atlantic (Church and Stevens, 1971). The continuity of the margin and similarities throughout its length seem to favor a uniform major ocean rather than a chain of small ocean basins with expectable regional irregularities.

In the Bay of Islands area of western Newfoundland the ophiolite slice is locally underlain by foliated gabbros, amphibolites, mafic dikes, and volcanic rocks (Little Port slice assemblage; Williams, 1973) that in turn are underlain by a distinctive unaltered alkaline volcanic suite (Skinner Cove slice assemblage, Strong, in press) (Fig. 4). Toward the north at Hare Bay, mafic pillow lavas (Cape Onion Slice), undated polymictic conglomerates and sandy limestones (Grandois slice), and a mega mélange which has huge recycled volcanic and rodingitized amphibolite and gabbro blocks now in a black shale matrix (Milan Arm Melange), all intervene between lower structural slices of clastic sediments and the overlying ophiolite slice. These assemblages and their structural stacking orders serve to indicate the variety of rocks that must have lain at or near the continental margin before Ordovician transport.

Among the lower structural slices of clastic sedimentary rocks the lowest slices contain the youngest parts of the stratigraphic sections. In New York and Vermont, the two lowest slices are underlain by wildflysch type conglomerate whose matrix is marine black shale and whose fragments are dominantly rocks of the Taconic sequence. This suggests that the lower slices were emplaced in a marine environment, probably as a moving archipelago, and that the final emplacement was a near-surface gravity-sliding phenomenon. Fossils in the matrix of the wildflysch type conglomerate date the emplacement of these slices to the [illegible] var. intermedius zone (Zen, 1967). In Newfoundland the lower structural slices are unconformably overlain by the Middle Ordovician neoautochthonous Long Point Formation (Rodgers, 1965), which grades downward into autochthonous flysch at the western leading edge of the allochthon. It is older than upper parts of the Taconic sequence in New York, indicating that the Newfoundland clastic slices were emplaced earlier than their New York analogues.

The youngest transported rocks in the Taconic allochthon of New York (Pawlet Formation) are equivalent to the youngest rocks of the underlying autochthonous flysch. In the allochthon, the Pawlet rests unconformably on rocks of various ages. This unconformity is interpreted to reflect the beginning of the movements that led to gravity sliding, and conceivably the Pawlet Formation was deposited partly on a moving substrate and partly after the allochthon had come to rest (Zen, 1968). Soft rock deformation accompanied the emplacement of these lowest structural slices.

Recumbent folding and penetrative deformation characterize only the upper parts of the autochthonous sequences where they were locally overridden by more rigid higher structural slices, e.g., Canada Bay, Newfoundland.

All the transported rock groups of western Newfoundland, regardless of lithology or structural position in the stacking order, are underlain by thin zones of shaly mélange with sedimentary, volcanic, and plutonic exotic blocks. The Newfoundland mélanges are in most respects similar to the wildflysch-type conglomerates of New York, and they are interpreted as formed during the later stages of transport when the structural slices (including the ophiolite) moved across a shaly sedimentary terrane by gravity sliding. The mélanges are thought to represent the combined effects of surficial mass wastage (Bruckner, 1966) and tectonic mixing (Stevens, 1965) at the soles of the advancing slices. The local occurrence of large serpentinite, gabbro, diorite, and volcanic blocks within even the lower mélanges that separate sedimentary rock slices clearly attests to the proximity of the ophiolite slice during formation of the mélanges. This implies that in Newfoundland the lowermost mélange zones are the surfaces of latest movement and that the transported rocks were emplaced along them as an already assembled allochthon. The ophiolite slice, now the structurally highest, is interpreted as the first to have moved.

New fossil discoveries in western Newfoundland indicate that the volcanic rocks in at least two of the higher structural slices (Skinner Cove and Cape Onion) are Lower Ordovician and therefore equivalent to parts of the transported clastic sequences in lower structural slices (Williams, 1971; A. Berger, personal communication, 1973). Determination of the order of structural stacking combined with facies considerations indicate that the structurally highest slices are the farthest traveled, i.e., the on-land [illegible] lay most easterly at the time of their formation. If the occurrence of ultramafic debris in the flysch within sedimentary slices of the Humber Arm allochthon can be taken as evidence that the Bay of Islands ophiolite slice was moving during flysch deposition, then the assembly and transport of the slices progressed from east to west, and it was a relatively slow process that extended over about five graptolite zones. The geology of part of the Humber Arm

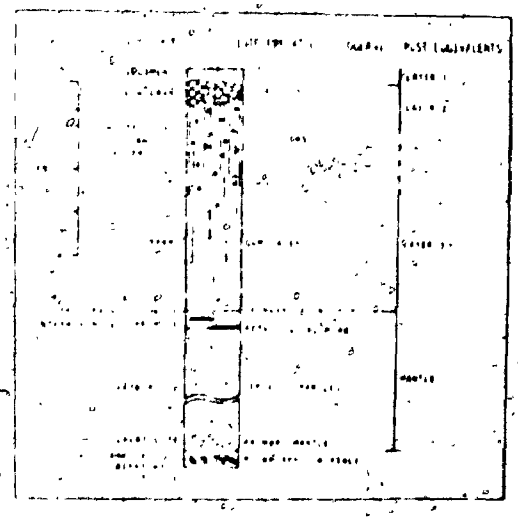


Fig. 4. Interpretation of the Bay of Islands Complex as oceanic crust and mantle

allochthons is summarized in Figure 3, and a restored section of the Bay of Islands ophiolite complex and its interpretation as oceanic crust and mantle is depicted in Figure 4.

Displacement of Allochthons

In western Newfoundland the ophiolites are underlain by thin (1000 ft) metamorphic aureoles that are interpreted as the result of initial uprooting and earliest transport. The aureoles parallel the stratigraphic base of the ophiolite complexes and the rocks exhibit decreasing metamorphic grade and decreasing intensity in subhorizontal schistosities downward from the stratigraphic base of the ultramafic rocks. Williams and Smyth (1973) suggested that the aureole rocks represent volcanic rocks and graywackes like those of the Maiden Point Formation and, as that formation originally lay at the edge of the continent, the aureoles must result from the obduction of hot ophiolite across the continental margin. The contacts between the aureoles and ultramafic rocks, which represent the level of earliest transport of the ophiolite [illegible] zones in the [illegible] Islands area that are truncated by the present subhorizontal structural bases of the ophiolite slices. The absence of metamorphism and penetrative fabrics like those in the aureoles in sedimentary rocks of lower structural slices supports the interpretation that the aureoles formed during the earliest and most intense deformation that occurred farthest east, and that this event predated gravity sliding. This conclusion is also supported by the occurrence of schistose aureole blocks in shaly melange beneath some of the ophiolite slices. Initial obduction can be regarded as the subduction of the continental margin beneath oceanic lithosphere.

The direction of sheeted dikes within the ophiolite complexes should roughly parallel the direction of the oceanic ridge at which the ophiolites originated. This direction is expectedly northeast, as the Appalachian System and ancient continental margin trend in that general direction. The best examples of sheeted dikes in the Bay of Islands Complex (Williams and Malpas, 1972), however, trend northwest and suggest that either the ophiolites were rotated during transport or else they represent oceanic crust that was stripped normal to the direction of the continental margin. Studies are presently in progress to ascertain the direction of ophiolite transport as indicated by the facing direction of early recumbent folds in the aureole rocks with respect to both the direction of sheeted dikes in the same structural slices and the direction of the ancient continental margin.

In most respects the tectonic setting of the transported ophiolites in western Newfoundland is similar to that of the Semail ophiolite nappe in the Oman Mountains of the Persian Gulf (Glennie et al., 1974). In both areas the ophiolite sequences form the highest structural slices and they were transported soon after their formation, during the Ordovician in the northern Appalachians and during the Cretaceous in the Oman.

Regional metamorphism and polyphase deformation, which affected eastern parts of the late Precambrian clastic sequences that were marginal to the continent, e.g., Fleur de Lys Supergroup in Newfoundland, are either related to earliest ophiolite obduction or else to the closing of a small ocean basin at the continental margin (Kennedy, 1974). The transported Maiden Point Formation, which is at least partly equivalent to the Fleur de Lys Supergroup, displays west-facing recumbent folds that predate its Middle Ordovician emplacement.

Postemplacement Deformation

Thrusting and the local development of penetrative cleavage are later events that affected the already emplaced allochthons. At Beacraft Mountain in New York, Silurian rocks unconformably overlie deformed Taconic sequence rocks that were uncleaved at the time of their arrival, as inferred from the fact that shale blocks in wildflysch type conglom[illegible] strike in western Newfoundland, autochthonous Cambrian and Ordovician rocks were deformed penetratively before the deposition of Silurian beds at White Bay (Lock, 1969). Locally at Canada Bay in Newfoundland, prograde greenschist metamorphism was developed in autochthonous rocks (Sugarloaf Schist) and thrust faulting and cataclasis affected basement rocks that occur in thrust slices among the Paleozoic successions (Smyth, 1973).

The close of Taconic orogeny marked an end to the major developmental stage of the ancient continental margin, for the margin was now transformed from a rifted zone of active deposition to a relatively stable deformed zone. Parts of the deformed margin in the Northern Appalachians were affected only slightly by later orogenic events, although Acadian (Devonian) deformation is recognized in most northern localities. The proto-Atlantic was virtually closed in Newfoundland during the Middle Ordovician, as Late Ordovician and Silurian rocks there record a change from deep water marine to terrestrial conditions (Williams, 1967). Farther south in New Brunswick and New England, Silurian land masses and shelf areas bordered the northeast-trending Fredericton Trough (McKerrow and Ziegler, 1971), which possibly represented a much-contracted proto-Atlantic Ocean.

Acadian orogeny represents shortening and lateral compression that probably resulted from continued closing and tightening of the already contracted proto-Atlantic Ocean. Where intense along the western margin of the Appalachians, it may be the result of the restoration of gravitational stability after the obduction of dense ophiolite sheets in a way similar to that demonstrated by Ramberg (1967) in centrifuge experiments.

Paleomagnetic evidence suggests that the proto-

Atlantic closed during the Taconic orogeny in the Northern Appalachians, but that it was not finally destroyed farther south until Permo-Carboniferous time (Alleghanian deformation), when Africa collided with North America (Smith et al., 1973). This does not imply that earlier orogenic episodes did not affect this southern area.

VOLCANIC ISLAND COMPLEXES AND SUBDUCTION EAST OF THE ANCIENT MARGIN

Early to Middle Ordovician volcanic rocks abound to the east of the ancient continental margin. Examples are known all the way from northeastern Newfoundland southward through central New Brunswick and northern Maine to Vermont and probably Connecticut. Many of these volcanic sequences, such as the Snooks Arm and Lushs Bight Groups of northeast Newfoundland, are much too thick to correspond to oceanic crustal layer 2, although some of them are clearly built upon an ophiolite suite. At Long Island of north-central Newfoundland a sequence of predominantly volcanic rocks in excess of 45,000 ft shows a lithological evolution from lowermost mafic dikes, gabbros and pillow lavas upward through deep-water cherts and turbidites into pyroclastic rocks and volcaniclastic sedimentary rocks capped by limestone and subaerial tuffs. The overall deep to shallow water lithic change is accompanied by geochemical changes in the volcanic rocks from low potassium tholeiites at the base to calc-alkaline low-silica andesites toward the top that show progressive enrichment in Al_2O_3 and K_2O and a decrease in CaO and MgO (Kean and Strong, in press). Other nearby volcanic sequences of comparable age, e.g., Mortons Harbour Group (Strong and Payne, 1973) and Roberts Arm Group (Strong, 1973a), show similar lithological and geochemical features, and all are interpreted as ancient analogues of modern island arcs.

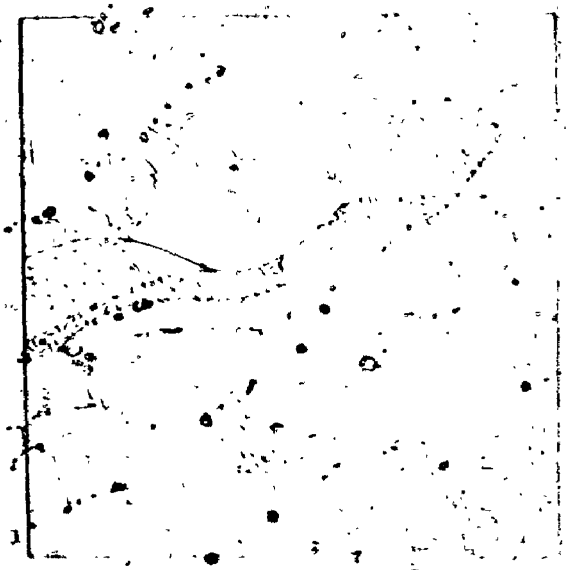
Calc-alkaline volcanic accumulations decrease in thickness from east to west across the successive ophiolite belts in northeast Newfoundland, from thicknesses of about 20,000 ft in Notre Dame Bay to only a few thousand feet at the Baie Verte Lineament to a virtual absence of calc-alkaline volcanic products atop the westward transported Bay of Islands Complex. The age of the volcanic rocks in northeastern Newfoundland indicates that the island arcs were growing east of the continental margin during emplacement of the west Newfoundland allochthons and furthermore that the evolution of the volcanic islands ceased at the time of final emplacement of the allochthons.

This decrease in calc-alkaline volcanic activity toward the ancient continental margin of eastern North America, coupled with the age of the volcanic rocks and the time of ophiolite obduction, suggests that any subduction zone that existed at the ancient continental margin during this period dipped eastward, at least in Newfoundland. Although contrary to most recent models (e.g., Dewey, 1969; Bird and Dewey, 1970; Dewey and Bird, 1971; Hatcher, 1972; Kennedy, 1973), eastward subduction during the Early and Middle Ordovician would explain the general lack of Ordovician volcanism and intrusion west of the ancient margin and at the same time provide a plausible mechanism for ophiolite obduction, for the structural stacking order of all the transported rocks in western Newfoundland, and for their mode of final emplacement as an already assembled allochthon. Other features that appear to indicate eastward subduction are as follows: (1) a gradual K_2O increase in granitic rocks from central to eastern Newfoundland (Strong et al., 1974); (2) the zonation of mineral deposits throughout the Appalachian System (Strong, 1973b); (3) the petrochemistry of early Paleozoic volcanic rocks southward across Appalachian correlatives in the British Caledonides, which show variation from oceanic to island arc and continental types (Fitton and Hughes, 1970); and (4) seismic-refraction profiles conducted along marine passages through the Appalachians in the north, which show that interfaces between levels of contrasting velocity are consistently inclined southeastward down to the 12-km limit of penetration [illegible] tion that even such fundamental aspects of the ancient margin as polarity and exact position of a subduction zone are difficult to determine in the Appalachians.

OTHER ANCIENT CONTINENTAL MARGINS AND THE DEFINITION OF THE APPALACHIAN GEOSYNCLINE

At least two other geologically distinct areas, interpreted as ancient continental margins, are recognized in the northern Appalachians of Newfoundland and Nova Scotia (Fig. 5).

East of the volcanic-ophiolite terrane of central Newfoundland, an undated crystalline basement complex is overlain by an areally extensive multideformed clastic sequence that displays a structural style and metamorphic facies similar to that of the late Precambrian-Cambrian clastic rocks along the ancient eastern margin of North America to the west. Second phase isoclines in the metamorphosed clastic sequence face southeast toward the opposing foreland, and this deformation predated nearby Middle Ordovician graywackes that contain fragments of the metamorphic rocks (Kennedy and McGonigal, 1972). The western boundary of this zone is locally marked by a shaly mélange that includes volcanic blocks and large blocks of predeformed metamorphic rocks. The western boundary is also marked by a belt of discontinuous mafic-ultramafic complexes and volcanic rocks along the Gander River that either represent dismembered ophiolite or diapiric intrusions (Kean, 1974). Possi-



more subjective. The [illegible] exists as ally in the northern Appalachians [illegible] west Newfoundland and it may exist [illegible] of the [illegible] and in other parts of the system.

[illegible] western Newfoundland [illegible] they form the eastern and western [illegible] of the central [illegible] The eastern [illegible] Cape Ray [illegible] The [illegible] Newfoundland [illegible] Cape Ray [illegible] Cape Breton Islands [illegible] Cape Ray [illegible]

[illegible] North America [illegible] Ridge Province [illegible]

CONCLUDING REMARKS

[illegible]

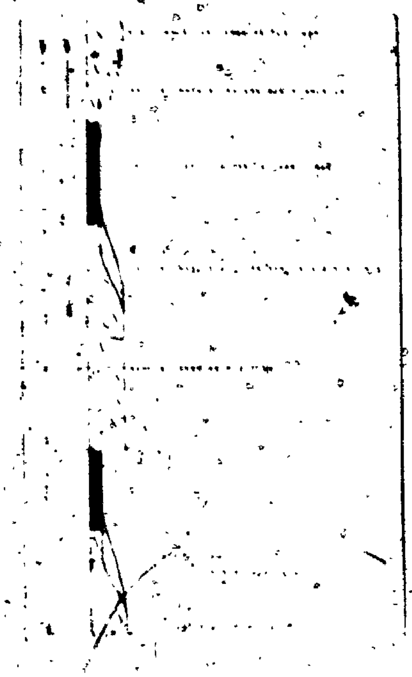


Fig. [illegible] [illegible] of the northern Appalachians [illegible] of the [illegible] of the Appalachian [illegible]

[illegible] has greatly influenced our thinking on such [illegible] the [illegible] and the [illegible] of continents and ocean basins. [illegible] continental [illegible] ocean basins [illegible]

SUMMARY

The [illegible] continental margin of eastern North America is represented by a zone of partially [illegible] along the western [illegible] of the Appalachian [illegible]. The margin was [illegible] sedimentation and [illegible] in the formation of [illegible]

[illegible]

ACKNOWLEDGMENTS

[illegible]

BIBLIOGRAPHY

[illegible]

Newfoundland [illegible] Memorial Univ. Newfoundland

1959 [illegible] west Newfoundland [illegible] North America [illegible]

[illegible] Bull. v. 84 [illegible]

[illegible] section of Appalachian [illegible] Newfoundland [illegible] Mining [illegible]

[illegible]

[illegible] Geol. Assoc. Can. v. 24 [illegible]

[illegible]

[illegible] Can. Spec. Paper [illegible]

[illegible] alternate [illegible] west Newfoundland Appalachians and the evidence for their transportation [illegible] Geol. Assoc. Can. v. 24 [illegible]

[illegible] Bay of Islands map area, Newfoundland: Geol. Survey Can. Paper [illegible]

[illegible] Bay of Islands [illegible] western Newfoundland [illegible]

[illegible] Newfoundland [illegible]

Kennedy, M. J. [illegible] The Appalachian [illegible] Geol. Assoc. Can. Spec. Paper [illegible]

Kennedy, M. J. [illegible] 1974 The [illegible] Appalachian [illegible] New York [illegible]

Watson [illegible]

[illegible] Continental [illegible]

[illegible] New York [illegible]

[illegible] Appalachian [illegible]

[illegible] New York [illegible]

Reprinted from:

Program of the Annual General Meeting of the Geological Association of Canada, Newfoundland Section

Spring Meeting, 1986

GEOLOGICAL [illegible]

[illegible] SECTION

Spring Meeting, March 1[illegible], 19[illegible]

LARGE [illegible] [illegible] [illegible] [illegible] [illegible]
[illegible]

R.K. Stevens and N.P. James, Department of Geology, Memorial University of Newfoundland, St. John's, Newfoundland, Canada [illegible]

The Cambro-Ordovician St. George Group, host rock for Pb-Zn mineralization in western Newfoundland, is a series of shelf carbonates whose [illegible] reflects deposition in a shallow [illegible] [illegible] rocks were deposited during a time [illegible] reef [illegible] metazoans with rigid skeletons, [illegible] [illegible] extinct and the coral-stromatoporoid assemblage had not yet evolved. We have discovered, in the subtidal facies, a series of [illegible] carbonate mounds, whose formation we tentatively ascribe to sponges. These structures, first discovered in Hare Bay, can be recognized as an integral part of the St. George Group as far south as Port au Port Peninsula.

The mound or reef facies comprises a series of rounded heads, from 1 to 2 meters in diameter and up to 1 meter high. Each head is composed of a series of upward [illegible], the walls of which are [illegible] and the interiors filled with dark, burrowed lime mudstone. Skeletal grainstones and packstones, commonly burrowed and containing [illegible], surround the closely packed heads. Associated with the mounds are large solitary siliceous sponges ([illegible]) and possibly the colonial form [illegible] sp. In Hare Bay the total thickness of the reef [illegible] [illegible] meters, [illegible] thins toward Port au Port where it is less than [illegible] meters thick.

The complex, irregular nature of the mounds along with extensive diagenesis has created a rock that strongly resembles a burrowed dolomitic limestone, likely the reason they have gone undetected for such a long time. In addition much of the silicification, so common in the St. George Group, may be [illegible] silica [illegible] [illegible]. This extensive diagenesis along with the [illegible] [illegible] also creates a rock type [illegible] [illegible] [illegible] to the "[illegible]" [illegible] host rock [illegible]. These reef mounds have a striking resemblance to the so-called [illegible] Valley where the rock is [illegible] associated with [illegible] mineralization.

REFERENCES

A.G., 1876. The Geological Survey in Newfoundland. Nature, v. 14, p. 254.

Bailey, E.B., 1927. Across Canada with Princeton. Nature, v. 120, p. 673-675.

Bailey, E.B., 1929. The Palaeozoic mountain systems of Europe and America. Brit. Assoc. Advance. Sci., Sect. C, Pres. Addr., p. 57-76.

Baird, D.M., 1975. A kind of white obscure. Geoscience Canada, V.2, p. 213-219.

Barrow, G., 1912. On the geology of Lower Deeside and the southern Highland Border. Proc. Geol. Assoc. Lond., v. 23, p. 274-290.

Beck, R.H., 1972. The oceans, the new frontier in exploration. Australian Petrol. Explor. Assoc. Jour., v. 12, pt. 2, p. 7-28.

Bell, R., 1892. Alexander Murray, F.G.S., F.R.S.C., C.M.B. Can. Rec. Scie., v. 5, p. 82-93.

Betz, F., Jr., 1939. Geology and mineral deposits of the Canada Bay area, northern Newfoundland. Nfld. Geol. Surv. Bull., no. 16, 53 p.

Betts, R.M., 1936. Bibliography of the Geology of Newfoundland, 1818-1936. Dept. Nat. Res. Nfld. Geol. Sec. Bull., no. 5, 35 p.

Billings, E., 1862. Further observations on the age of the Red Sand rock formation (Potsdam group) of Canada and Vermont. Amer. Jour. Sci., 2nd ser., v. 33, p. 101-137.

Bird, J.M., and Dewey, J.F., 1970. Lithospheric plate continental margin tectonics and the evolution of the Appalachian orogen. Geol. Soc. Amer. Bull., v. 81, p. 1031-1060.

Bruckner, W.D., 1966. Stratigraphy and structure of west-central Newfoundland. In Poole, W.H., ed., Guidebook, Geology of parts of Atlantic Provinces. Geol. Assoc. Can. and Min. Assoc. Can., Ann. Mtg. Halifax, 1966, p. 137-155.

Bucher, W.H., 1955. Deformation in Orogenic Belts. Geol. Soc. Amer., Spec. Paper 62, p. 343-368.

Buddington, A.F., and Hess, H.H., 1937. Layered peridotite laccoliths in the Trout River area, Newfoundland. Amer. Jour. Sci., v. 33, p. 380-388.

Bursnall, J.T., and de Wit, M.J., 1975. Timing and development of the Orthotectonic Zone in the Appalachian Orogen of Northwest Newfoundland. Can. J. Earth Sci., v. 12, p. 1712-1722.

Butler, J., and Bartlett, C., 1969. Bibliography of the geology of Newfoundland and Labrador 1814 through 1968. Nfld. Dept. Mines., Agric. and Res., Min. Res. Div., Bull. 38, 271 p.

Church, W.R., 1965. Structural evolution of northeast Newfoundland: comparison with that of the British Caledonides. Maritime Seds., v. 1, p. 10-14.

Church, W.R., 1969. Metamorphic rocks of the Burlington Peninsula and adjoining areas of Newfoundland, and their bearing on Continental Drift in the North Atlantic. In Kay, M., ed., North Atlantic - Geology and Continental Drift. Amer. Assoc. Petrol. Geol. Mem. 12, p. 212-233.

Church, W.R., 1972. Ophiolite: its definition, origin as oceanic crust and mode of emplacement in orogenic belts. Pub. Earth Phys. Branch - Dept. Energy, Mines and Resources (Canada), v. 42, no. 3, p. 71-85.

Church, W.R., and Stevens, R.K., 1968. Crustal evolution of the western margin of the Newfoundland Appalachians, abstr. Prog. Geol. Soc. Amer., Ann. mtg., 1968, Mexico City, Mexico, p. 53-54.

Church, W.R., and Stevens, R.K., 1970. Mantle Peridotite and early Paleozoic ophiolite complexes of the Newfoundland Appalachians, abstr. Program and Abstracts, Internat. Symp. on Mechanical Properties and Processes in the Mantle, Flagstaff, Arizona.

Church, W.R., and Stevens, R.K., 1971. Early Paleozoic ophiolite complexes of the Newfoundland Appalachians as mantle-oceanic crust sequences. Journ. Geophys. Res., v. 75, p. 1460-1466.

Comeau, R.L., 1972. Transported slices of the Coastal Complex, Bay of Islands Western Newfoundland. unpubl. M.Sc. thesis, Memorial University of Newfoundland, 105 p.

Cooper, J.R., 1936. Geology of the southern half of the Bay of Islands igneous complex. Nfld. Dept. Nat. Res., Geol. Sec. Bull. 4, 62 p.

Cooper, J.R., 1937. Geology and mineral deposits of the Hare Bay area. Nfld. Dept. Nat. Res., Geol. Sec. Bull. 9, 36 p.

Davies, H.L., 1968. Papuan Ultramafic Belt. XXIII Internat. Geol. Congr., v. 1, p. 209-220.

Dewey, J.F., 1969. The evolution of the Appalachian/Caledonian orogen. Nature, v. 222, p. 124-129.

Dewey, J.F., 1974. Continental margins and ophiolite obduction: Appalachian Caledonian System. In Burk, C.A., and Drake, C.L., eds., The Geology of Continental Margins; Springer-Verlag, New York, p. 933-950.

Dewey, J.F., and Bird, J.M., 1971. Origin and emplacement of the ophiolite suite: Appalachian ophiolites in Newfoundland. Journ. Geophys. Res., V. 76, p. 3179 3206.

Dietz, R.S., 1963. Collapsing continental rises an actualistic concept of geosynclines and mountain building. Jour. Geol., v. 71, p. 314-333.

Dietz, R.S., and Holden, J.C., 1966. Miogeoclines (miogeosynclines) in space and time. Journ. Geol., v. 74, p. 566-583

Drake, C.L., Ewing, M. and Sutton, [illegible] 1959. Continental margins and geosynclines the east coast of [illegible]th America north of Cape Hatteras, In Ahrens, L.H., Press, [illegible] Rankama, K. and Runcorn, S.K., eds., Physics and Chemistry of the Earth, v. 3. Pergamon Press, Elmsford, N.Y., p. 110-198.

Dunbar, C.O., 1934. Mid Ordovician thrust faulting in western Newfoundland, abstr. Geol. Soc. Amer. Proc 1933, p. 76 77.

Gass, I.G., 1968. In the Troodos Massif of Cyprus a fragment of Mesozoic ocean floor? Nature, v. 220, p. 39-42.

Gass, I.G., and Smewing, J.D., 1973. Intrusion, extrusion and metamorphism at constructive margins. evidence from the Troodos Massif, Cyprus. Nature, v. 242, p. 26-29.

Gillis, J.W., 1966. Great Northern Peninsula. In. Geol. Surv. Canada, Paper 61-1, pt. A, p. 178-181.

Graciansky, P.C. de, 1973. Le problem des "Coloured Melanges" a propos de formations chaotiques associées aux ophiolites de Lycie Occidentale (Turquie). Revue de Géogr. Phys. et de Géol. Dynam., v. 15, p. 555 566.

Hamilton, W., 1973. Tectonics of the Indonesian region. Geol. Soc. Malaysia Bull., v. 6, p. 3-10.

Harrington, B.J., 1883. Life of Sir William E. Logan, Kt. Dawson Bros., Montreal, 432 p.

Howley, J.P., 1909. Geological map of Newfoundland. 1:108,800. reprinted 1915 and 1925, Montreal.

Ingerson, E., 1935. Layered peridotitic laccoliths of the Trout River area, Newfoundland. Amer. Jour. Sci., 5th ser., v. 29, p. 422-440.

Ingerson, E., 1937. Layered peridotitic laccoliths in the Trout River area, Newfoundland - A Reply. Amer. Jour. Sci., V. 33, p. 389-392.

Johnson, H., 1941. Paleozoic lowlands of western Newfoundland. New York Acad. Sci, Trans. ser. 2, v. 3, p. 141-145.

Karig, D.E., 1974. Tectonic erosion at trenches. Earth and Planet. Sci. Letters, v. 21, p. 209-212.

Kay, M., 1945. Paleogeographic and palenspastic maps. Bull. Amer. Assoc. Petrol. Geol., v. 29, p. 426-450.

Kay, M., 1951. North American Geosynclines. Geol. Soc. Amer., Mem. 48, 143 p.

Kay, M., ed., 1969. North Atlantic - Geology and Continental Drift. Amer. Assoc. Petrol. Geol., Mem. 12, 1082 p.

Keith, A., 1913. Further discoveries in the Taconic Mountains, abstr. Geol. Soc. Amer. Bull., v. 24, p. 680.

Kennedy, M.J., 1975. Repetitive orogeny in the northeastern Appalachians - new Plate Tectonic Models based upon Newfoundland examples. Tectonophys., v. 28, p. 39-87.

Kidd, W.S.F., 1974. Evolution of the Baie Verte lineament, Burlington Peninsula, Newfoundland. unpubl. Ph.D. thesis, Cambridge Univ., Cambridge, England.

Kindle, C.H., and Whittington, H.B., 1958. Stratigraphy of the Cow Head region, western Newfoundland. Geol. Soc. Amer. Bull., v. 69, p. 315-342.

Kindle, C.H., and Whittington, H.B., 1959. Some stratigraphic problems of the Cow Head region, western Newfoundland. New York Acad. Sci. Trans., Ser. 2, v. 22, p. 7-18.

Kindle, C.H., and Whittington, H.B., 1965. New Cambrian and Ordovician fossil localities in western Newfoundland. Geol. Soc. Amer. Bull., v. 76, p. 683-688.

Lemoine, M., 1973. About gravity gliding Tectonics in the Western Alps. In DeJong, K.A., and Scholten, R., eds. Gravity and Tectonics; Wiley-Interscience, p. 201-216.

Logan, W.E., 1863. Geological Survey of Canada. Report of its progress from its commencement to 1863. Montreal, 982 p.

Lilly, H., 1964. Possible "Taconic" Klippen in western Newfoundland. Amer. Jour. Sci., v. 262, p. 1130-1135.

Lilly, H.D., 1967. Some notes on stratigraphy and structural style in central west Newfoundland. In Geology of the Atlantic Region. Geol. Assoc. Canada, Spec. Paper No. 4, eds. Neale, E.R.W. and Williams, H., p. 201-211.

Malpas, J., Stevens, R.K., and Strong, D.F., 1973. Amphibolite associated with Newfoundland ophiolite. Geology, v. 1, p. 45-47.

Mattinson, J.M., 1975. Early Paleozoic ophiolite complexes of Newfoundland: Isotopic ages of zircons. Geology, v. 3, p. 181-183.

Merla, G., 1957. Essay on the Geology of the northern Apennines. A.G.I.P. Mineratia, Firenze, 30 p.

Murray, A., 1873. Geological map of Newfoundland. London.

Murray, A., 1877. Geological map of Newfoundland. Montreal.

Murray, A., and Howley, J.P., 1881. Geological Survey of Newfoundland from 1864-1880. London, Stanford, 536 p.

Murray, A., and Howley, J.P., 1918. Reports of the Geological Survey of Newfoundland for 1881-1909. London, Stanford, 725 p.

Neale, E.R.W., Kean, B.F. and Upadhyay, H.D., 1975. Post Ophiolite unconformity, Tilt Cove-Belts Cove Area, Newfoundland. Can. Jour. Earth Sci., v. 12, p. 880-886.

Nelson, S.J., 1955. Geology of Portland Creek-Port Saunders area, west coast. Nfld. Geol. Surv. Rept. 7, 58 p.

Normun, R.E., and Strong, D.F., 1975. The geology and geochemistry of ophiolitic rocks exposed at Ming's Bight, Newfoundland. Can. Jour. Earth Sci., v. 12, p. 777-797.

Oxley, P., 1953. Stratigraphy and structure of the Western Brook, St. Paul's, and Parsons Pond areas, St. Barbe district, western Newfoundland. Nfld. Geol. Surv. Rept. 5, 53 p.

Phillips, W.E.A., Kennedy, M.J., and Dunlop, G.M., 1969. Geological comparison of western Ireland and northeastern Newfoundland. In Kay, M., ed. North Atlantic - Geology and Continental Drift. Amer. Assoc. Petrol. Geol., Mem. 12, p. 194-211.

Ramberg, H., 1967. Gravity, deformation and the Earth's crust. Academic Press, London, 214 p.

Reinhardt, B.M., 1969. On the genesis and emplacement of ophiolites in the Oman Mountains geosyncline. Schweiz., Mineral., Petrogr. Mitt., v. 49, p. 1-30.

Riccio, L., 1976. Stratigraphy and petrology of peridotite and gabbro complexes of west Newfoundland. unpubl. Ph.D. thesis, Univers. Western Ontario, 175 p.

Rodgers, J., 1965, Long Point and Clam Bank Formations, western Newfoundland. Proc. Geol. Assoc. Can., v. 16, p. 83-94.

Rodgers, J., and Neale, E.R.W., 1963. Possible "Taconic" klippen in western Newfoundland. Amer. Jour. Sci., v. 261, p. 713-730.

Ruedemann, R., 1909. Types of inliers observed in New York. N.Y. State Mus. Bull., 133, p. 164-193.

Ruedemann, R., 1947. - see ADDENDUM

Schuchert, C., 1928. The hypothesis of Continental Displacement. In van Watershoot van der Gracht, ed., Theory of Continental Drift, a Symposium on the Origin and Motion both Inter-continental and Intra-continental as proposed by A. Wegener. Amer. Assoc. Petrol. Geol., London. 240 p.

Schuchert, C., 1930. Orogenic times of the northern Appalachians. Geol. Soc. Amer. Bull., v. 40, p. 701-724.

Schuchert, C., and Dunbar, C.O., 1934. Stratigraphy of western Newfoundland. Geol. Soc. America Mem. 1, 123 p.

Seely, D.R., Vail, P.R. and Walton, G.G., 1974. Trench Slope Model. In Burk, C.A. and Drake, C.L., eds., The Geology of Continental Margins. Springer-Verlag, New York, p. 249-260.

Shiraki, K., 1971. Metamorphic basement rocks of Yap Islands, Western Pacific: Possible oceanic crust beneath an Island Arc. Earth and Planet. Sci. Letts., v. 13, p. 167-174.

Smith, C.H., 1952. Bay of Islands Igenous Complex - northern half. unpubl. Ph.D. thesis, Yale University, 142 p.

Smith, C.H., 1958. Bay of Islands Igneous Complex, western Newfoundland. Geol. Surv. Canada. Mem. 290, 132 p.

Smyth, W.R., 1974. The stratigraphy and structure of the southern part of the Hare Bay Allochthon. unpubl. Ph.D. thesis, Memorial University of Newfoundland, 172 p.

Snelgrove, A.K., 1931. Geology and ore deposits of Betts Cove-Tilt Cove area, Notre Dame Bay, Newfoundland. Bull. Can. Inst. of Min. and Met., no. 228, p. 477-519.

Stevens, R.K., 1965. Geology of the Humber Arm area, west Newfoundland. unpubl. M.Sc. thesis, Memorial University of Newfoundland, 121 p.

Stevens, R.K., 1967. Great Northern Peninsula (Parts of 2L, M 12I,P). In Geol. Surv. Canada Paper 61-1 Part A, p. 186-188.

Stevens, R.K., 1967a. The thrust sheets of western Newfoundland, abstr. Program for the Gander Confr., Columbia Univ., p. 23.

Stevens, R.K., 1967b. Humber Arm and Stephenville areas. In Field Trip Guide, Gander Conference, Columbia Univ., 6 p.

Stevens, R.K., 1968. Taconic klippen of western Newfoundland (2L, M). In Geol. Surv. Canada Paper 68-1, pt. A, p. 8-10.

Stevens, R.K., 1969. Anote on the Quebec Group Allochthon. Unpublished ms., 14 p.

Stevens, R.K., 1970. Cambro-Ordovician flysch sedimentation and tectonics in west Newfoundland and their possible bearing on a Proto-Atlantic Ocean. In Lajoie, J., ed., Flysch sedimentology in North America, Geol. Assoc. Canada, Spec. Paper no. 7, p. 165-177.

Stevens, R.K., 1974. Sir William Logan and the Taconic Problem. Geoscience Canada, v.1, p. 40-44.

Stevens, R.K., 1974a. A regurgitation model for the evolution of the Burlington Peninsula. abstr., Geol. Assoc. Canada, Nfld. sect., Spring mtg., St. John's, Nfld.

Stevens, R.K., Church, W.R. and St. Julien, P., 1969. Age of the ultramafic rocks in the north-western Appalachians, abstr. Program Geol. Soc. Amer. Ann. mtg., Atlantic City, p. 215-216.

Strong, D.F., 1973. Plate Tectonic Setting of Appalachian-Caledonian Mineral Deposits as indicated by Newfoundland examples. A.I.M.E. Soc. Min. Engin., preprint no. 73-1-320, 31 p.

Strong, D.F., 1974. An "off-Axis" alkali volcanic suite associated with the Bay of Islands ophiolites, Newfoundland. Earth and Planet. Sci. Letts., v. 21, p. 301-309.

Strong, D.F., 1974a, ed. Metallogeny and Plate Tectonics: A Guidebook to Newfoundland Mineral Deposits. St. John's, Nfld., Canada, 171 p.

Strong, D.F., Dickson, W.L., O'Driscoll, C.F., Kean, B.F. and Stevens, R.K., 1974. Geochemical evidence for eastwards Appalachian subduction in Newfoundland. Nature, v. 248, p. 37-39.

Sullivan, J.W., 1940. The geology and mineral resources of the Port-au-Port area, Newfoundland. unpubl. Ph.D. dissert., Yale Univ., 187 p.

Troelsen, J.C., 1947. Geology of the Bonne Bay-Trout River area, Newfoundland. unpubl. Ph.D. dissert., Yale Univ., 289 p.

Tuke, M.F., 1966. Lower Paleozoic rocks and klippen of the Pistolet Bay area Northern Newfoundland. unpubl. Ph.D. thesis, Univ. of Ottawa, 142 p.

Tuke, M.F., 1968. Autochthonous and allochthonous rocks in the Pistolet Bay area in northernmost Newfoundland. Can. Jour. Earth Sci., v. 5, p. 501-513.

Tuke, M.F., and Baird, D.M., 1967. Klippen in northern Newfoundland. In Appalachian Tectonics. ed. Clark, T.H., Roy. Soc. Can., Spec. Pub. No. 10, p. 3-9.

Upahyay, H.D., Dewey, J.F. and Neale, E.R.W., 1971. The Betts Cove ophiolite complex, Newfoundland: Appalachian oceanic crust and mantle. Proc. Geol. Assoc. Can., v. 24, p. 27-34.

Walthier, T.N., 1949. Geology and mineral deposits of the area between Corner Brooke and Stephenville, western Newfoundland; geology and mineral deposits of the area between Lewis Hills and Bay St. George, western Newfoundland. Nfld. Geol. Surv. Bull. 35, 87 p.

Wegener, A., 1924. The origin of continents and oceans. Dover publications, New York, 1966, reprint. 246 p.

Weitz, J.L., 1953. Geology of the Bay of Islands area, western Newfoundland. unpubl. Ph.D. dissert., Yale Univ., 182 p.

Williams, A., Strachan, I., Bassett, D.A., Dean, W.T., Ingham, J.K., Wright, A.D. and Whittington, H.B., 1972. A correlation of Ordovician rocks in the British Isles. Geol. Soc. London Spec. Rept., No. 3, 74 p.

Williams, H., 1964. The Appalachians in northeastern Newfoundland - a two-sided symmetrical system. Amer. Jour. Sci., v. 262, p. 1137-1158.

Williams, H., 1971. Mafic-ultramafic complexes in west Newfoundland - Appalachians and the evidence for their transportation: a review and interim report. Proc. Geol. Assoc. Can., v. 24, p. 9-25.

Williams, H., and Malpas, J., 1972. Sheeted dikes and brecciated dike rocks within transported igneous complexes, Bay of Islands, western Newfoundland. Can. Jour. Earth Sci., v. 9, p. 1216-1229.

Williams, H., and Smyth, W.R., 1973. Metamorphic aureoles beneath ophiolite suites and Alpine peridotites: tectonic implications with west Newfoundland examples. Amer. Jour. Sci., v. 273, p. 594-621.

Williams, H., Smyth, W.R., and Stevens, R.K., 1973. Hare Bay Allochthon, northern Newfoundland. Geol. Surv. Canada, Paper 73-1, pt. A, p. 8-14.

Williams, H., and Stevens, R.K., 1969. Geology of Belle Isle - northern extremity of the deformed Appalachian miogeosynclinal belt. Can. Jour. Earth Sci., v. 6, p. 1145-1157.

Williams, H., and Stevens, R.K., 1974. The ancient continental margin of eastern North America. In Burk, C.A., and Drake, C.L., eds., The Geology of Continental Margins, Springer-Verlag, New York, p. 781-796.

Wilson, J.T., 1962. Cabot Fault, an Appalachian equivalent of the San Andreas and Great Glen Faults and some implications for continental displacement. Nature, v. 195, p. 135-138.

Wilson, J.T., 1966. Did the Atlantic Ocean close and reopen? Nature, v. 211, p. 676.

Wise, D., and Bird, J.M., 1964. International Field Institute, Italy, 1964. Geotimes, v. 9, p. 12-15.

Zaslow, M., 1975. Reading the Rocks. MacMillan and Co., Canada Ltd., Toronto, 599 p.

Zen, E-an, 1961. Stratigraphy and structure at the north end of the Taconic Range in west-central Vermont. Geol. Soc. Amer. Bull., v. 72, p. 293-338.

Zen, E-an, 1967. Time and space relationships of the Taconic allochthon and autochthon. Geol. Soc. Amer. Spec. Paper no. 97, 107 p.

Zen, E-an, 1969. Nature of the Ordovician orogeny in the Taconic Area. In Zen, E-an, White, W.S., Hadley, J.B., and Thompson, J.B., Jr., eds., Studies of Appalachian Geology, Northern and Maritime. Interscience, p. 129 139.

Zen, E-an, 1972. The Taconide Zone and the Taconic orogeny in the west part of the northern Appalachian orogen. Geol. Soc. Amer. Spec. Paper 135, 72 p.

ADDENDUM

Ruedeman, R., 1947. Graptolites of North America. Geol. Soc. America Mem. 19, 652 p.