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Evolution of Pre-Carboniferous Tectonostratigraphic Zones in the New Brunswick Appalachians

A. A. Ruitenberg, L. R. Fyffe, S. R. McCutcheon, C. J. St. Peter, R. R. Irrinki et D. V. Venugopal

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Résumé de l'article

New Brunswick is divided into five tectonostratigraphic zones based upon Cambrian-Ordovician and to a lesser extent Upper Precambrian lithofacies. Sub-zones are distinguished by the characteristics of overlying pre-Carboniferous strata, and tectonic styles.

The paleogeography and tectonic evolution of these zones can be related to the development of two oceanic basins, which transgressed onto the adjacent disrupted continental crust. Opening of the northern oceanic basin began during the Cambrian and closing was completed during late Ordovician time. The southern basin was initiated during the late Precambrian or Cambrian, and closed during the Silurian to early Devonian.

The description of tectonostratigraphic zones in this report is based upon a synthesis of detailed stratigraphie and structural studies carried out in New Brunswick during the past 10 years. Most of these surveys were conducted under the auspicies of the Geological Survey of Canada and Mineral Resources Branch, New Brunswick Department of Natural Resources with financial assistance of the Canada Department of Regional Economic Expansion. The present synthesis constitutes a progress report (Canadian Contribution No. 4) of a continuing investigation conducted in co-operation with the Canadian IGCP (International Geological Correlation Program) Caledonide Orogen Project.

Five major tectonostratigraphic zones (Fig. 1) were delineated in the present study based upon contrasting lithostratigraphic faciès of Cambrian-Ordovician and to a lesser extent, Upper Precambrian strata. Subdivisions of these zones are mainly based upon characteristics of overlying Silurian and Lower Devonian rocks, and structural style. As this study is confined to the pre-Carboniferous tectonic evolution, the Carboniferous strata are designated as cover rocks. Previous structural-stratigraphie subdivisions, based upon the characteristics of the dominant exposed rock units in various belts, were mainly designed to assist in the delineation of mineral zones (Potter et al., 1969) or major structural complexes (Rodgers, 1970). A previous tectonostratigraphic zonation based upon correlation with Newfoundland (Williams et al., 1972) did not adequately represent the geology of New Brunswick. Similarly, previous tectonic interpretations by Bird and Dewey (1970) and McKerrow and Ziegler (1971), required revision, but some aspects of models proposed by Poole (1976) and Rast era/., (1976a) are consistent with the tectonostratigraphic zonation outlined in this report.

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S. R. McCutcheon, C. J. St. Peter,
R. R. Irrinki, and D. V. Venugopal
Mineral Resources Branch
New Brunswick Department
of Natural Resources,
Sussex, N.B. E0E 1P0

Summary

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Zone 1

Zone 1 covers a large area in northern and northwestern New Brunswick that includes three major structural complexes described here as subzones 1a, 1b, and 1c (Fig. 1, Tables I and II). These sub-zones are referred to respectively as Gaspé Synclinorium, Aroostook-Matapedia Anticlinorium and Chaleur Bay Synclinorium by Rodgers (1970) and Kedgwick Zone, Matapedia-

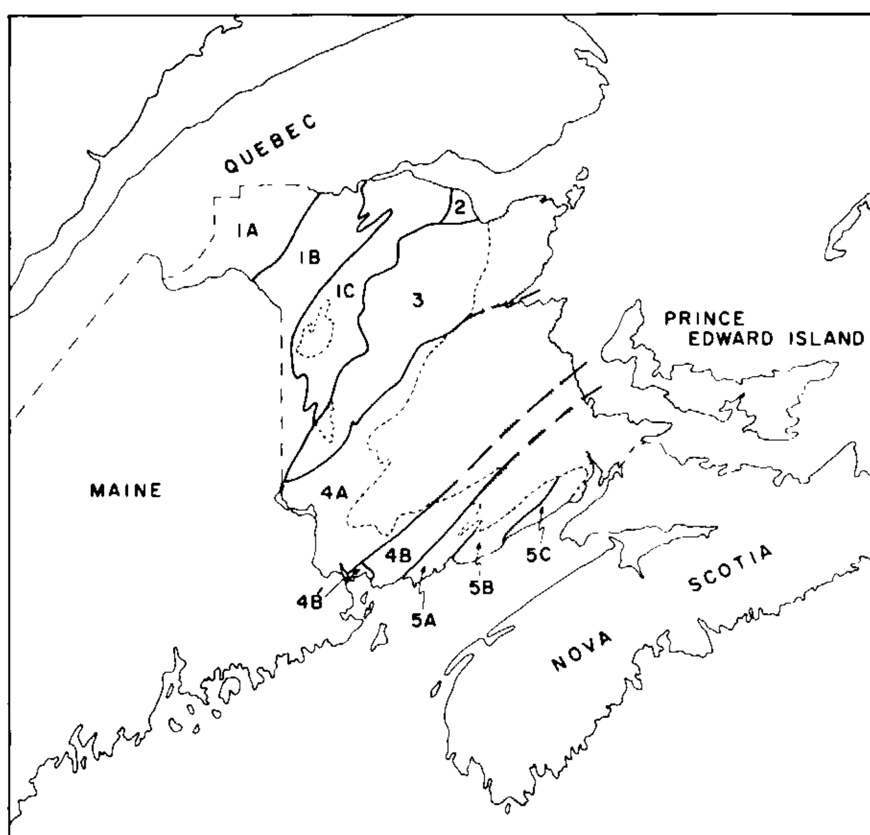


Figure 1
Pre-Carboniferous tectonostratigraphic zones in New Brunswick.

Aroostook Zone and Tobique Zone by Potter *et al.*, (1969).

The oldest rocks inferred to underlie all or most of zone 1 are exposed in sub-zone 1b (Fig.1). The sequence comprises Caradocian turbiditic rocks of the Grog Brook Group and the conformably overlying Ashgillian to Lower Llandoverian calcareous sedimentary rocks of the Matapedia Group (St. Peter, in press; Hamilton-Smith, 1970) (Table I).

Dark-grey laminated argillite interbedded with argillaceous sandstone is most abundant in the Grog Brook Group. Interbeds of pebble conglomerate and graded greywacke are largely confined to the upper part of the group. The conglomerate contains abundant mafic and felsic volcanic clasts derived from uplifted areas to the northwest and southeast.

The Matapedia Group generally consists of basal lithic limestone with interbeds of laminated arenaceous limestone overlain by a thick sequence of interbedded argillaceous limestone and calcareous shale (St. Peter, in press). Mafic tuff and chert, correlated with similar rocks of the Tetagouche Group, underlie the Matapedia Group in the core of the Popelogan anticline, on the southeastern margin of sub-zone 1b (Table I). The tuff and chert is replaced along strike by conglomerate and greywacke of the Grog Brook Group.

Sub-zone 1a consists of the Silurian Perham Formation (Upper Llandoverian to Ludlovian; Boucot *et al.*, 1964) and disconformably overlying Devonian Temiscouata Formation (Emsian: St. Peter and Boucot, in prep.).

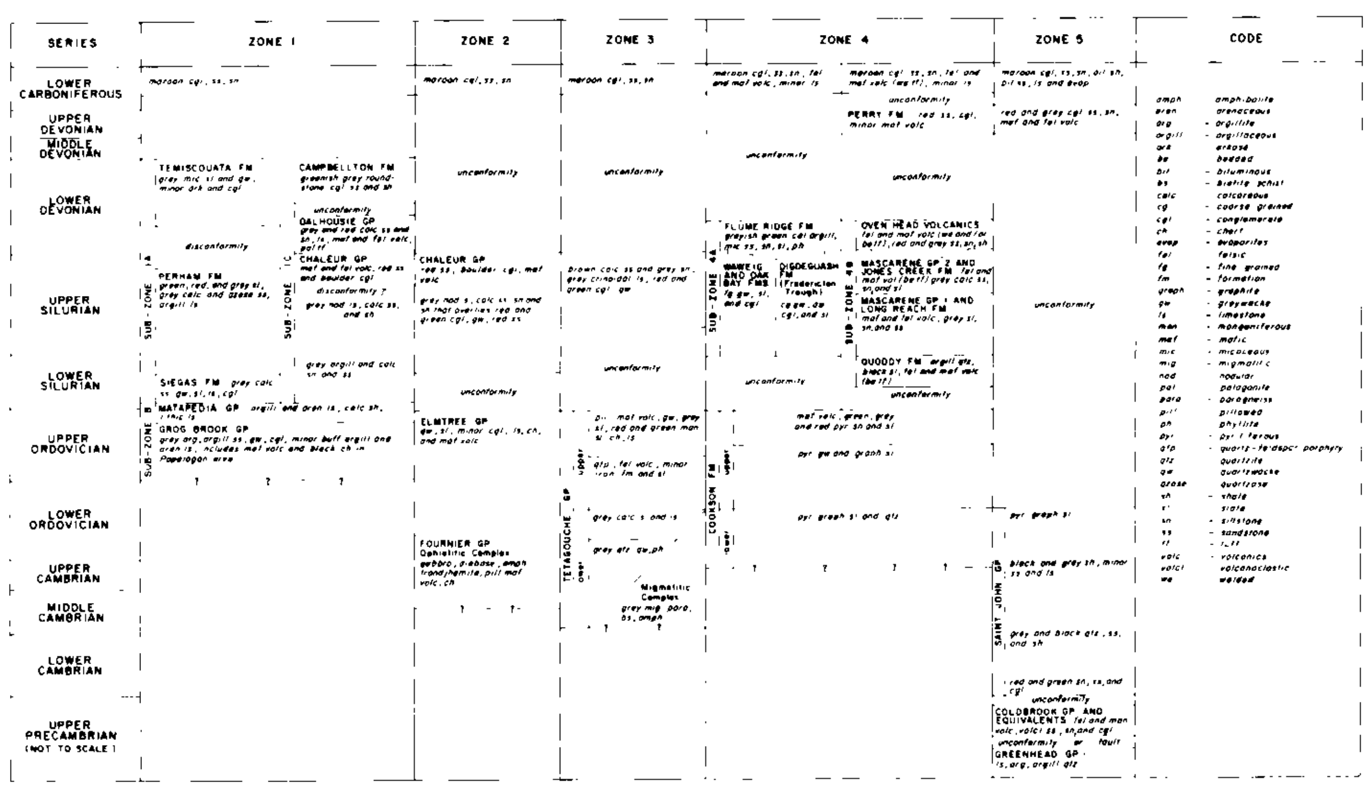
The Perham Formation is composed of green, red and grey slate, grey calcareous and quartzose sandstone, and argillaceous limestone. The red slate is locally ferruginous and manganiferous. Cyclic alternation of red and green slate (oxidizing and reducing environments), and the presence of oolites and limestone breccias suggest a subaerial to subtidal depositional environment. In northwestern New Brunswick, the Perham Formation is separated from the Matapedia Group by the intervening, but conformable thin turbiditic sequence of the Siegas Formation. The source area for the Siegas Formation was to the north (Hamilton-Smith, 1970).

The Temiscouata Formation is a flyschoid sequence composed of grey micaceous slate and greywacke. The rocks reflect a marine transgression and relatively rapid subsidence.

Sub-zone 1c, along the northwestern margin of the Miramichi Anticlinorium (zone 3), consists of the Silurian Chaleur Group, the Devonian Dalhousie Group, and the Devonian Campbellton Formation (Ami, 1900; Alcock, 1935). Calcalkaline volcanic rocks are abundant in all units but the Campbellton Formation.

In northern New Brunswick, the basal rocks of the Chaleur Group in sub-zone 1c generally consist of a sequence of dark-grey, laminated argillaceous and calcareous siltstone and sandstone (Late Llandoverian to Wenlockian) that grade downward into limestone of the Matapedia Group. Grey nodular limestone and calcareous sandstone and shale in the Chaleur Bay area, represent a shallower water facies of the same age (Noble and Howells, 1974).

The basal rocks of the Chaleur Group are overlain by a succession of amygdaloidal andesite and basalt, red arkosic sandstone and volcanic boulder conglomerate, and rhyolite of Ludlow age (Greiner, 1970) or Wenlockian-Ludlovian age (Potter, 1965). In the Chaleur Bay area, the Chaleur Group is conformably overlain by the Dalhousie Group consisting of calcareous



sandstone, siltstone and limestone with intercalated andesite, basalt and tuff (see Alcock, 1935). The upper part of the group consists of rhyolite and tuffaceous sandstone containing rare narrow coal seams. These rocks are unconformably overlain by continental, greenish grey conglomerate and sandstone of the Campbellton Formation (Siegenian-Emsian). Along the northwestern margin of sub-zone 1c, a sequence of grey and red sandstone, siltstone, rhyolite and basalt, is of the same age as the Dalhousie Group (Potter, 1965).

Structure, Metamorphism and Intrusive Activity. Rocks of zone 1 were folded and metamorphosed during the Acadian orogeny (Table II) (Lower-Middle Devonian), but bedding and other sedimentary stuctures are well preserved. Regional metamorphism is sub-greenschist with zeolites commonly present in the Lower Devonian palagonite tuffs of the Dalhousie Group (Mossman and Bachinski, 1972).

A cleavage that mostly strikes northeast and dips steeply is generally prominent in the Silurian but less developed in the Devonian rocks. Associated folds are close to tight and plunge gently northeast or southwest. Locally folds predate the cleavage (Stringer, 1975).

The most prominent faults strike northeasterly and have right lateral offsets of several kilometres. Small mafic and felsic hypabyssal intrusions occur locally in zone 1 (Table II)

Zone 2

Zone 2 is referred to by Rodgers (1970) as the Elmtree Dome and consists of the Elmtree and Fournier Groups, that are unconformably overlain by rocks of the Chaleur Group.

The Fournier Group (Young, 1911; Fyffe 1974) consists of intensely deformed green pyroxene and hornblende gabbro with bands of amphibolite. Dykes of light pink trondhjemite and diabase cut the gabbro. Basalt, with pillows enclosed in red and grey chert, envelop the gabbroic rocks.

The Elmtree Group outcrops mostly to the south of and, on the basis of pillow tops, conformably overlies the Fournier Group. Grey quartzose greywacke and interbedded grey slate are the characteristic rock types, whereas conglomerate, limestone and chert occur in minor amounts. A poorly preserved graptolite suggests a Caradocian to Llandoverian age for the Elmtree Group (Dean, 1975).

Basal conglomerate of the Chaleur Group unconformably overlies both the Fournier and Elmtree Groups. The Silurian sequence overlying the conglomerate is lithologically similar to that of sub-zone 1c.

Structure and Metamorphism. The ophitic texture of the gabbro in the Fournier Group is deformed by cataclastic foliation defined by hornblende and granulated plagioclase. Trondhjemite dykes truncate the well-developed foliation in the gabbros and exhibit a weak internal foliation. In contrast to the gabbro, pillow basalts of the Fournier Group show only a weak schistosity and the effects of lower greenschist facies metamorphism.

Chemical analyses of the Fournier Group show that the gabbro is extremely low in TiO_2 and K_2O (written commun. G. P. Vankateswaran). These chemical characteristics and the presence of spilitized basalt are consistent with the interpretation that the Fournier Group represents oceanic crust (Pajari *et al.*, 1976).

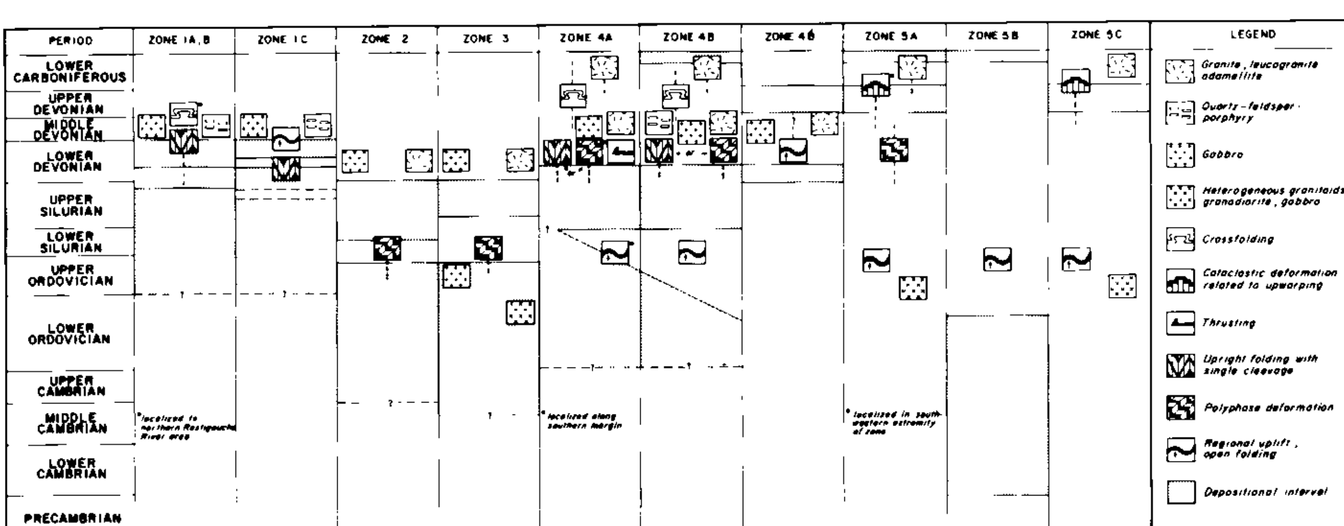
The Elmtree Group has a prominent, steeply dipping, northeast trending slaty cleavage that locally is cut by a moderately dipping crenulation cleavage. It has been regionally metamorphosed to lower greenschist facies.

Zone 3

Zone 3 (Fig. 1), referred to as the Miramichi Anticlinorium (Rodgers, 1970) or Miramichi Zone (Potter *et al.*, 1969), is composed of an intensely deformed belt of Cambro-Ordovician volcanic and sedimentary, and minor Silurian sedimentary rocks.

Rocks exposed along the western margin of the anticlinorium consist of a migmatitic complex of interbedded sillimanite-bearing paragneiss, biotite schist, and amphibolite intruded by Ordovician and Devonian gabbro and granite.

Grey quartzite, quartz wacke, greenish grey phyllite, and calcareous



slate of the lower Tetagouche Group (Table I) are probably less metamorphosed equivalents of the migmatitic complex. The calcareous slate at the top of the lower Tetagouche Group was dated as Lower Ordovician (Fyffe, 1976). The lowermost part of the lower Tetagouche Group is lithologically similar to the quartzite-quartz wacke sequence of the Cambrian Grand Pitch Formation described by Neuman (1962) in northeastern Maine.

A thick succession of rhyolite tuff and porphyry of the upper Tetagouche Group overlies the quartzose sequence. Iron formation and slate interbedded with the felsic volcanic rocks are associated with a number of large stratiform lead-zinc deposits in the Bathurst area (Davies *et al.*, 1973). A sequence of pillow basalts, feldspathic greywacke, red and grey slate, and limestone is intercalated with the felsic volcanic sequence. Graptolites of Caradocian age occur in slate interbedded with the basalt (Helmstaedt, 1971). A similar stratigraphic sequence is found in the extreme southwestern part of the Miramichi Anticlinorium, but felsic volcanic rocks are present only in small amounts (Poole, 1963; Venugopal, in prep.).

Chemically, the Tetagouche volcanic rocks exhibit a bimodal distribution with andesite virtually lacking (Davies *et al.*, 1973). The felsic volcanic rocks have a rhyolitic to dacitic composition and the basaltic rocks are spilitized and exhibit an iron enrichment trend. Both alkalic and tholeiitic basalts are present. Upper Silurian (Ludlovian) conglomerate unconformably overlies basaltic rocks of the Tetagouche Group along the northwestern margin of the anticlinorium.

Structure, Metamorphism and Intrusive Activity. The Tetagouche Group has been polydeformed during the Taconian orogeny (Table II). The first phase of deformation produced upright isoclinal folds that were subsequently deformed by tight second folds. The crenulation cleavage associated with the second deformation is subhorizontal in the southwestern part of the area, whereas it is steeply dipping in the northeastern part. Folds associated with the third deformation trend north-northwesterly in the western part of the Tetagouche Group and northeasterly in the eastern part (Helmstaedt, 1971).

Regional metamorphism associated with the Taconian orogeny varies from chloritic grade in the northern part to biotite grade in the east-central part of the anticlinorium. Sillimanite-grade metamorphism within the migmatitic complex postdates the earlier Taconian fabric and is probably Acadian in age. In the southwestern part of the anticlinorium the rocks have undergone only Acadian metamorphism of prehnite-pumpellyite grade (Venugopal, in prep.).

The Upper Silurian conglomerate that unconformably overlies the basaltic rocks of the Tetagouche Group was deformed during the Acadian orogeny (Lower Middle Devonian) and contains pebbles of the Tetagouche Group that were earlier deformed during the Taconian (Helmstaedt, 1971; Rodgers, 1971). This effectively dates the Taconian orogeny in the anticlinorium between the Middle Ordovician and Upper Silurian.

Mafic and felsic intrusions are abundant in zone 3 (Table II), in contrast with zone 1 to the northwest. The oldest highly deformed intrusions were probably emplaced during the Lower Ordovician (Fyffe *et al.*, 1977). The younger intrusions truncate and locally are concordant with the Acadian fabric.

Zone 4

Zone 4 (Fig.1) includes a broad belt of intensely deformed Ordovician and Silurian sedimentary and volcanic rocks between the Miramichi Anticlinorium (zone 3) and the Upper Precambrian rocks of the Caledonia Highlands (zone 5). Volcanic rocks are nearly absent in sub-zone 4a, but abundant in sub-zone 4b (Mascarene-Nerepis Volcanic Belt). The Precambrian-Paleozoic complex comprising zones 4 and 5 was collectively referred to as the Kennebecasis Anticlinorium by Rodgers (1970) and Kennebecasis Zone by Potter *et al.* (1969).

Sub-zone 4a is partly separated from zone 3 (Miramichi Anticlinorium) and entirely from sub-zone 4b (Mascarene-Nerepis Volcanic Belt) by faults and intrusions. The northwestern part of sub-zone 4a has been referred to as the Fredericton Trough (McKerrow and Ziegler, 1971).

Six major rocks units are included in zone sub-zone 4a: pelitic and arenaceous rocks of the Ordovician Cookson Formation; turbidites and conglomerates of the Silurian Waweig, Digdeguash and Oak Bay Formations; Silurian turbidites of the Fredericton Trough; and calcareous clastic sedimentary rocks of the Upper Silurian-Lower Devonian Flume Ridge Formation (Poole, 1963; Ruitenberg, 1967, 1968; Ruitenberg and Ludman, in press).

The lowermost part of the Cookson Formation in southwestern New Brunswick, consists of black, pyritiferous, highly graphitic slate with interbedded grey sandstone, siltstone and quartzite. These rocks grade upwards into thick bedded, pyritiferous greywacke and interbedded carbonaceous slate. The upper part of the unit consists of dark greyish green pyritiferous siltstone, slate and mafic volcanic rocks. Cumming (1967) used graptolites to assign an Arenigian age to the lowermost part of the Cookson Formation in New Brunswick, but examination of new collections by Riva suggests a possible Tremadocian age (Ruitenberg and Ludman, in press). These rocks are stratigraphic correlatives of the upper Saint John Group (zone 5) and the lower Tetagouche Group (zone 3) (Table I). In the Cookson Formation of the Woodland area in Maine, thick massive quartzites that underlie the graphitic slate member may extend into the Cambrian (Ruitenberg and Ludman, in press).

The Waweig Formation is composed of dense, fine-grained sandstone and siltstone of greywacke composition and non-graphitic slate. A shelly fauna in these rocks has been dated Late Llandoverian to Pridolian (Berry and Boucot, 1970) and uppermost Ludlovian to Pridolian (Pickerill, 1976). Polymictic conglomerate at the base of the Waweig Formation is referred to as the Oak Bay Conglomerate. The Waweig Formation interfingers with well-bedded greywacke, quartz wacke, polymictic granule conglomerate and non-graphitic slate of the Digdeguash Formation (Ruitenberg, 1967). The wackes of the Digdeguash Formation are generally coarser than those of the Waweig Formation. Further north Poole (1963) distinguished three turbidite units composed respectively of grey fine-and coarse-grained greywackes, conglomerates and slate; green and grey-green slate and greywacke; and grey and green-grey quartzose greywacke and slate. D. V. Venugopal recently mapped limestone, calcareous slate and basalt on the northwest margin of the Fredericton Trough (not included in Table I).

The Waweig and Digdeguash Formations grade upward into greyish green calcareous argillaceous sandstone and siltsone, slate and phyllite of the Flume Ridge Formation (Ruitenberg, 1967).

Mafic and felsic flows, tuff, agglomerates, breccias, clastic and minor calcareous sedimentary rocks of the Mascarene-Nerepis belt and Campobello Island (zone 4b) were deposited contemporaneously with the sedimentary rocks of zone 4a (Ruitenberg, 1968, 1972; Ruitenberg and Ludman, in press). The southwestern extension of this zone in Maine is referred to as the Coastal Volcanic Belt.

The Llandoverian Quoddy Formation, that outcrops on Campobello Island, is the oldest rock unit in zone 4b. It consists of argillaceous quartzite, black slate, and felsic and mafic volcanic rocks. The Mascarene Group 1 (Ruitenberg, 1972) and Long Reach Formation (Wenlockian-Ludlovian: Berry and Boucot, 1970) consist of mafic and very minor felsic tuff and flows, grey slate, siltstone and sandstone. The tuff is generally bedded and pillows are common in mafic flows. These rocks are conformably overlain by the Mascarene Group 2 (Ruitenberg, 1972) and Jones Creek Formation (Pridolian: Berry and Boucot, 1970) respectively. The Macarene Group 2 consists of felsic and mafic tuff flows, and grey calcareous sandstone, siltstone and slate. The Jones Creek Formation (Mackenzie, 1964) consists of similar rocks, but sediments are more abundant than volcanics. Numerous small, stratiform base metal sulphide deposits occur in pyroclastic and sedimentary rocks of the Mascarene Group 2 and Jones Creek Formation.

The Lower Devonian Ovenhead Volcanics and associated rocks (sub-zone 4b) consist of felsic and mafic tuffs, red and grey sandstone, siltstone and shale. The tuffs differ from those in the Mascarene-Nerepis Belt in that they are mostly welded and only rarely bedded. Most of the sedimentary rocks reflect a fluviatle depositional environment. The Ovenhead Volcanics are unconformably overlain by red sandstone, conglomerate and minor mafic volcanic rocks of the Upper Devonian Perry Formation (see Ruitenberg, 1968).

Stucture, Metamorphism and Intrusive Activity. The southeastern part of sub-zone 4a and most of sub-zone 4b have been affected by Acadian polyphase deformation, whereas only one phase of folding has deformed most of the northwestern part (Table II). The main conpressive phases of the Acadian orogeny (D1 and D2) predate the Middle Devonian, whereas younger distentional phases (D3 and D4) probably continued into the Lower Carboniferous (Ruitenberg, 1967; Ruitenberg and Ludman, in press).

The first and main phase deformation affected all stratigraphic units in zone 4 and produced northeast-trending, close to isoclinal, upright folds. A penetrative cleavage generally accompanied by chlorite metamorphism was associated with this deformation (Ruitenberg, 1967, 1968; Brown and Helmstaedt, 1970). Effects of prehnite-pumpellyite metamorphism were recently recognized in parts of zone 4b by D. V. Venugopal.

Recumbent second folds have locally deformed the early penetrative cleavage and bedding in the southern part of zone 4a. A gently dipping crenulation cleavage defines the axial surfaces of these folds in fine-grained rocks. Thrust faulting was associated with this deformation in southwestern New Brunswick. Second phase folds in zone 4b differ from those in zone 4a in that they are generally steeply plunging.

A third deformation phase produced steeply plunging S- and Z- shaped cross-folds that formed mainly in the vicinity of northeast and northwest trending fault zones. A fourth deformation resulted in gently plunging kink-bands that are generally well-developed in thinly bedded, fine-grained sedimentary rocks.

Mafic and locally ultramafic intrusions containing nickel-copper sulphide deposits were emplaced along the southern margins of sub-zone 4a during early Middle Devonian time. Fuchsite occurs locally in the contact zone of a small ultramafic intrusion in the northeastern part of sub-zone 4b. Similar ultramafites in the southern Appalachians described by Chidister and Cady (1972) are considered to be indicators of distentional tectonics.

Devonian and Lower Carboniferous felsic intrusions occur along the southern margin of sub-zone 4a and sub-zone 4b. Prominent contact metamorphic aureoles associated with these intrusions are overprinted on the penetrative cleavage.

Zone 5

Zone 5 constitutes a belt of Upper Precambrian sedimentary and volcanic rocks (Green Head and Coldbrook Groups), overlain in part by Cambrian and Ordovician sedimentary rocks of the Saint John Group and Carboniferous clastic sedimentary rocks. Zone 5 is separated from zone 4 by the Beaver Harbour-Belleisle Fault.

The oldest rocks in zone 5 are limestone, dolostone, argillite, and argillaceous quartzite, and metamorphic equivalents of the Greenhead Group (probably Neohelikian; Hoffman, 1974). The Greenhead Group is in fault contact with, and probably underlies Hadrynian volcanic rocks of the Coldbrook Group and its stratigraphic equivalents (Ruitenberg *et al.*, 1973; Giles and Ruitenberg, 1977).

The Coldbrook Group and its stratigraphic equivalents have been divided into three broad northeasterly trending belts, each of which is characterized by specific rock assemblages. These volcanic belts are referred to as the Western (5a), Central (5b) and Eastern (5c) Volcanic Belts.

The Eastern Volcanic belt consists of mafic and felsic tuff and volcanogenic sediments composed of mafic and felsic detritus, with lesser amounts of intercalated flows. Waterlain tuff of the Eastern Volcanic Belt grades laterally into coarse lithic tuff and volcanic breccias of the Central Volcanic Belt. Felsic lithic, crystal and welded tuff and flows are most abundant in the Central olcanic Belt, whereas mafic volcanic rocks are much more abundant in the Eastern Volcanic Belt. The Western Volcanic Belt, whereas mafic volcanic rocks are much more abundant in the rocks than in the Central Volcanic Belt, but coarse volcanic breccias are less abundant.

The stratigraphy of the Cambrian to Lower Ordovician Saint John Group was described in detail by Alcock (1938). The lowermost unit consists of continental, Lower Cambrian red and green siltstone, sandstone and conglomerate (Table I). It is overlain by Lower Cambrian, grey and black quartzite, sandstone and shale. The Middle and Upper Cambrian is represented by black and grey shale, minor sandstone and limestone, which is overlain by Lower Ordovician, pyritiferous and locally graptolitic slate, that is correlated with the lower Cookson Formation in zone 4 (Table I).

Structure, Metamorphism and Intrusive Activity. The Greenhead Group has been intensely polydeformed and metamorphosed. The time of this tectonic event is not known, but it probably predates deposition of the weakly metamorphosed Coldbrook Group and equivalents.

A broad mylonite zone along the northwestern margin of the Western Volcanic Belt, was probably formed during the Acadian orogeny (early Middle Devonian). A K-Ar age of 369 ± 21 my (Helmstaedt, 1968) associated with the early penetrative fabric in mafic volcanic rocks of the Western Volcanic Belt, is consistent with deformation during the Acadian orogeny. The rocks of the Central Volcanic Belt have mostly been gently folded and rarely show effects of penetrative deformation. The Eastern Volcanic Belt and adjacent intrusive rocks have been deformed by penetrative cataclastic deformation related to doming or upwarping during latest Devonian and/or earliest Carboniferous (Ruitenberg *et al.*, 1973). Metamorphism associated with this deformation is lower greenschist facies.

Large plutons of diorite to quartz diorite composition intruded the Coldbrook Group during Ordovician time. Numerous small potash-rich felsic intrusions were emplaced during Late Devonian to Early Carboniferous time (Giles and Ruitenberg, 1977; Ruitenberg *et al.*, in press).

Discussion

Several different interpretations have been proposed for the tectonic evolution of the northern Appalachians (Bird and Dewey, 1970; Church and Stevens, 1971 and Poole, 1976), but some fundamental aspects are accepted by all these authors. It is generally agreed that the Appalachian system evolved upon and between the disrupted margins of a once continuous pre-Hadrynian crystalline basement that presently constitutes the Canadian and Afro-European shields, and isolated intervening blocks. The system expanded from the Hadrynian to Early Ordovician, and contracted from about that time until the Middle Devonian, when the belt again became subjected to distention. The present interpretation is based mainly upon detailed stratigraphic and structural studies by the authors in New Brunswick, and upon comparison with other parts of the northern Appalachians from literature review and reconnaissance excursions.

Precambrian. The typical platformal carbonates and clastic sedimentary rocks of the possible Neohelikian (Hoffmann, 1974) Greenhead Group (in zone 5a) and the volcanic and sedimentary rocks of the Hadrynian Coldbrook Group and stratigraphic equivalents constitute the earliest deposition in the northern Appalachians.

The stratigraphy of the volcanic belts in zones 5a and 5b (terrestrial felsic and minor mafic volcanics) and zone 5c (waterlain mafic and felsic volcanic and sedimentary rocks) suggest deposition along the northwest margin of a large basin (Giles and Ruitenberg, 1977).

Two possible tectonic interpretations have been proposed to explain the Upper Precambrian volcanism (Giles and Ruitenberg, 1977). The first one suggests that volcanism and formation of the basin was initiated along a rift zone in continental crust. The second interpretation advanced by Rast *et al.*, (1976b) suggests that the Coldbrook Group and other Hadrynian volcanic rocks in the northern Appalachians represent an ensialic island arc formed along the northwestern margin of a closing oceanic basin. Available geologic data is consistent with the first interpretation, but further work may prove the second to be a viable alternative.

Cambrian. The Precambrian rocks of zone 5 constituted a relatively stable microcontinental block through Cambrian time (Figs. 2 and 3).

The Saint John Group (Table I) stratigraphy suggests deposition of fluviatile clastic sediments on the microcontinent (Fig. 2) during earliest Cambrian time. Transport direction of these sediments is from the north (Patel, 1973). Subsequent marine transgression during Early Cambrian time is reflected in a typical shallow water, platformal sedimentary sequence (Fig. 2).

Similarly an extensive carbonate-sandstone sequence resulted from Cambrian marine transgression onto the Canadian Shield (St. Julien and Hubert, 1975). The Lower Cambrian, in part allochthonous, shale-feldspathic sandstone and clastic-carbonate assemblages exposed south of the Cambrian shelf sequence in the Eastern Townships and Gaspé (St. Julien and

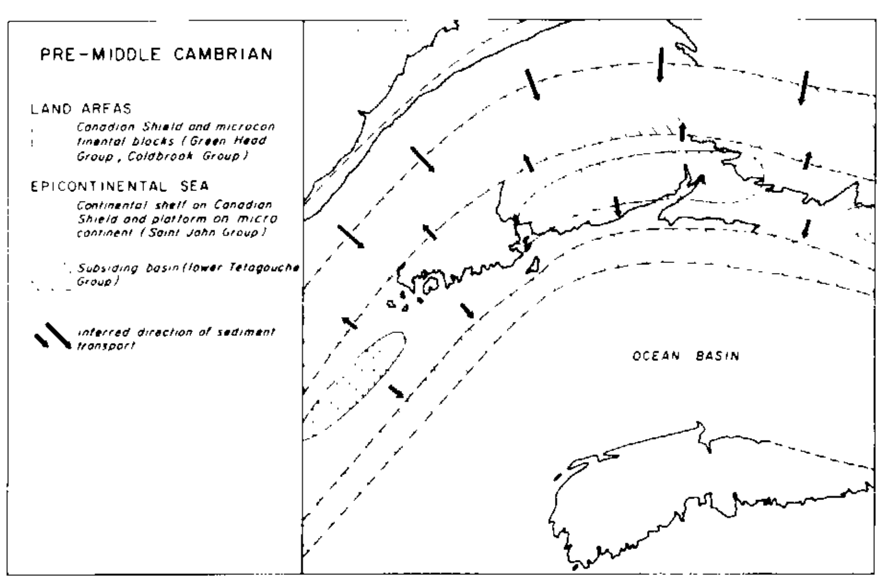


Figure 2
Schematic pre-Middle Cambrian paleogeography and tectonic setting of New Brunswick

Hubert, 1975; Poole, 1976) and possibly the lowermost part of the Tetagouche Group in New Brunswick (zone 3) reflect deposition in deeper water environments. These sediments were probably deposited in a basin formed on subsiding continental crust that was subjected to extension by thinning and marginal normal faulting (Poole, 1976).

Ophiolitic complexes in the Eastern Townships of Quebec (St. Julien and Hubert, 1975) and western Newfoundland (Dewey and Bird, 1971 and Kennedy, 1973) suggest that continuing crustal extension during Middle and/or Late Cambrian, and possible Early Ordovician led to the formation of a marginal oceanic basin (Fig. 3). The Fournier Group (zone 2), in northern New Brunswick probably reflects a late phase of this development.

Poole (1976) suggested that an oceanic basin also formed southeast of zone 5 during Cambrian time (Figs. 2 and 3). This could have resulted from continued rifting that probably started in this belt during Hadrynian time (see above). The Cambrian-Ordovician wacke-slate sequence of the Meguma Group in Nova Scotia (Schenk, 1971) could represent continental rise deposition on the African continental margin of this basin.

The lithologies of the upper Saint John Group (shale, and minor sandstone and limestone; zone 5) suggest a transition from shallow to deeper water (platform to microcontinental rise) during Middle and Late Cambrian time. The quartzite-quartz wacke-phyllite assemblage of the lower Tetagouche Group (zone 3) and the lowermost sediments of the Cookson Formation (zone 4) probably represent deposition on the microcontinental rise. Deposition of carbonates and arenites (platformal) continued through the Middle and Late Cambrian, and Early Ordovician on the Canadian Shield (St. Julien and Hubert, 1975; Poole, 1976). However the Upper Cambrian limestone-conglomerate assemblage of the Eastern Townships reflects continental rise deposits according to these authors.

Ordovician. The black pyritiferous slates of the lower Cookson Formation (zone 4) and the upper Saint John Group (zone 5) reflect deposition in a deep water euxinic environment. Deposition of these sediments on the microcontinent suggests continued marine transgression accompanied by accelerated subsidence (Fig. 4), during the Early Ordovician. The first appearance of greywackes in the upper Cookson, later during the Ordovician, probably coincided approximately with the onset of Tetagouche volcanism to the north (Ruitenberg and Ludman, in press).

The bimodal felsic-mafic volcanic sequence of the Lower Ordovician Tetagouche Group (zone 3) probably represents an ensialic island arc (Davies *et al.*, 1973; Ruitenberg, 1976). The lowermost part of the quartz wacke-slate sequence of the Elmtree Group (zone 2) that overlies the Fournier Group may be an arc-trench gap deposit. The

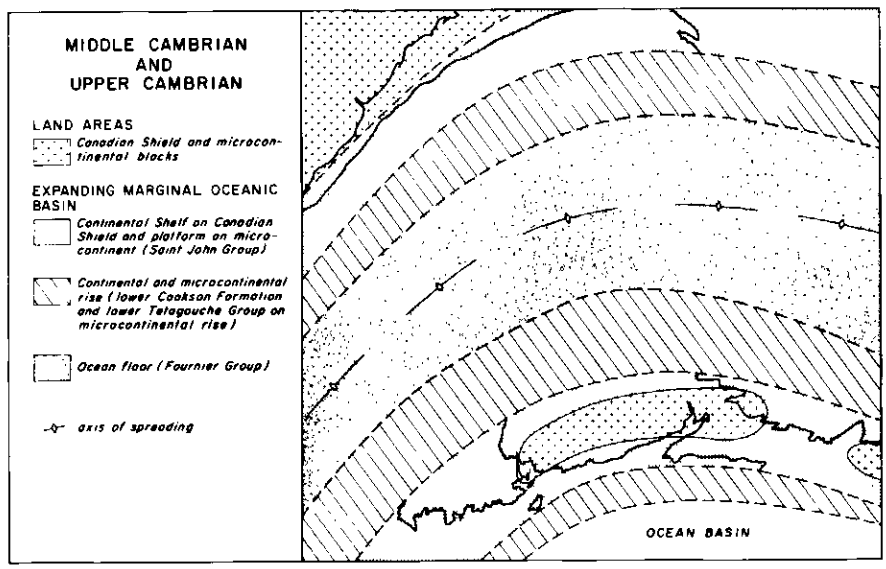


Figure 3
Schematic Middle and Upper Cambrian paleogeography and tectonic setting of New Brunswick.

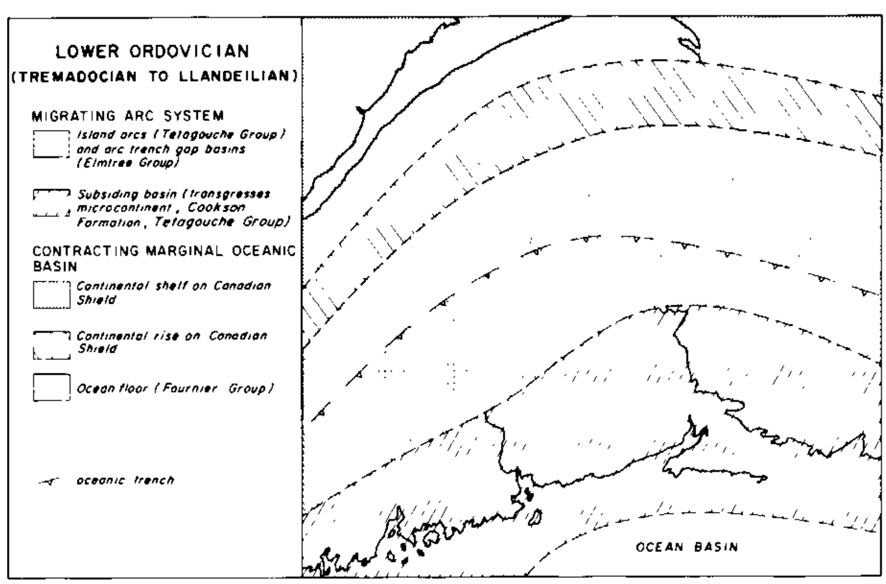


Figure 4
Schematic Lower Ordovician paleogeography and tectonic setting of New Brunswick.

fact that the Tetagouche volcanic rocks overlie clastic quartzose sedimentary rocks (Table I) and are situated immediately south of the Fournier ophiolitic complex suggests that they were deposited on the outer margin of the microcontinental slope, probably during southward closing of the marginal oceanic basin (Fig. 4). Closing of the marginal basin by subduction to the south was first proposed by Church and Stevens (1971) in Newfoundland, Laurent (1975) in the Eastern Townships and Rast *et al.*, (1976a) in New Brunswick. Closing of the basin by subduction to the south is also supported by the emplacement of highly deformed granitic intrusions south of the Tetagouche Arc, during the Early Ordovician (Fyffe *et al.*, 1977).

The calc-alkaline volcanic rocks of the Ascot-Weedon belt in the Eastern Townships of Quebec (Suavé *et al.*, 1972) are probably also related to the closing of the marginal basin, but this volcanic sequence formed on oceanic crust (St. Julien and Hubert, 1975; Laurent, 1975). It is notable that all the known large stratiform lead-zinc-copper sulphide deposits in the northern Appalachians occur in the ensialic volcanic rocks of the Tetagouche Group, whereas only relatively small sulphide deposits occur in island arc volcanic rocks that presumably formed on oceanic crust like the Ascot-Weedon belt (Ruitenberg, 1976).

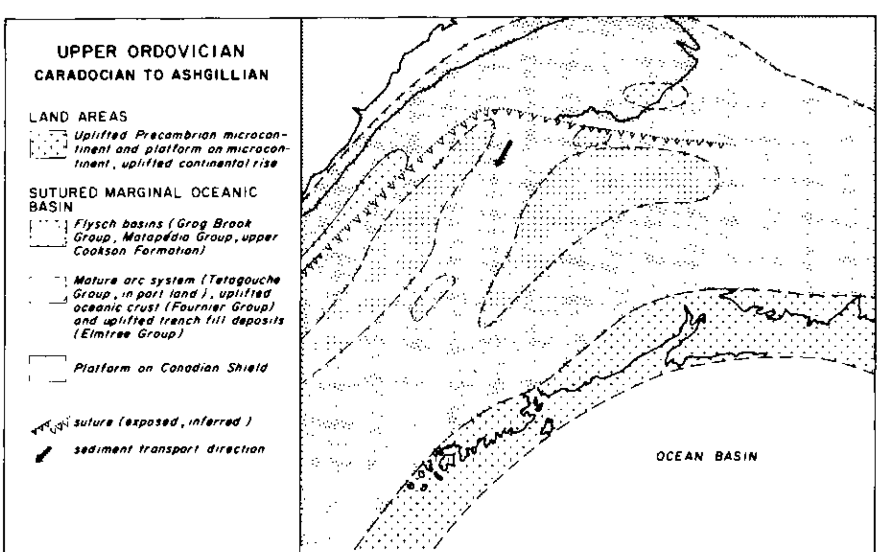


Figure 5
Schematic Upper Ordovician paleogeography and tectonic setting of New Brunswick.

Closing of the marginal oceanic basin was completed during Late Ordovician time (Taconian orogeny, Rodgers, 1971). The Tetagouche, Fournier and Elmtree Groups (zones 2 and 3) were intensely polydeformed and became part of a large geanticlinal belt. Extensive flysch basins represented by the Grog Brook and Matapedia groups, and upper Cookson Formation probably reflect synorogenic deposits (Fig. 5). In the Eastern Townships and western Newfoundland, the rise of major geanticlinal belts was accompanied by the emplacement of large allochthonous masses upon the Canadian Shield.

Evidence for polyphase deformation associated with the Taconian orogeny in New Brunswick is confined to zones 2 and 3. However, the unconformable relationships between Lower Ordovician and Silurian strata in southwestern New Brunswick does suggest regional uplift, probably accompanied by open folding, of Lower Ordovician strata in zone 4 during the Taconian orogeny

Silurian-Lower Devonian. The strata of zone 1 suggest deposition throughout Silurian time in an epicontinental sea. The argillaceous facies of the Chaleur Group and the Siegas Formation (St. Peters, in press) reflect relatively deep water, distal facies, whereas shallow water and fluviatile sedimentary rocks of the Perham Formation and Chaleur Group represent proximal facies (Fig. 6). Mainly terrestrial calc-alkaline volcanic rocks associated with the Chaleur Group might reflect local reactivation of the Tetagouche arc. Stratigraphic equivalents of the Silurian strata in zone 1 unconformably overlie the Elmtree and Tetagouche groups, suggesting that the epicontinental sea was slightly transgressive onto the mature Tetagouche arc. The abundance of volcanic fragments in the Perham Formation suggests however, that much of the mature arc was a land area during the Silurian.

In zone 4, three distinct lithofacies developed simultaneously during the Silurian: a deep water turbidite facies (Digdeguash Formation, Fredericton Trough turbidites), a shallower water facies (Waweig Formation) and a mainly submarine volcanic facies (Mascarene-Nerepis Belt). During Late Silurian and Early Devonian these deposits were covered by a relatively uniform blanket of calcareous and micaceous clastic sediments of the Flume Ridge Formation. Terrestrial and minor submarine volcanism continued north of the Mascarene-Nerepis Belt and its southwestern extension in Maine, during Early Devonian time.

The transition from deep to shallow marine, and beginning of terrestrial deposition suggests an island arc associated with closing of a marine basin. The bimodal compositional distribution and stratigraphic evidence suggests that the volcanic arc formed on sialic crust. Poole (1976) proposed that the Silurian-Lower Devonian volcanic and sedimentary rocks were deposited above a northerly dipping subduction zone, associated with closing of the oceanic basin that originated during Cambrian time (Fig. 2 to Fig. 6). This model implies that the thick turbidite sequence of the Fredericton Trough represents a behind-the-arc basin. McKerrow and Ziegler (1971), and Rast and Stringer (1975), on the other hand, suggested that the Silurian-Lower Devonian volcanism in this belt was associated with closing of the Fredericton Trough by subduction to the south. It was assumed by McKerrow and Ziegler that an oceanic trench lay along the southern margin of the Fredericton Trough. The present authors did not find evidence for oceanic trench deposits in this area, but rather suggest that this entire turbidite belt represents a continuous basin that formed on sialic crust, thus supporting the model of Poole (1976).

Middle Devonian - Carboniferous. Early-Middle Devonian was the time when most of the Northern Appalachian Belt was subjected to intense deformation (Acadian orogeny). The main or early phase of this deformation produced mainly tight folds as a result of northwest-southeast shortening (Table II). In New Brunswick, it appears that Acadian polyphase deformation was most prominent along the southern margin of zone 4 and zone 5a.

Batholiths and smaller plutons composed of granitic, mafic and locally ultramafic intrusive rocks were emplaced chiefly after the main compressive deformation phases. This is suggested by the fact that contact metamorphic aureoles of Devonian and Lower Carboniferous intrusions are generally superimposed upon the penetrative fabric, although a few plutons appear to be synkinematic.

As a result of the Acadian orogeny, marine sedimentation was mostly replaced by fluvial, non-marine sedimentation with the exception of short episodes of shallow marine transgression during the Early Carboniferous or Late Devonian in the coastal belt of southeastern New Brunswick (Ruitenberg *et al.*, 1977).

It is possible that the tectonic regime described by Poole (1976) to explain the Silurian volcanism of southern New Brunswick, continued beyond this time. This is suggested by the successive emplacement, in distentional zones north of (or behind) the Silurian island arc (zone 4b), of the Lower Devonian, mainly terrestrial volcanic complex, Middle Devonian granitic batholith with associated mafic and locally ultramafic intrusions, and Lower Carboniferous felsic intrusions and sub-volcanic stocks (Ruitenberg, 1967, 1968; Ruitenberg and Ludman, in press). Continued existence of this tectonic regime also provides an explanation for the Upper Devonian to Lower Carboniferous igneous activity and penetrative deformation associated with upwarping along the southeastern margin of the Precambrian belt (zone 5c) (Fundy Cataclastic Zone, Ruitenberg *et al.*, 1973).

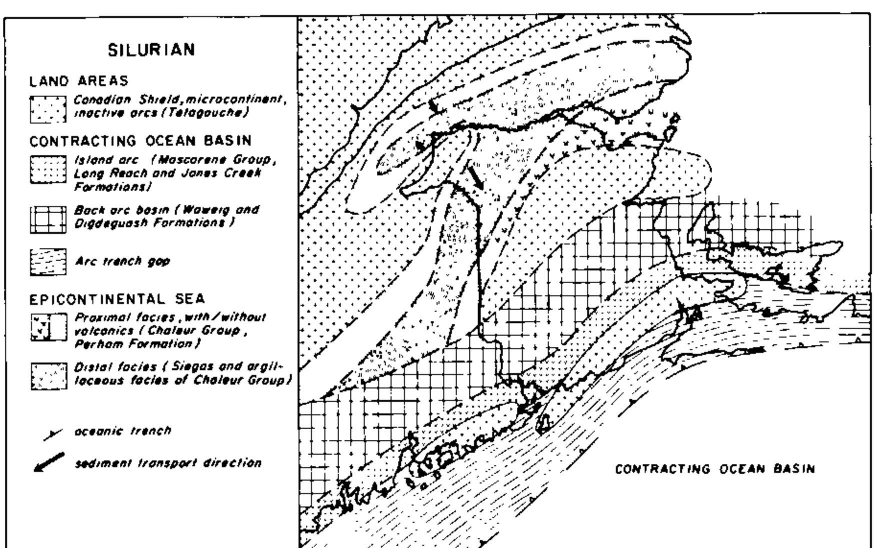


Figure 6
Schematic Silurian Paleogeography and tectonic setting of New Brunswick.

Conclusions

The tectonostratigraphic zonation of New Brunswick reflects several stages in the tectonic evolution of the northern Appalachians.

Initial distension in the Precambrian basement during the Hadrynian was accompanied by an extensive belt of active volcanism (zone 5), south of which an oceanic basin eventually formed (Poole, 1976). Thinning of the continental crust behind this volcanic belt led to the development of an epicontinental sea (on disrupted continental crust) and the formation of a microcontinental block. Continued extension between the microcontinental block and the Canadian Shield, during Cambrian time, produced a marginal oceanic basin that is reflected by ophiolitic complexes in the Eastern Townships, western Newfoundland and northern New Brunswick (zone 2).

Closing of the marginal oceanic basin by subduction to the south, during Ordovician time, led to development of a broad volcanic arc system, part of which developed on sialic crust overlain by a thick clastic wedge (Tetagouche Arc), and part on oceanic crust (Ascot Weedon arc, Eastern Townships, Quebec). Stratigraphic evidence suggests that the microcontinental block that presently constitutes much of southern New Brunswick, subsided prior to and during the development of the arc.

During the Taconian orogeny, closing of the marginal oceanic basin was completed, the Tetagouche and Fournier Groups were polydeformed and became part of a developing geanticlinal belt.

The mature Tetagouche arc provided detritus to extensive flysch basins during the late Ordovician. During the Silurian these were gradually filled and new, probably fault controlled, basins developed during the early Devonian. Associated volcanic activity was probably related to local reactivation of the Tetagouche arc.

An (ensialic) island arc developed further south (zone 4b) along the margin of the microcontinent (zone 5) during the Silurian, probably as a result of the closing by subduction to the north of the adjacent oceanic basin (south of the microcontinent) (Poole, 1976). An extensive flysch basin formed during this time behind the arc (zone 4a). Successive phases of subsequent igneous activity behind the mature arc suggests that this tectonic regime continued intermittently into Early Carboniferous time. It is notable that intense polyphase deformation associated with the Acadian orogeny (early Middle Devonian) appears to have been prominent along this belt, whereas generally only effects of one deformation phase have been found further to the north.

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