Evolution of Precarboniferous Tectonostratigraphic Zones in the New Brunswick Appalachians

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Summary
New Brunswick is divided into five tectonostratigraphic zones based upon Cambrian-Ordovician and to a lesser extent 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-stratigraphic subdivisions, based upon 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 Zieglar (1971), required revision, but some aspects of models proposed by Poole (1976) and Rast et al. (1976) are consistent with the tectonostratigraphic zonation outlined in this report.

Zone 1
Zone 1 covers a large area in northern and northeastern 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 Synciniorium, Aroostook-Matapedia Anticlinorium and Chaleur Bay Syncinorium 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
contemporaneously overlying Ashgillian to Lower Llandovery 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 basalt 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 Papelican 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 Llandovery to Ludlovian; Boucot et al., 1964) and
discontinuously 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
cololites 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
dyschoidal 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 Dalhouse Group,
and the Devonian Campbellton
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 Llandovery 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 (Nobie and Howells, 1974).

The basal rocks of the Chaleur Group
are overlain by a succession of
amygduoidal andesite and basalt, red
arkosic sandstone and volcanic boulder
conglomerate, and rhyolite of Ludlovian
(Greiner, 1970) or Wenlockian-
Ludlovian age (Potter, 1965). In the
Chaleur Bay area, the Chaleur Group is
conformably overlain by the Dalhouse
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 (Siegelsen-Emsonian). 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 structures 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 striking 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 northeastward 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 Elmree Dome and consists of the Elmree 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 Elmree 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 Elmree Group (Dean, 1975).

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

**Structure and Metamorphism.** The ophiolitic 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 TiO₂ and K₂O (written commun. G. P. Vankateswaran). These chemical characteristics and the presence of splinted basalt are consistent with the interpretation that the Fournier Group represents oceanic crust (Pajari and others, 1976).

The Elmree 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 and others, 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 migmatic 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 migmatic 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 rhyoite 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 alkaline and tholeiitic basalts are present. Upper Silurian ( Ludovician) conglomerate unconformably overlies basaltic rocks of the Tetagouche Group along the southwestern margin of the anticlinorium.

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 migmatic complex postdates the earlier Taconic 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 Taconic (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-Neripis 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-Neripis Volcanic Belt) by faults and intrusions. The southwestern part of sub-zone 4a has been referred to as the Fredericton Trough (McKerrow and Ziegler, 1971).

Six major rock 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; Rutenberg, 1967; Rutenberg 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 (1957) 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 (Rutenberg 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 II). In the Cookson Formation of the Woodland area in Maine, thick massive quartzites that underlie the graphitic slate member may extend into the Cambrian (Rutenberg and Ludman, in press).

The Waweig Formation is composed of dense, line-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 Ludovician to Pridolian (Pickett, 1979). 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 (Rutenberg, 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 greywackes; and grey and green-grey quartzose greywacke and slate. D. V. Venugopal recently mapped limestone, calcareous
sable and basalt on the northwest margin of the Fredericton Trough (not included in Table I).

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

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

The Llandoverian Quoedy Formation, that outcrops on Campbello Island, is the oldest rock unit in zone 4b. It consists of argillaceous quartzite, black slate, and felsic and mafic volcanic rocks. The Maccarion Group 1 (Ruitenber, 1972) and Long Reach Formation (Wenlockian-Ludovician: Berry and Boucot, 1970) consist of mafic and very minor felsic tuff and flows, grey slate, siltstone and sandstone. The tufa is generally bedded and pillows are common in mafic flows. These rocks are conformably overlain by the Maccarion Group 2 (Ruitenber, 1972) and Jones Creek Formation (Pridolian: Berry and Boucot, 1970) respectively. The Maccarion 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 Maccarion Group 2 and Jones Creek Formation.

The Lower Devonian Overhead 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 Maccarion-Nerapius Belt in that they are mostly welded and only rarely bedded. Most of the sedimentary rocks reflect a fluviatile depositional environment. The Overhead Volcanics are unconformably overlain by red sandstone, conglomerate and minor mafic volcanic rocks of the Upper Devonian Perry Formation (see Ruitenber, 1968).

**Structure, 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 compressive 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 (Ruitenber, 1967; Ruitenber 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 (Ruitenber, 1967, 1968; Brown and Helmaestaed, 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 Chidster 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 Neoheilkian; Hoffman, 1974). The Greenhead Group is in fault contact with, and probably underlies Hadrynian volcanic rocks of the Coldbrook Group and its stratigraphic equivalents (Ruitenber et al., 1973; Giles and Ruitenber, 1977).

The Coldbrook Group and its stratigraphic equivalents have been divided into three broad northeast-southeast 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 volcanics, 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 Acock (1938). The lowermost unit consists of continental, Lower Cambrian red and green siltstone, sandstone and conglomerate (Table I). It is overlain by the Middle and 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 (Rutenberg 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 Rutenberg, 1977; Rutenberg 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 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 Rutenberg, 1977).

Two possible tectonic interpretations have been proposed to explain the Upper Precambrian volcanism (Giles and Rutenberg, 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 fluvialite 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
suggested 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 (Rutenberg and Ludman, in press).

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

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

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**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 replacement 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 (St-Jacques 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 (Ruttenberg, 1976).

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 Cockson 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 Segas Formation (St. Peters, in press) reflect relatively deep-water, distal facies, whereas shallow water and fluvialite 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 reheating 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 (Digdeguate 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 oceanic 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. 8). 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 (Ruitenbergh 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 distalional zones north of (or behind) the Silurian island arc (zone 4b), of the Lower Devonian, mainly terrestrial volcanic complex. Middle Devonian granitic batholiths with associated mafic and locally ultramafic intrusions, and Lower Carboniferous felsic intrusions and sub-volcanic stocks (Ruitenbergh, 1967, 1968; Ruitenbergh 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, Ruitenbergh et al., 1973).

**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 episodic continental 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 Weeden 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 Fourrier 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). 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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**Figure 6**

Schematic Silurian Paleogeography and tectonic setting of New Brunswick.
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