PRE-CARBONIFEROUS METALLOGENY OF THE CANADIAN APPALACHIANS

Cees R. van Staal

Geological Survey of Canada, 601 Booth St., Ottawa, ON, K1A 0E8, Canada

E-mail: Cees.Van_Staal@nrcan-rncan.gc.ca

Introduction

The Canadian Appalachians stretch from the northernmost tip of Newfoundland through Nova Scotia, Prince Edward Island and New Brunswick into southern Quebec (Fig. 1). The Appalachian Orogen defines a linear mountain belt that was formed by the closure of the late Neoproterozoic-Early Paleozoic Iapetus and Paleozoic Rheic oceans, which led to accretion of several oceanic and continental arc terranes, and microcontinents to Laurentia.

The tectonic evolution of the Canadian Appalachians and its metallogeny is the topic of this paper. Newfoundland, of all segments of the Canadian Appalachians, is endowed with the best exposures, mainly because of its long and indented coastline, and also because of the relative scarcity of post-Ordovician cover sequences compared to maritime Canada and adjacent Quebec. Its relatively well-preserved record of Cambro-Ordovician events is generally taken as a template for the remainder of the Northern Appalachians.

Opening and Closing of the Iapetus Ocean

There is a general consensus that Laurentia formed the core of a large supercontinent, called Rodinia, during the Neoproterozoic. Protracted rifting and dispersal of Rodinia into smaller continental fragments (ca. 750-570 Ma) eventually led to the break-out of Laurentia. This new continent moved rapidly north from a high southerly latitude (Cawood et al., 2001; Buchan et al., 2004) to a near equatorial position at the terminal Neoproterozoic (Hodych et al., 2004) and the opening of the Iapetus Ocean. While Laurentia was moving north, a new large continental mass called Gondwana was being assembled at high southerly latitudes as a result of late Neoproterozoic to Early Cambrian collisions.

The southern arm of the Iapetus Ocean separated the south-facing margin of Laurentia from the west Gondwana cratons (Amazonia and Rio de la Plata), while the northern arm separated Laurentia's east-facing margin from Baltica (Meert and Torsvik, 2003), which was an isolated continen-

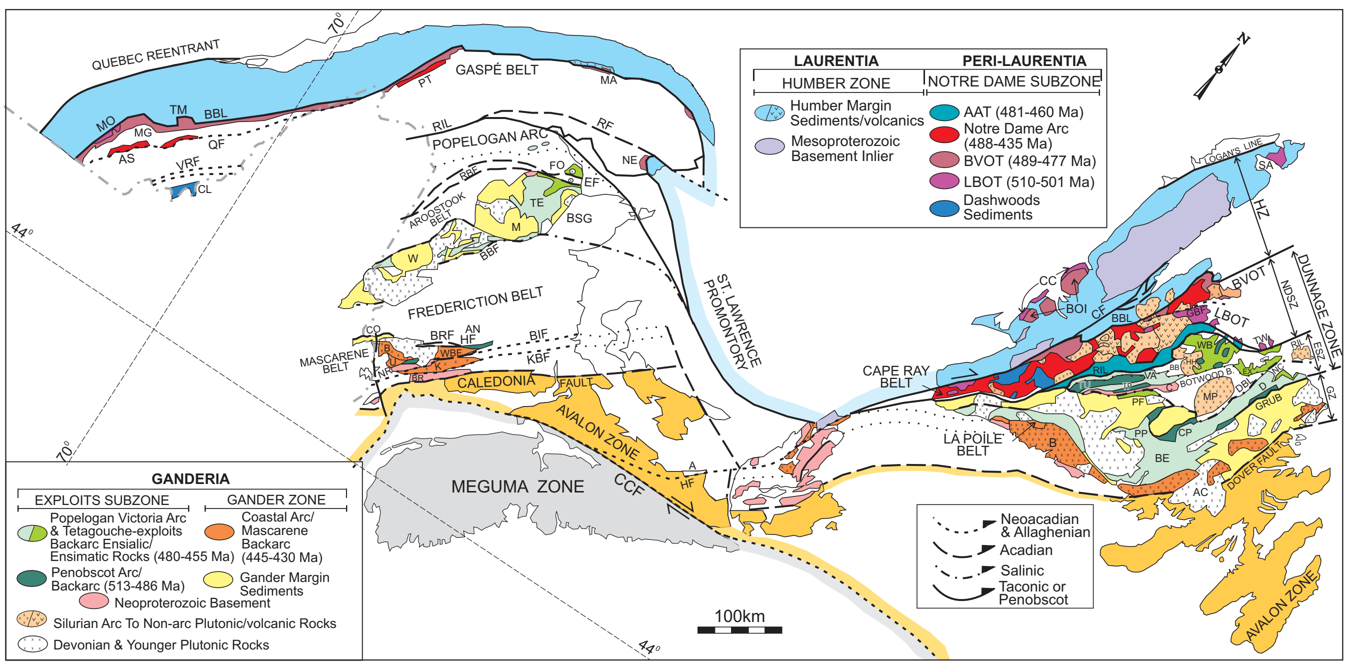

Fig. 1. Simplified geological map of the Canadian Appalachians with the distribution of the tectonostratigraphic zones, subzones and major tectonic elements discussed in text. Met. Sole: metamorphic sole; BOI: Bay of Island Complex; CC: Coastal Complex; BBL: Baie Verte Brompton Line; SA: St. Anthony Complex; HZ: Humber Zone; NDSZ: Notre Dame subzone; BVOT: Baie Verte oceanic tract; LBOT: Lushs Bight oceanic tract; RIL: Red Indian Line; TW: Twillingate trondhjemite; ESZ: Exploits subzone; WB: Wild Bight Group; EX: Exploits Group; HH: Hodges Hill Pluton; BB: Badger Belt; VA: Victoria arc; TP: Tally Pond Group; C: Cripple Back-Valentine Lake plutons; MP: Mount Peyton pluton; NC: Noggin Cove Formation; PF: Pine Falls Formation; DBL: Dog Bay Line; B: Burgeo batholith; BE: Baie d'Espoir Group; PP: Pipestone Pond Complex; CP: Coy Pond Complex; GRUB: Gander River ultrabasic belt; AC: Ackley granite

tal plate. By the end of the Cambrian (ca. 490 Ma), the southern arm of Iapetus had achieved a significant width, locally in the order of 4000- 5000 km (Johnson et al., 1991; Trench et al., 1992, MacNiocaill and Smethurst, 1994).

Iapetus was not only wide, but must also have been a complex ocean with several spreading centers. Evidence for the latter is circumstantial at best, but some of it is provided by geological evidence for Early Cambrian rifting and departure of ribbon-shaped microcontinents from the northern and southern parts of eastern Laurentia's Appalachian margin (Astini and Thomas, 1999; Waldron and van Staal, 2001). Such rifting presumably happens as a result of an inboard ridge jump (Müller et al., 2001), which, if correct, demands that a spreading ridge system must have been present near the Laurentian margin during the Neoproterozoic-Cambrian boundary. Laurentia at this time was already situated at low southerly latitudes (~ 19°S, Hodych et al., 2004), after Iapetus had already opened into a substantial ocean due to spreading accommodated by different, presumably intraoceanic spreading centers.

The closure of Iapetus' southern arm was largely responsible for the formation of the Appalachians and British Caledonides and terminated with the docking of the Avalonian microcontinent (see below); the susbsequent closure of the Rheic Ocean caused accretion of Meguma and terminated with assembly of Gondwana and Laurentia into the Pangea supercontinent. The latter was accompanied by large-scale Alleghenian-Variscan tectonic events during the Carboniferous-Permian. With the exceptions of localized deformation and plutonism associated with major strike-slip fault zones, the Canadian Appalachians largely escaped the penetrative effects of the Alleghenian terminal orogenic events and hence, these will not be discussed herein.

Cambrian-Ordovician Tectonostratigraphic Divisions

Based on sharp contrasts in lithology, stratigraphy, fauna, structure, geophysics, plutonism and metallogeny of Lower Paleozoic and older rocks, Williams (1979, 1995), Williams et al. (1988) and Williams and Grant (1998) have subdivided the Canadian Appalachians into tectonostratigraphic zones and subzones. Such divisions are useful in discussing the tectonic architecture of an accretionary orogen made up of different blocks, each of which had in part a distinct tectonic history. Hence, these zones and subzones are retained herein as a first order division to discuss the distinctive tectonic rock assemblages present in the Canadian Appalachians.

From west to east, the Canadian Appalachians have been divided into the Humber, Dunnage, Gander, Avalon and Meguma zones (Fig. 1). The Humber zone represents the remnants of Laurentia's Appalachian margin involved in Paleozoic orogenic events. The Gander, Avalon and Meguma zones, represent peri-Gondwanan microcontinents (Ganderia, Avalonia and Meguma respectively) that crossed the Iapetus Ocean and were sequentially accreted to Laurentia from the late Ordovician to Middle Devonian (450-380 Ma). In the broad sense, the Dunnage zone mainly contains the remnants of accreted continental and oceanic arc terranes that formed within the realm of the Iapetus Ocean. Based on their provenance they have been subdivided into the peri-Laurentian Notre Dame and largely peri-Gondwanan Exploits subzones (Williams et al., 1988). The latter is tectonically linked to the Gander Zone

Humber Zone

The Canadian Humber Zone occurs in western Newfoundland and southern Quebec (Fig. 1). It is underlain by the remnants of deformed Late Neoproterozoic-Ordovician rocks deposited on crystalline basement of the Grenville structural province during rifting and passive margin development. Grenvillian basement is locally exposed in western Newfoundland in a series of structural inliers (Fig. 1). Grenvillian basement is not exposed in Quebec's Humber zone, but an isolated, fault-bounded body of Grenvillian rocks is exposed in northwestern Cape Breton Island (Miller and Barr, 2000). The geometry of the Humber zone between Newfoundland and Quebec defines a large sinuous geometry (Fig. 1), which is generally interpreted to reflect a promontory-reentrant pair formed during rifting (Thomas, 1977). They are known as the St. Lawrence promontory and Quebec reentrant.

The western boundary of the Humber zone is generally defined as the limit of penetrative macroscopic Paleozoic deformation and is commonly referred to as the Appalachian structural front. The western boundary of structurally transported rocks, which is commonly coincident or nearly so with the structural front, is Logan's Line. The eastern limit of the Humber Zone is defined by a complex and long-lived fault zone marked by mélanges and numerous discontinuous ophiolitic fragments of various sizes, known as the Baie Verte-Brompton Line (BBL; Williams and St. Julien, 1982).

Commencement of rift-related activity in the Canadian segment of east Laurentia had started by at least 615 Ma (Kamo et al., 1989) and lasted until ca. 540 Ma. It resulted mainly in mafic magmatism and siliciclastic sediments deposited in fault-bounded grabens. Paleomagnetic data indicate that Iapetus must have opened by at least 570 Ma (Cawood et al., 2001). Another phase of late Neoproterozoic rifting-related magmatism (565-550 Ma) took place after this event and was followed shortly by deposition of a Lower Cambrian transgressive sequence (Figs. 2, 3), generally interpreted to represent a rift-drift transition (Williams and Hiscott, 1987; Lavoie et al., 2003). Waldron and van Staal (2001) related this event to separation of a ribbon-shaped microcontinent from Laurentia, the remnants of which have been detected at depth in the Notre Dame subzone of Newfoundland's Dunnage Zone (Fig. 1) based on isotopic evidence and the age of inherited zircons in the Lower Ordovician arc plutons (Dubé et al., 1996; Swinden et al., 1997; Whalen et al., 1997). This microcontinent is referred to as Dashwoods, which became the foundation of the continental, Early to Middle Ordovician phases of the Notre Dame arc (van Staal et al., 1998). Sparse faunal and paleomagnetic data suggests that Dashwoods remained close to Laurentia (Johnson et al., 1991; Nowlan and Neuman, 1995) from which it was separated by the Humber seaway (Waldron and van Staal, 2001). Similar lines of evidence suggest that Dashwoods or an equivalent ribbon continent along strike is also present in the subsurface of the Dunnage

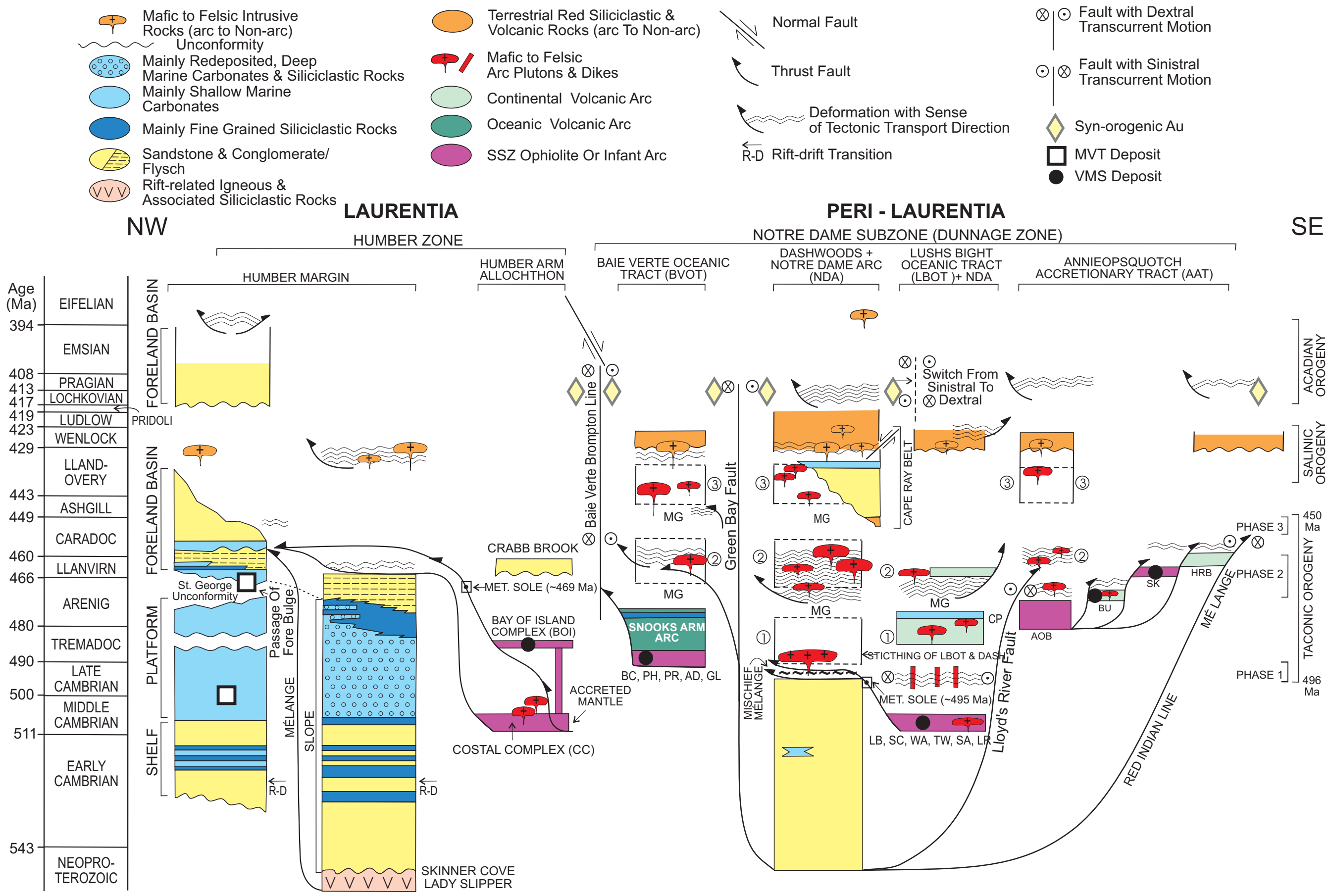

FIG. 2. Summary of the stratigrapic and tectonic evolution of the Humber zone and Notre Dame subzone in Newfoundland. AD: Advocate complex; AOB: Annieopsquotch ophiolite belt; BC: Betts Cove Complex; BU: Buchans and Robert Arm groups; GL: Grand Lake Complex HRB: Harbour round Formation; LB: Lushs Bight Group; LR: Long Range mafic-ultramafic complex; MG: magmatic gap; PH: Pacquet Harbour Group; PR: Point Rousse Complex; SA: St. Anthony Complex; SC: Sleepy Cove Group; WA: Western Arm Group.

Zone of southern Quebec (e.g. Tremblay et al., 1994).

The early stages of seafloor spreading in the Humber seaway and construction of the passive margin herein referred to as the Humber margin, start with a Lower Cambrian, dominantly siliciclastic shelf with occasional carbonate deposits (Figs. 2, 3). A carbonate platform was erected during the Middle Cambrian to Early Ordovocian (James et al., 1989) in Newfoundland. Clastic sediments, transported carbonate rocks and pelagic shales mainly characterized the passive margin's slope. The shallow-marine platform segment of the passive margin is poorly preserved in Quebec. Siliciclastic rocks deposited on the passive margin's slope and rise have been preserved mainly here (Lavoie et al., 2003).

During the middle to late Arenig (ca. 475 Ma) the passive Humber margin in Newfoundland and Quebec was converted into a convergent margin as a result of progressive loading by an overriding composite oceanic terrane comprising the Coastal Complex and Bay of Islands ophiolite (Fig. 2) and a trailing arc terrane (Notre Dame/Snooks Arm arc). The Bay of Islands ophiolite represents oceanic lithosphere formed in the Humber seaway. The closure of the Humber Seaway heralds the main phase of the Taconic Orogeny. Obduction created a foreland migrating peripheral bulge (Jacobi, 1981; Knight et al., 1991), evidence for which is provided by diachronous uplift and local karst erosion (Jacobi, 1981), and formation of a marine foreland basin. Taconic loading of the outboard part of the passive margin and formation of a marine foreland basin appears to have started slightly later, at the end of the Arenig (ca. 470 Ma), in the Quebec reentrant (Fig. 3, Malo et al., 2001; Lavoie et al., 2003).

Dunnage Zone

The Dunnage Zone mainly contains the remnants of Cambro-Ordovician oceanic infant arc (Stern and Bloomer, 1992) and arc terranes that existed within the Iapetus Ocean. The Dunnage zone is best preserved in Newfoundland, but important segments are also exposed in New Brunswick and Southern Quebec (Fig. 1). Paleomagnetic, fossil and other geological evidence indicate that these terranes either have a peri-Laurentian provenance (Notre Dame subzone) or a peri-Gondwanan provenance (Exploits subzone). This suggests that there were several subduction zones active within Iapetus at the same time. Iapetus thus was a complex ocean, more akin to the modern Pacific than the Atlantic Ocean (van Staal et al., 1998). True Iapetan oceanic lithosphere formed at mid-oceanic spreading centers, far removed from subduction zones, does not seem to have been preserved and probably was lost during subduction.

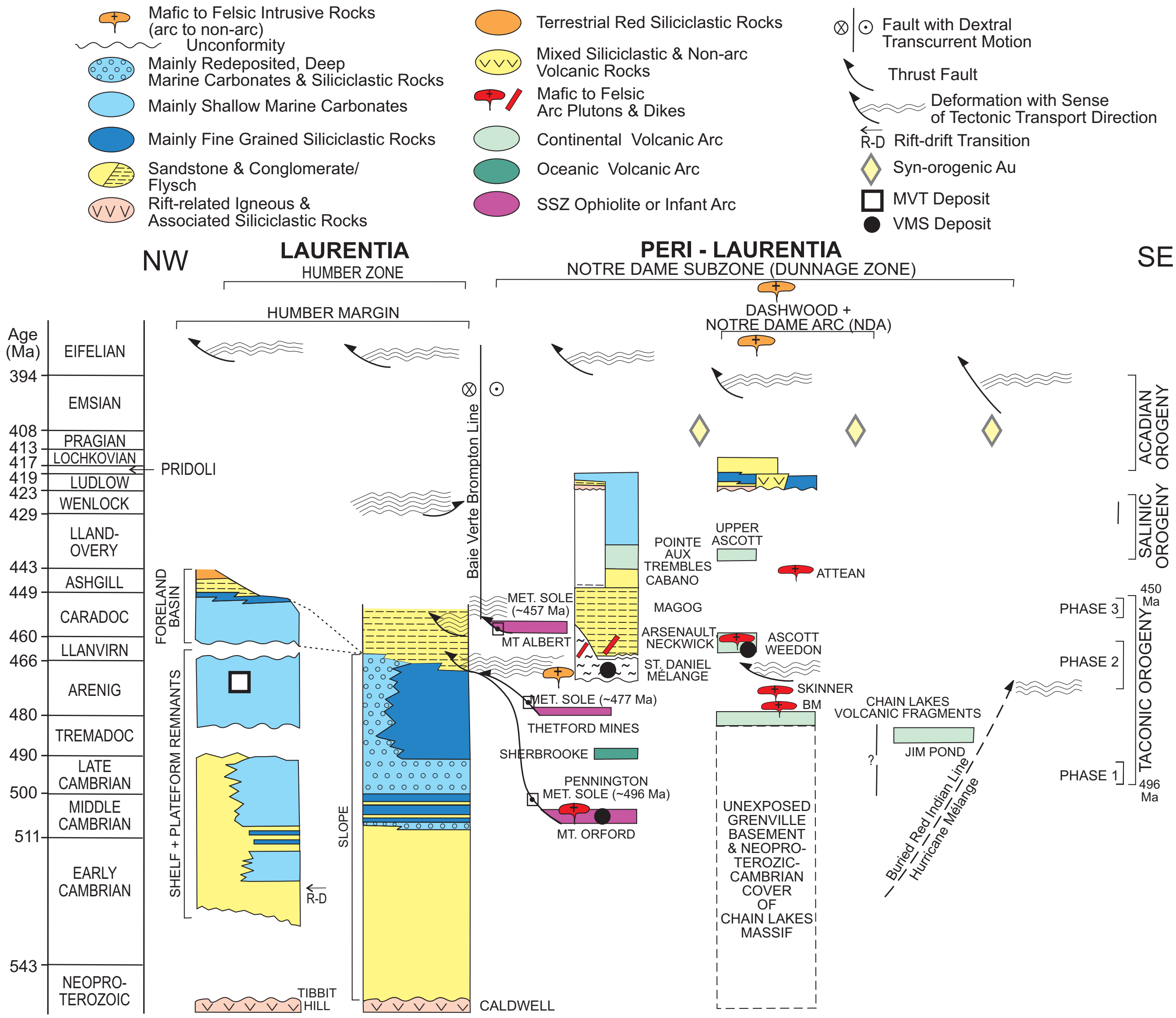

FIG. 3. Summary of the stratigrapic and tectonic evolution of the Humber zone and Notre Dame subzone in Quebec.

Notre Dame Subzone

The Notre Dame subzone (Fig. 1) is exposed in Newfoundland and Southern Quebec. It lies immediately to the east of the Humber zone separated by the Baie Verte-Brompton Line. Its eastern boundary with the Exploits subzone is defined by the Red Indian Line, a major suture marked mainly by mélanges (e.g. Sops Head-Dunnage mélange complexes; Hibbard and Williams, 1979; McConnell et al., 2002), which juxtaposes rocks formed on opposite sides of the Iapetus Ocean (Figs. 2, 4). The Red Indian Line is well exposed in Newfoundland (Williams et al., 1988), but is hidden beneath Middle Paleozoic cover sequences of the Gaspé - Aroostook belt in northernmost New Brunswick near the border with Quebec (Fig 1). It surfaces again in parts of northern Maine (van Staal et al., 1998, 2003a).

The Notre Dame subzone in Newfoundland comprises three distinct Cambrian to Middle Ordovician (507-462 Ma) oceanic terranes and a continental magmatic arc (the Notre Dame arc) built on Dashwoods. The Notre Dame arc was intermittently active between ca. 488 and 435 Ma (Fig. 4). The oldest oceanic rocks occur in the Middle to Upper Cambrian (510-501 Ma) Lushs Bight oceanic tract (LBOT; Elliot et al., 1991; Szybinski, 1995; Swinden et al., 1997), which primarily includes the Lushs Bight, Western Arm, Cutwell, Moreton's Harbour, and Sleepy Cove groups and numerous gabbroic to trondhjemitic intrusives (Fig. 4). The Cambrian Coastal Complex (CC) of Karson and Dewey (1978), which includes the arc-like Little Port Complex (Jenner et al., 1991), is preserved as an obducted sheet in the westernmost part of the Humber Zone of central Newfoundland (Fig. 1, Cawood and Suhr, 1992), and the ophiolitic St. Anthony complex in northern Newfoundland, which has an Upper Cambrian metamorphic sole (ca. 495 Ma, Jamieson, 1988; G. Dunning, pers. comm., 2004) are coeval and probably correlatives of the LBOT (Fig. 4).

The LBOT is characterized by an association of pillow basalts, sheeted dikes, gabbro and rare ultramafic rocks

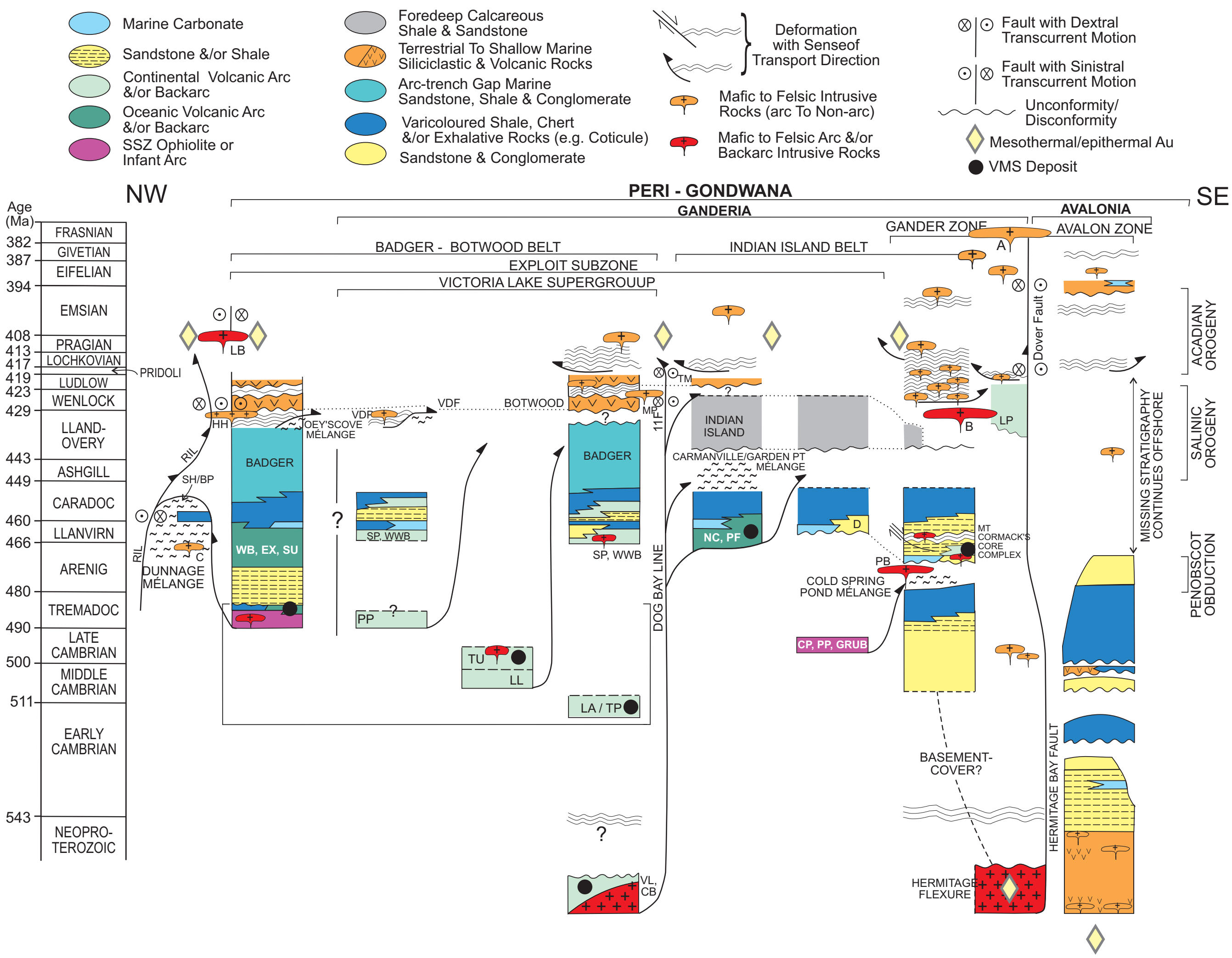

FIG. 4. Summary of the tectonostratigraphic evolution of the Exploits subzone, and Gander and Avalon zones in Newfoundland. RIL: Red Indian Line; SH/BP: Sops Head/Boones Point Complex; WB: Wild Bight Group; EX: Exploits Group; SU: Summerford Group; HH: Hodges Hill pluton; LB: Loon Bay pluton; PP: Pats Pond Group; SP:Sutherlands Point Group; WWB: Wigwam Brook Group; VDP: Victoria Delta porphyry; VDF: Victoria Delta fault; TU: Tulks Group; VL: Valentine Lake pluton; CB: Crippleback pluton; LL:Long Lake Group; LA/TP: Lake Ambrose Formation/Tally Pond Group; MP: Mount Peyton pluton; NC: Noggin Cove Formation; PF: Pine Falls Formation; TM: Ten Mile Lake Formation; CP: Coy Pond Complex; PP; Pipestone Pond Complex; GRUB: Gander River ultrabasic belt; PB: Partridgeberry granite; D: Davidsville Group; B: Burgeo granite; LP: La Poile Group; A: Ackley granite

(Kean et al., 1995), which indicate an oceanic, ophiolitic affinity. Consanguineous intrusive bodies of juvenile trondhjemite (e.g. Twillingate trondhjemite; Williams and Payne, 1975; Fryer et al., 1992) and diorite, and the abundance of boninite and primitive island arc tholeiite (Swinden, 1996; Swinden et al., 1997) suggest that this tract represents supra-subduction zone oceanic crust, probably an infant arc terrane formed during subduction initiation at ca. 510 Ma. (van Staal et al., 1998). A paleomagnetic study of the Moreton's Harbour Group yielded a low southerly latitude of ca. 10°S (Johnson et al., 1991) and suggests the LBOT formed near the Laurentian margin. This is in keeping with the low ε_{Nd} values ranging from 0 to +2.8, which suggest the presence of older crust recycled via subduction of continental-derived sediment (Swinden et al., 1997). Field relationships, structures and isotopic evidence of crustally contaminated cross-cutting dikes suggest that the LBOT was deformed and emplaced onto Laurentian continental crust (Figs. 2, 5) between 500 and 490 Ma, shortly after its formation (Szybinski, 1995; Swinden et al., 1997 and below). Relationships in the southern and central parts of the Notre Dame subzone suggest that correlatives of the LBOT, such as the ophiolitic Long Range complex (Hall and van Staal, 1999; Waldron and van Staal, 2001) were also emplaced onto the Dashwoods ribbon continent before intrusion of the ca. 488 Ma Cape Ray granodiorite (Dubé et al., 1996), which is a stitching pluton of the first phase of the continental Notre Dame arc (van Staal et al., 1998; 2003b) and formed when the subduction zone stepped back during the earliest Tremadoc (ca. 489 Ma) in the Humber seaway (Fig. 5).

Some correlatives of the LBOT, such as the Coastal Complex and St. Anthony Complex, lack evidence of ever being emplaced onto Dashwoods, suggesting that the latter did not form a continuous ribbon along the Laurentian margin. Instead these bodies apparently converged uninterrupted with the Humber margin, onto which they were emplaced during the Early Ordovician (Fig. 2). The ca. 504 Ma supra-

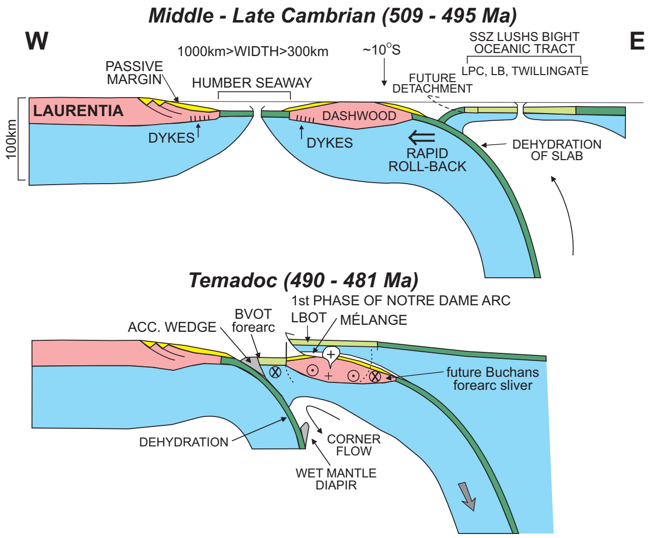

FIG. 5. Diagram with Cambrian-Early Ordovician tectonic evolution of the Humber margin and outboard peri-Laurentian terranes. Rapid hinge retreat of the east-dipping (present coordinates) Dashwoods plate is responsible for formation of the infant arc terrane represented by the Lushs Bight oceanic tract. Stepping-back of the subduction zone in the Humber Seaway produces the Baie Verte oceanic tract, and the Snooks Arm- and Notre Dame arcs.

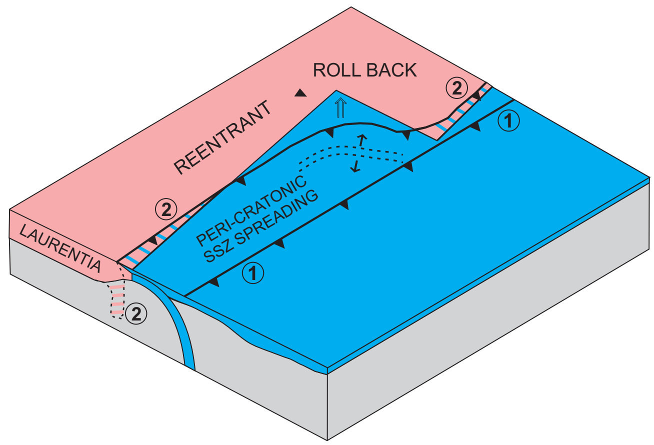

FIG. 6. Formation of peri-collisional ophiolites by spreading induced by progressive rollback of the subduction zone into oceanic lithosphere trapped in reentrants in the Humber margin.

subduction zone Mt. Orford ophiolite in Southern Quebec (David and Marquis, 1994; Huot et al., 2002) may be an equivalent of the Coastal Complex infant arc crust in southern Quebec (Figs. 1, 3).

After obduction of the majority of the LBOT onto Dashwoods, a new suprasubduction zone oceanic tract was formed during stepping back of the east-dipping subduction zone into the Humber Seaway (Fig. 5). The remnants of this oceanic tract have been preserved mainly as a narrow fault-bounded wedge along the Baie Verte Brompton line (Fig. 1) and are referred to as the Baie Verte Oceanic tract (BVOT). The ophiolitic component of the BVOT is significantly younger than its counterpart in the LBOT and has yielded two identical ages of ca. 489 Ma (Dunning and Krogh, 1985; Cawood et al., 1996). The BVOT ophiolites became the basement to an oceanic arc-back arc complex during the Tremadoc and early Arenig (487-476 Ma, Williams, 1992; Ramezani et al., 2002), referred to as the Snooks Arm arc (Bedard et al., 2000). The oceanic Snooks Arm arc is coeval with the first phase of the continental Notre Dame arc (Fig. 2). The Notre Dame and Snooks Arm arcs probably formed part of a once continuous arc system, possibly like the present day Sunda (continental) and Banda (oceanic) arcs in Indonesia. The bulk of the southern Quebec ophiolite belt and oceanic elements of the second oceanic arc of Tremblay (1992) in southern Quebec (Sherbrooke arc, Fig. 3) probably correlate with the ophiolitic foundation of the BVOT and its Snooks Arm arc suprastructure. The BVOT was emplaced diachronously onto the Humber margin during the Early Ordovician with collision taking place first along 1st and 2nd order promontories in the margin. Peri-collisional spreading in reentrants (Cawood and Suhr, 1992; Schroetter et al., 2003) due to rollback and/or transtension may have been responsible for the generation of anomalously young suprasubduction zone ophiolites such as the Bay of Islands, Thetford Mines and Mt. Albert (Fig. 6, see also below).

The continental Notre Dame magmatic arc in Newfoundland existed intermittently from ca. 488-435 Ma and is represented by three major magmatic pulses separated by two significant gaps, which are thought to be due to collisional events (Fig. 2, Whalen et al., 2003; van Staal et al., 2003b). The first phase is represented by granodiorite to diorite plutons, which ranges in age from ca. 488 Ma to 477 Ma (Szybinski 1995; Dubé et al., 1996). Isotopic evidence and inherited zircons suggest these plutons came up through continental crust of the Dashwoods microcontinent. For example the ca. 488 Ma Cape Ray granodiorite contains inherited Precambrian zircons and has a ε_{Nd} of - 4.5 (Whalen et al., 1997b). Arenig collision between Dashwoods and the Humber margin (Waldron and van Staal, 2001) led to an 8 to10 Ma gap in magmatic activity (477-467 Ma; MG in Fig. 2), to be followed by the second phase of the Notre Dame arc, which peaked from 464-456 Ma with a major flare-up of tonalite intrusions (Whalen et al., 1997a). Only two bodies are older with ages between 469 and 465 Ma (Whalen et al., 1987; Dubé et al., 1996). The third phase, mainly represented by calc-alkaline gabbro to quartz diorite, lasted from 445 to 435 Ma (e.g. Whalen, 1989), and was caused by west-directed subduction of Exploits backarc oceanic lithosphere beneath Laurentia (van Staal, 1994). Arc magmatism is followed by a 433-429 Ma mixed arc/non-arc-like bimodal suite related to break-off of the oceanic slab from the Gander margin (Whalen et al., 1996; van Staal et al., 2003b, 2004b). Equivalents of the Notre Dame arc are poorly preserved in Quebec, probably because a large part is buried beneath the Siluro-Devonian cover sequences of the Gaspé belt (Fig. 1). The Middle Ordovician-Early Silurian volcanic and plutonic rocks of the Ascot-Weedon continental arc complex (Tremblay, 1992) are correlatives of the second and third phase of the Notre Dame arc respectively. So are the Lower Silurian (early Llandovery) andesites and associated calc-alkaline igneous rocks of the Pointe aux Trembles Formation that were deposited above equivalents of the Middle to Upper Ordovician Magog Group (Fig. 3) near the border with New Brunswick (David and Gariepy, 1990). The undated gabbro-diorite sills and tuffaceous rocks in the Middle-Upper Ordovician Magog Group (Tremblay et al., 1995) probably also form part of the Notre Dame arc (Fig. 3). The Magog Group, its correlatives along strike (e.g. Neckwick and Arsenault formations in Gaspé) and the underlying St. Daniel mélange have been interpreted as a syn-collisional forearc sequence (Cousineau and St. Julien, 1992; Malo et al., 2001) to the second phase of the Notre Dame arc. Alternatively they were deposited in a back-arc basin (Kim et al., 2003).

The Arenig-Llanvirn (480-462 Ma) Annieopsquotch accretionary tract (AAT; van Staal et al., 1998, Zagrosevski et al., 2003; Lissenberg et al., in press) is the youngest oceanic terrane in Newfoundland. The AAT is sandwiched between the Lloyd's River-Hungry Mountain-Lobster Cove fault system and the Red Indian Line (Fig. 2; Colman-Sadd et al., 1992a; van Staal et al., 1998; Lissenberg and van Staal, 2002). The AAT comprises a tectonic collage of 480-473 Ma infant arc ophiolite (e.g. Annieopsquotch ophiolite belt, Lissenberg et al., in press), arc and backarc terranes (e.g. Buchan-Robert Arm belt, Swinden et al., 1997; Zagorevski et al., subm.) that formed as a result of west-directed subduction outboard of the Dashwoods (Fig. 7a). The AAT is not present in Southern Quebec, but correlatives may be exposed immediately across the border in northern Maine in the Boil Mountain and Jim Pond complexes (Gerbi et al., subm.).

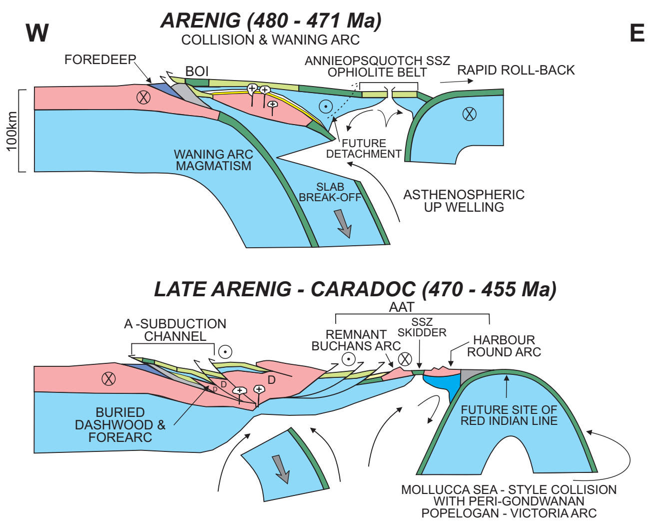

FIG. 7. A. Diagram showing the Taconic collision of Dashwoods with the Humber margin, subduction initiation west of Dashwoods responsible for the Annieopsquotch ophiolite belt; B. collisional thickening of the Notre Dame arc, breakoff of the Humber margin slab and start of accretion of the Annieopsquotch ophiolite belt.

Exploits Subzone

A nearly continuous section through the Exploits Subzone is exposed in central Newfoundland, between the Red Indian Line and the GRUB Line-Day Cove fault system (Figs. 1, 4). Its oldest Paleozoic volcanic rocks are Lower Cambrian to Tremadoc (514-486 Ma), which have been interpreted as remnants of a peri-Gondwanan arc/back arc complex (Colman-Sadd et al., 1992b; Jenner and Swinden, 1993), named the Penobscot complex (van Staal et al., 1998). The Cambrian arc elements of the Penobscot complex occur mainly in the ensialic Victoria Lake Supergroup (Dunning et al., 1991; Rogers et al., subm.), which also includes a fault-bounded belt of Late Neoproterozoic arc plutonic and volcanic rocks (565 Ma; Evans et al., 1990). Zircon inheritance of the latter in the Lower Cambrian volcanic rocks suggests a basement-cover relationship. Ensialic arc activity continued intermittently until at least 486 Ma (Zagorevski et al., 2004; O'Brien et al., 1997). The arc elements of the Penobscot complex are solely preserved in the western half of the Exploits Subzone in Newfoundland (Fig. 1), comprising both ensialic and ensimatic segments (Figs. 1, 4). They define a discontinuous belt that roughly follows the trace of the Red Indian Line. Related back-arc ophiolitic rocks (GRUB, Coy Pond and Pipestone Pond complexes) are Upper Cambrian (ca. 494 Ma; Dunning and Krogh, 1985; Jenner and Swinden, 1993) and are restricted to the eastern half of the Exploits Subzone. They are localized along the faulted boundary with the Middle Cambrian-upper Tremadoc arenites and shales of the Gander Zone (e.g. Currie, 1992), which were deposited on the leading edge of the Gondwanan Gander margin (van Staal, 1994).

Correlative volcanic rocks of the Penobscot arc/back-arc complex also occur in New Brunswick in the 497-493 Ma Annidale belt (Figs. 1, 8; McLeod et al., 1992) and the adjacent New River Belt (Johnson and McLeod, 1996). All these rocks are situated in the eastern part of the Exploits subzone or as isolated bodies within the Gander Zone. In contrast to Newfoundland, exposed equivalents of the Penobscot complex are rare or absent in the western half of the Exploits Subzone of New Brunswick. However, they may be present beneath the extensive Late Ordovician-Devonian cover of the Aroostook belt. The ca. 550 Ma Upsalquitch gabbro exposed in northwestern New Brunswick (Figs. 1, 8; van Staal et al., 1996) at the structural bottom of the Fournier nappe probably represent an example of such basement.

The Arenig composite crust of the Penobscot complex (Exploits Subzone) and Gander margin sedimentary rocks (Gander Zone) are locally disconformably overlain by Middle Ordovician rocks, which form part of an overstep sequence (Williams and Piasecki, 1990; Colman Sadd et al., 1992b) that was deposited across the whole of the Exploits subzone and part of the Gander Zone, both in Newfoundland and New Brunswick (Figs. 4, 8; van Staal and Fyffe, 1995; van Staal and Williams, 1991). Although this sequence has similar faunal characteristics and shares some lithologies across its whole width, there are also marked lithological differences from west to east. The western half is characterized by abundant arc and back-arc volcanic rock, whereas the eastern half of the Exploits subzone mainly comprises volcanogenic sandstones and shales with minor felsic and rare mafic volcanic rocks (Fig. 4, Valverde-Vaquero et al., in press). The lithological contrast between these two parts of the Exploits subzone persists into the Late Silurian. The boundary between the western and eastern halves of the Exploits subzone is the Dog Bay Line (Williams et al., 1993), which is an Early to Late Silurian suture formed after closing a wide back-arc basin, named the Exploits basin in Newfoundland and the Tetagouche basin in New Brunswick (van Staal, 1994). The western half of this back-arc basin represents the remnants of its active side (Popelogan-Victoria arc), the eastern half the passive side (Davidsville-

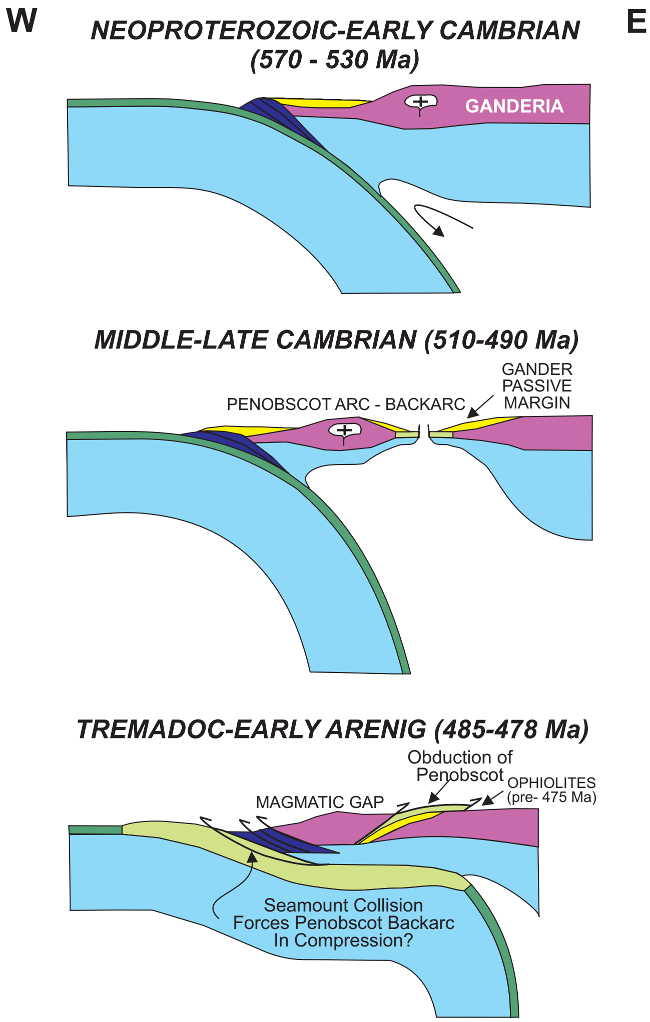

FIG. 8. Summary of the tectonostratigraphic evolution of the Exploits Subzone, and Gander and Avalon zones in Maritime Canada and Maine. GB: Grog Brook Group; CB: Chase Brook Formation (Maine); G: Goulette Brook Formation; PO:Popelogan Formation; BM: Bald Mountain volcanic sequence of Winterville Formation (Maine); M: Matapedia Group; CH: Chaleurs Group; D: Dalhousie Group; FO: Fournier Group; W: Weir Formation; LV: la Vieille Formation; SF: Simpsons Field Formation; LP: La Plante Formation; PV: Pointe Verte Formation; BL: Blueschist nappe; C: Clemville Formation; BRM: Belledune River mélange; MG: Miramichi Group; MM: Miramichi mélange: SH: Sheephouse Brook Group; TE: Tetagouche Group; CL: California Lake Group; T: Tomogonops Formation; ME: Mount Elisabeth pluton; WG: Woodstock Group; OM: Oak Mountain Formation; MEG: Meductic Group; LG: Lake St. George (Maine); L: Lincoln Sill (Maine); LOT: Liberty-Orrington thrust; BBF: Bamford Brook fault; RF: Ragged Falls pluton; SI: Simpsons Island Formation; MOL: Mosquito Lake Formation; M: Megunticook Formation; B: Battie quartzite (Maine); P: Penobscot Formation (Maine); C: Calais Formation; W: Woodland Formation; KM: Kendall Mountain Formation; CG: Cookson Group; FB: Fredericton Belt sequence; NU: North Union (Maine); MO: Mohannes pluton; SH: Spruce Head pluton (Maine); MW: Mount Waldo pluton (Maine); E: Ellsworth complex (Maine); C: Castine volcanics (Maine); LB: Lawson Brook schist; AK: Ames Knobb (Maine);P: Pocomoonshine gabbro; S: Sedgwick pluton (Maine); SPF: Sennebec Pond fault; HDF: Honeydale fault; CR: Crocker Hill Formation; GP: Goss Point Formation; MAG: Mascarene Group; KG: Kingston Group; SS: St. Stephen gabbro; KBF: Kennebecasis fault; F: Ferrona Formation; DP:Dunn Point volcanics; AG: Arisaig Group; G: Goldenville Group; H: Halifax Group; WR: White Rock Group; T: Torbrook Group: South Mountain batholith.

Cookson margin). The western half is represented by the post-Tremadoc parts of the Victoria Lake Supergroup, and Wild Bight and Exploits groups in Newfoundland, and the Balmoral Group and Bathurst Supergroup in New Brunswick (van Staal et al., 1998, 2003a). The eastern half comprises the Davidsville, Baie d'Espoir, Bay du Nord and Harbour le Cou groups in Newfoundland (Valverde-Vaquero et al., in press), and the Meductic and upper part of the Cookson Group in New Brunswick (van Staal et al., 2003a). The Popelogan - Victoria arc (PVA)/Tetagouche - Exploits back arc (TEB) system was active between 478 and 454 Ma.

Gander Zone

The Gander zone (Figs. 1, 4, 8) is defined by a distinct monotonous sequence of Lower Cambrian to Tremadoc (~520-480 Ma) arenites, siltstones and/or and shales, generally considered to represent the outboard part (outer shelf to slope) of a passive margin, the Gander margin (van Staal, 1994). This distinctive sequence can be traced from northeast Newfoundland into New Brunswick and Maine and has been called various names: Gander Group and Spruce Brook Formation in eastern and central Newfoundland, and Miramichi, Woodstock and Cookson groups in northern, eastern and southern New Brunswick, respectively. They are separated from the adjacent Avalon zone by the Dover-Hermitage Bay- Caledonia Fault system (Figs. 1, 8). Detrital zircon studies have shown that sandstones of all three groups in New Brunswick's Gander Zone have an identical provenance and are approximately coeval (van Staal et al., 2004a). The detrital zircon data combined with field relationships and scarce fossils indicate a dominantly Middle Cambrian to Tremadoc age. The Tremadoc part of the sequence is mainly represented by dark grey or black shales (van Staal and Fyffe, 1995; van Staal et al., 2003a). Field relationships and detrital zircon and titanite data indicate a similar age range in Newfoundland (O'Neill, 1991; Colman-Sadd et al., 1992b).

The Neoproterozoic rocks of the Hermitage flexure in southern Newfoundland (O'Brien et al., 1996) are generally inferred to represent basement to the Paleozoic sedimentary rocks of the Gander Zone on basis of their spatial association, isotopic signatures (Kerr et al., 1995) and Early Paleozoic orogenic overprint (Dunning and O'Brien, 1989; O'Brien et al., 1993). A basement-cover relationship, however, has not been identified anywhere in Newfoundland. Such a relationship may be preserved in southern New Brunswick where quartz-rich arenite and conglomerate of the Matthews Lake Formation disconformably overlie Cambrian and Neoproterozoic igneous rocks of the New River Belt (Johnson and McLeod, 1996). The detrital zircon content of the Matthews Lake Formation is indistinguishable from that of the Miramichi, Woodstock and Cookson groups but different from that of the Paleozoic cover on the classical Avalon Zone (van Staal et al., 2004a). Based on this and other isotopic arguments (Samson et al., 2000), the Gander and Avalon zones are thought to represent two separate peri-Gondwanan basement blocks (van Staal et al., 1996; Barr et al., 2002), named Ganderia and Avalonia (van Staal et al., 1998), which shared a somewhat similar Neoproterozoic history, although each had a distinct tectonic evolution during the Early Paleozoic.

Isotopic, detrital mineral, paleomagnetic and fossil data indicate that Ganderia's provenance is a Gondwanan craton that contains Archean, Paleo-, Meso- and Neoproterozoic rocks. On basis of a process of elimination, this craton is generally inferred to be Amazonia (van Staal et al., 1996).

Avalon zone

The Avalon Zone of the Canadian Appalachians forms part of a distinctive belt of Neoproterozoic, largely juvenile arc-related volcano-sedimentary sequences and associated plutonic rocks that experienced a complicated and long-lived tectonic history before deposition of a Cambrian-Ordovician shale- rich platformal sedimentary succession (O'Brien et al., 1996; Landing, 1996; Kerr et al., 1995). The Avalon Zone can be traced from the British Caledonides (e.g. Gibbons and Horak, 1996) to Rhode Island and in Canada comprises Eastern Newfoundland, and the Mira and Caledonia terranes of Nova Scotia and New Brunswick respectively (Barr and Kerr, 1997; Barr et al., 1998). Palaeomagnetic data indicate that Avalonia resided at high southerly latitude near Gondwana from the Middle Cambrian to the end of the Early Ordovician (Johnson and van der Voo, 1986; van der Voo and Johnson, 1985; MacNiocaill, 2000; Hamilton and Murphy, 2004) following more intermediate latitude during the Late Neoproteozoic (~ 580 Ma, McNamara et al., 2001). Fossils also show strong links to Gondwana (e.g. Fortey and Cocks, 2003), but previous proposed connections to Northwest Africa are inconsistent with a wide range of geological arguments (e.g. Landing, 1996), which led Murphy et al. (2002) to propose an alternative position opposite the Neoproterozoic northern margin of Amazonia.

Middle Cambrian to Middle Ordovician rift-related volcanic rocks are presumably mainly related to Avalonia's rifting and departure from Gondwana. Avalonia had reached intermediate latitude of ca. 32°S by the earliest Silurian (ca. 440 Ma), still ca. 1000 km away from the Laurentian margin (Hodych and Buchan, 1998). Avalonia's accretion to Laurentia during the latest Silurian is the principal cause of the mainly Early Devonian Acadian Orogeny.

Meguma Zone

The Meguma zone represents the most outboard terrane preserved in the Canadian Appalachians and is only exposed on land in southern Nova Scotia (Fig. 1). However, its regional extent is much larger and its rocks have been traced offshore by an extensive set of geophysical and well data from the southernmost part of the Grand Banks southeast of Newfoundland across the Scotian shelf, and the Gulf of Maine to southernmost Cape Cod (Hutchinson et al., 1988; Keen et al., 1991; Pe-Piper and Jansa, 1999).

The basal part of the exposed Meguma zone comprises a thick (< 10 km) Cambrian to Early Ordovician turbiditic sandstone-shale sequence of the Meguma Supergroup (Fig. 9), which was largely deposited on the continental rise and/or slope to outer shelf of a Gondwanan passive margin with the youngest part of the Halifax Group at the top of the Meguma Supergroup representing a shoaling succession (Schenk, 1997). A combination of detrital zircon, sedimentological and sparse fossil data suggest an original provenance along the Northwest African continental margin (e.g. Krogh and Keppie, 1990; Schenk, 1997), but the data set at present is relatively small and other parts of Gondwana (e.g. Arabian shield) cannot be ruled out as source areas.

The Upper Ordovician to Early Devonian, dominantly shallow marine shelf siliciclastic sedimentary rocks of the Annapolis Supergroup disconformably overlies the Meguma Supergroup. At its base, the Annapolis Supergroup includes rift-related bimodal volcanic rocks of the Late Ordovician-Lower Silurian (~ 442-438 Ma) White Rock Group (Schenk, 1997; Keppie and Krogh, 2000; MacDonald et al., 2002). These rift-related volcanic rocks, which are coeval with similar rocks in parts of the Armorican terrane assemblage, may mark the onset of rifting and departure of Meguma from Gondwana. The top of the Annapolis Supergroup comprises the Lower Devonian (Lochkovian to Emsian) Torbrook Group, which in turn is unconformably overlain by Triassic red beds; the unconformity marking the Neoacadian Orogeny (397-350 Ma; van Staal, 2005)

The Meguma zone experienced intense, puctuated orogenesis during the late Early Devonian to Early Carboniferous (~ 395-320 Ma, Hicks et al., 1999; Culshaw and Reynolds, 1997). Fossil evidence suggests that during the Late Silurian, Meguma was close to Avalonia and/or Baltica and probably separated from Gondwana (Bouyx et al., 1997). When combined with the evidence for Early to Middle Devonian orogenesis, this suggests that Meguma was a microcontinent or part thereof during at least the Silurian and Devonian, as Gondwana was not accreted until the Carboniferous-Permian Alleghanian orogeny.

Middle Paleozoic Sedimentary and Volcanic Belts

Middle Paleozoic sedimentary and volcanic rocks occur in syn-collisional and/or successor basins. Successor basins form near the end of orogenic activity on top of largely inactive fold-thrust belts (Ingersoll, 1988). However, since the Appalachians comprise many different collisional events, deposition of a successor basin above an inactive collision zone, may be syn-tectonic with respect to another convergence zone initiated elsewhere. For example a subduction-collision complex may become the foundation of a backarc or forearc basin following a subduction polarity reversal (e.g. van Staal, 1994). In general, the middle Paleozoic basins formed while orogenesis was ongoing and hence, impose important constraints on the tectonic settings. They are described below as belts following the nomenclature of Williams (1995).

Gaspé, Aroostook, Cape Ray and Badger Belts

The Late Ordovician-Early Devonian Gaspé-Aroostook belt (GAB) extends from western New England into Northern New Brunswick and adjacent Quebec (Matapedia and Gaspé) and buried the Ordovician structures associated with the Red Indian Line in Maritime Canada. The GAB continues offshore beneath the Gulf of St. Lawrence to possibly reemerge in southwest Newfoundland.

The Upper Ordovician-Upper Silurian rocks of the GAB are mainly represented by forearc siliciclastic turbidites grading upwards into more calcareous rocks to be finally replaced by Wenlock-Ludlow red beds, basalt and rhyolite (Fig. 8; Walker and McCutcheon, 1995; van Staal and de

Roo, 1995; Wilson et al., 2004), immediately prior to Upper Silurian Salinic tectonism. The unconformably overlying Early Devonian upper part was mainly deposited in a westward propagating foreland basin (Bradley and Tucker, 2002).

The Upper Ordovician-Devonian Windsor Point Group is exposed near Cape Ray in southwestern Newfoundland (Fig. 1; Chorlton et al., 1995). It comprises in part a similar lithological assemblage, including marine limestone, conglomerate, greywacke, dark shale, rhyolite and pillow basalt (Dubé et al., 1996) as that found in the GAB, and therefore may represent a continuation of this belt in Newfoundland. The rocks are highly faulted and largely buried beneath a large west-verging Acadian metamorphic thrust sheet (Dubé et al., 1996; Valverde-Vaquero et al., 2003) and hence the internal stratigraphy and its along strike continuation is difficult to decipher. However, the Windsor Point Group projects along strike into Wenlock-Ludlow terrestrial red beds and volcanic rocks (Chandler, 1982), and also possibly connects with the Badger belt (Fig. 4), which was deposited on the eastern side of the Red Indian Line (Williams et al., 1995).

The Fredericton and Indian Island Belts

The Fredericton belt exposed in central New Brunswick and adjacent New England comprises a thick sequence of Llandovery to Ludlow marine, locally slightly calcareous turbidites that nowhere are interlayered with volcanic rocks. Deposition is coeval with formation of the east-facing Brunswick subduction complex preserved in the Miramichi Highlands to the northwest (van Staal, 1994; van Staal et al., 2003a), which also provided detritus to the former. The turbidites became strongly deformed, locally with marked easterly overturned structures (Park and Whitehead, 2003), before the end of the Silurian (West et al., 1992, 2003; Tucker et al., 2001). The Fredericton belt has been interpreted as a foredeep basin formed during Early to Late Silurian loading of the passive, Davidsville-Cookson margin by the overriding Brunswick subduction complex (van Staal and de Roo, 1995). It is separated from the latter by the Bamford Brook Fault in New Brunswick and the Codyville (Ludman et al., 1993) and Liberty-Orrington faults (Tucker et al., 2001 and West et al., 2003) in adjacent Maine (Figs. 1, 8). The continuation of the Fredericton belt to the northeast is interrupted by the Gulf of St. Lawrence. However, correlative rocks in a similar tectonic setting occur in northeastern and central Newfoundland in the Indian Island belt (Fig. 4), immediately east of the Dog Bay Line (Williams et al., 1993).

Kingston, Mascarene and La Poile Belts

The Kingston and Mascarene belts in southern New Brunswick and adjacent Maine comprise spatially and tectonically related sequences of Ashgill-Pridolian volcanic and sedimentary rocks (e.g. Fyffe et al., 1999), including the paleogeographically important Ashgill limestone with Laurentian mid-continent conodonts (Nowlan et al., 1997), that overlie Neoproterozoic-Cambrian basement isotopically, geologically and geophysically linked to Ganderia (Samson et al., 2000; McLeod et al., 2001; Johnson, 2001; van Staal et al., 2004a; King and Barr, 2004). The volcanic rocks were previously thought to be dominantly Upper Silurian-Lower Devonian in age, but U-Pb age dating has shown that the volcanic rocks are dominantly Llandovery (442-435 Ma; Barr et al., 2002; Miller and Fyffe, 2002). The youngest rocks of the Mascarene Group (Eastport Formation) were even thought to be Lower Devonian on basis of ostracodes fossils (Berdan, 1971). However, these rocks are intruded by the 423±3 Ma Utopia pluton (McLaughlin et al., 2003) after or during initial inversion of the Mascarene basin (Fyffe et al., 1999). The Lower Silurian volcanic rocks have compositions indicative of arc and backarc settings (Johnson and McLeod, 1996; Barr et al., 2002). Extensive mafic dike complexes (e.g. McLeod et al., 2001), locally sheeted, confirm that this short-lived arc was extensional. A change to more within-plate signatures in the igneous rocks during the Late Silurian (Seaman et al., 1995; van Wagoner et al., 2002) may either signal a change from oceanic convergence to an oblique collisional setting with Avalonia or diminution of the subduction component as a result of injection of progressively more uncontaminated asthenosphere during continuing backarc extension. Considering the Late Silurian age of the syntectonic Utopia pluton, the former interpretation is more likely.

Elements of the Kingston-Mascarene belt continue into Cape Breton Island (e.g. Barr and Jamieson, 1991; Price et al., 1999; Barr et al., 2002) and can also be traced into Newfoundland. The Silurian volcanic and sedimentary rocks of the La Poile belt (O'Brien et al., 1991) and associated arc intrusive rocks (e.g. the ca. 430 Ma Burgeo granite; Kerr et al., 1995) along Newfoundland's south coast were deposited on or intruded into Neoproterozoic-Cambrian Ganderian basement in a similar tectonic position as the Kingston-Mascarene belt.

Both the Kingston-Mascarene and La Poile belts were strongly shortened during the Early-Middle Devonian Acadian Orogeny. The start of the Acadian orogeny is herein defined by the inversion of the Mascarene and La Poile basins, which started during the latest Silurian around 421 Ma (Fyffe et al., 1999; O'Brien et al., 1991).

Arisaig Belt and Correlatives on the Grand Banks

Siluro-Devonian rocks are rarely exposed on land in Avalonia, but a 4000 m thick, folded Ordovician-Devonian succession underlies a large part of the offshore Grand Banks (King et al., 1986; Durling et al., 1987). Their folding formed part of the Acadian Orogeny, because folded Early Paleozoic successions are unconformably overlain by Upper Devonian red beds on land (Williams and O' Brien, 1995) and offshore (Durling et al., 1987). One of the few occurrences of pre-Acadian Siluro-Devonian rocks on land is the Arisaig belt in western Nova Scotia (Murphy and Keppie, 1995). Here Silurian-Early Devonian (Lochkovian; Boucot et al., 1974), dominantly platformal siliciclastic sediments disconformably overlie Middle Ordovician volcanic rocks of the Dunn Point Formation (Hamilton and Murphy, 2004), which themselves unconformably overlie Cambrian-lower Ordovician sedimentary rocks. Subsidence analysis suggests a passive margin setting during the Llandovery/Ludlow. The

Pridolian-Lochkovian rocks at the top of the Arisaig belt on the other hand, record a significant increase in subsidence rate, indicative of tectonic loading and foreland basin formation (Waldron et al., 1996). This tectonic loading coincides with initiation of the Acadian Orogeny and the time of Avalonia's accretion to Laurentia (which by this time included Ganderia). Hence, Avalonia was the lower plate during its collision with Laurentia, which is in accord with the presence of Silurian arc/backarc volcanic rocks on the southern margin of Ganderia (Kingston, Mascarene and La Poile Belts) and seismic interpretations (van der Velden et al., 2004).

Tectonic History, Deformation and Metamorphism

The vastly expanded database, particularly the large, high quality geochronological constraints, dictate that the tectonic history of the Appalachian Orogen (500-250 Ma) must have been complex. Orogenesis started in the Cambrian and continued into the Permian. The orogenic classification used herein is based on grouping of tectonic events that are temporally, spatially and kinematically related.

Taconic Orogeny

The Taconic Orogeny encompasses all deformation related to accretionary events in the peri-Laurentian realm between the Late Cambrian and Late Ordovician (500-450 Ma). Its full spectrum of critical rock assemblages and structures are best preserved and defined in Newfoundland and are augmented herein by data from Quebec (Figs. 2, 3)

Orogenesis started with obduction of the LBOT on the Dashwoods microcontinent in Newfoundland, followed by closure of the Humber Seaway and the main Iapetan tract, which led to accretion of the Dashwoods microcontinent in the Arenig (480-475 Ma) and collision with the peri-Gondwanan Popelogan-Victoria arc during Caradoc (455-450 Ma) (van Staal et al., 1998; Waldron and van Staal, 2001). These three events are called Taconic 1, 2 and 3.

Taconic 1

The composition and lithological make-up of the LBOT suggests an ophiolitic suprasubduction zone setting, i.e. oceanic spreading above a downgoing slab (Pearce et al., 1984) at ca. 510 Ma. The absence of any remnants of a pre-existing arc along the length of the Appalachian-Caledonian mountain chain, combined with the relative abundance of boninite and trondhjemite (Swinden, 1996; Swinden et al., 1997) suggests a formation during subduction initiation (e.g. Stern and Bloomer, 1992), rather than propagation of a back-arc spreading center into an arc, which is another environment where boninites can be generated (e.g. Monzier et al., 1993). Shortly after its formation, the LBOT was obducted onto the nearby Dashwoods ribbon continent (Fig. 5; Waldron and van Staal, 2001). At some places, correlatives of the LBOT, such as the CC and St. Anthony's Complex, apparently converged unhindered with the Humber margin, suggesting that at places Dashwoods and equivalent ribbon continental fragments were absent along Laurentia's eastern margin. Intraoceanic detachment of the LBOT lithosphere and its obduction onto Dashwoods started in the Middle to Late Cambrian, between 500 and 493 Ma (Swinden et al., 1997), consistent with the U-Pb zircon age (ca. 495 Ma) of the metamorphic sole of the St. Anthony's Complex (Fig. 2). Structures other than the St. Anthony's metamorphic sole, potentially associated with these events are Middle to Late Cambrian mylonites in the Twillingate area (Williams and Payne, 1975), chloritic shear zones in Lushs Bight (Szybinski, 1995) and mélanges in the Dashwoods (Fox and van Berkel, 1988; Hall and van Staal, 1999). Upper Cambrian (500-488 Ma) crustally contaminated dikes and plutons of the Notre Dame arc cut the shear zones and mélanges (Szybinski, 1995; Swinden et al., 1997; Whalen et al., 1997b). Locally, the mylonites and chloritic shear zones accommodated a component of dextral transcurrent shear (e.g. Szybinski, 1995), which has been related to dextral oblique convergence (van Staal et al., 1998; Dewey, 2002). Structures and metamorphism that could be related to the Taconic 1 in Quebec are unknown, although some workers (e.g. Huot et al., 2002) argued for late Cambrian tectonic interaction between Laurentian continental crust and LBOT oceanic lithosphere that could correspond with Taconic 1. The Cambrian amphibolites of the metamorphic sole to the ophiolitic Belvidere Complex in northern Vermont (505-490 Ma; Laird et al., 1993), potentially a correlative of the Mt. Orford ophiolite, indicate that intraoceanic detachment had started nearly coevally with intraoceanic decoupling of LBOT lithosphere in Newfoundland.

Taconic 2

Following obduction of the LBOT onto Dashwoods in Newfoundland subduction stepped back into the Humber Seaway at ca. 490 Ma, behind the now composite Dashwoods-LBOT lithosphere (Fig. 5). This jump of the subduction zone is invoked to explain both formation of the upper Cambrian-Tremadoc volcanic and plutonic rocks of the ensialic Notre Dame arc and the ca. 489 Ma suprasubduction zone oceanic lithosphere of the BVOT. The BVOT is compositionally similar to the LBOT (Swinden et al., 1997; Bédard et al., 1998) and is for identical reasons interpreted to have formed during subduction initiation. Dashwoods inherent buoyancy probably clogged the original subduction zone and forced the latter to step-back into the Humber Seaway. The early part of the BVOT (ca. 489 Ma) is mainly preserved and localized along the Baie Verte-Brompton Line (Fig. 1) and became the foundation to a Tremadoc-Arenig (487-475 Ma) extensional oceanic arc (Snooks Arm arc; Bédard et al., 2000) that is coeval with the continental Notre Dame arc. The existence of an arc system with both oceanic and continental substrates can be explained in several ways: firstly, the Snooks Arm arc was originally positioned along strike of the Notre Dame arc in a manner similar to the present day Sunda (continental) and Banda (oceanic) arcs in Indonesia, before their present juxtaposition due to forearc translation; secondly, the arc magmatic axis gradually moved westwards onto oceanic crust situated in the Notre Dame forearc (boninite-rich lower part of BVOT, Bédard et al., 1998) due to slab rollback; or thirdly, by a combination of processes 1 and 2. Available data do not allow discriminating among the various models, although there is evidence for Early-Middle Ordovician dextral oblique convergence (Cawood and Suhr, 1992; Dewey, 2002), which was especially localized in fault splays associated with the BBL (Brem et al., 2003).

While the Dashwoods and BVOT were invaded by arc magmas during the Tremadoc (488-480 Ma), the CC experienced transtension culminating in rifting and formation of the ca. 485 Ma Bay of Islands Ophiolite Complex (BOIC) (Kurth et al., 1998; Suhr and Edwards, 2000; Dewey, 2002). The CC had not been magmatically active for at least 10 Ma before the BOIC-related spreading took place. The BOIC thus could not have formed in a back arc basin *sensu stricto*, but more likely is an example of peri-collisional spreading (Harris, 1992; Bédard and Kim, 2002) due to rollback of the downgoing slab into a second order reentrant in the Laurentian margin after clogging of the subduction zone in nearby promontories (Fig. 7). The ca. 480 Ma Thetford Mines ophiolite complex in Quebec (Dunning and Pedersen, 1988; Whitehead et al., 2000) may have formed in a similar manner as the BOIC with the nearby ca. 505 Ma Mt. Orford and Belvidere ophiolites being the equivalent of the CC (Huot et al., 2002). The present juxtaposition of these parts of the Humber margin with Dashwoods-like crust east of the Baie Verte-Brompton line mainly due to Early-Middle Ordovician dextral translation (Brem et al., 2003), i.e. with Dashwoods coming from further north, possibly the latitude of Labrador as indicated by the nature of the zircon inheritance in the Notre Dame arc plutons (Whalen et al., 1997a).

Deformation associated with Taconic 2 probably started with intraoceanic ophiolite detachment in the Humber Seaway and along strike in Iapetus where Dashwoods was absent. No dated metamorphic soles are known in Newfoundland's BVOT, but in Quebec, the $^{40}Ar/^{39}Ar$ ages on hornblende of the metamorphic sole to the ophiolitic Pennington sheet, indicate that detachment had started here by 491±11 Ma (Whitehead et al., 1996). The age of this metamorphic sole overlaps with the oldest known U-Pb ages of ophiolite complexes in the BVOT in Newfoundland (ca. 489 Ma). In general, obduction of relatively thin ophiolitic slabs must take place shortly after their formation to produce a metamorphic sole, i.e. near the spreading center from which it was generated (Casey and Dewey, 1984; Hacker, 1991).

Loading of the Humber margin by oceanic lithosphere was well under way by at least 475 Ma in Newfoundland (Fig. 2; Waldron and van Staal, 2001), which barely overlaps with the age of the BOIC metamorphic sole (469±5 Ma, Dallmeyer and Williams, 1975). This supports the argument discussed above that the BOIC was generated in a second or third order reentrant (Cawood and Suhr, 1992) and hence its obduction took place slightly later than obduction of CC and BVOT lithosphere on nearby promontories. The Mt. Albert ophiolite complex in Gaspé (Figs. 1, 3) has yielded the youngest formation and emplacement age (ca. 458 Ma; Pincivy et al., 2003) of all peri-Laurentian ophiolites. It is significantly younger than initiation of loading of the Humber margin in northeastern Quebec, which was well under way by at least 470 Ma in most parts of the Quebec reentrant (Malo et al., 2001; Lavoie et al., 2003) and hence, the Mt. Albert ophiolite like the BOIC probably also formed by peri-collisional spreading. Slab rollback of oceanic lithosphere trapped in the inside corner of the Quebec reentrant is the preferred mechanism (Fig. 1).

Several lines of evidence suggest that most of the Humber Seaway was closed before 468 Ma both in Newfoundland and Quebec, and hence the ca. 462 Ma, voluminous second phase of the Notre Dame arc (Fig. 2) cannot be explained by subduction of Humber Seaway oceanic lithosphere. First, arc magmatism in Dashwoods was inactive by at least 475 Ma, and did not flare up seriously until ca. 462 Ma (Fig. 2, van Staal et al., 2003b), the magmatic gap corresponding to the Dashwoods-Laurentia collision (Waldron and van Staal, 2001). Second, rocks of the Notre Dame arc and internal parts of the Humber margin in both Quebec and Newfoundland were strongly shortened and metamorphosed between 470 and 460 Ma (Dunning and Cousineau, 1990; Castonguay et al., 2001; Pehrsson et al., 2003; Lissenberg et al., 2004; Gerbi et al., subm.), also consistent with collision. Third, parts of the oceanic Snooks Arm arc were deeply underthrust, locally to high pressure granulite facies conditions, beneath the Notre Dame arc before 460 Ma in Newfoundland (van Staal et al., 2004b). A late syn-collisional formation of the second phase of the Notre Dame arc is also consistent with mutual-crosscutting relationships between tonalite plutons and the main phase of deformation (D_2) and associated amphibolite facies metamorphism in Newfoundland's Dashwoods subzone (Fig. 2, Pehrsson et al., 2003). A clue to their tectonic setting is provided by geochemical studies, which showed that the tonalites include a minor, but significant component of non-arc like rocks, lacking Th-enrichment with respect to Nb. High La/Yb ratios suggest that garnet was locally present in the source area of both the arc and non-arc tonalites (Whalen et al., 1997a). Combined, these relationships have been explained by magma generation following break-off of the Laurentian slab beneath a collision-thickened Notre Dame arc and mantle upwelling (van Staal et al., 2003b, 2004b). Ensialic calc-alkaline arc magmatism in the Ascott Complex in the eastern townships of Quebec also overlaps with the age of peak Taconic deformation and metamorphism here (Whitehead et al., 1996; Castonguay et al., 2001), suggesting a similar syn-collisional setting as in Newfoundland.

Taconic 3

Collision between the Humber margin and Dashwoods probably started at promontories at the end of the Tremadoc. The start of this collision is thought to be the cause of initiation of a new, west-dipping subduction zone in the Iapetus immediately to the east of Dashwoods at ca. 481 Ma. The new subduction zone generated the Arenig (480-473 Ma) Annieopsquotch infant arc ophiolite belt (AOB; Lissenberg et al., in press) and finally the Llanvirn (465-460 Ma) Red Indian Lake arc in Newfoundland (Zagorevski et al., subm.). Shortly after its formation, at ca. 470 Ma, the AOB was accreted to Dashwoods and underthrust beneath the Notre Dame arc, which led to amphibolite facies metamorphism (ca. 6 kb, 700°C), together with a crustal flake containing the Buchans-Roberts Arm belt that had moved sinistrally into the arc-trench gap. This convergence initiated the Annieopsquotch Accretionary tract (AAT) and was probably induced by transfer of convergence from the now closed Humber seaway to the infant arc oceanic lithosphere represented by the AOB that separated Dashwoods from the west-dipping subduction zone. The main Iapetan tract that was situated between the AAT and the peri-Gondwanan Popelogan-Victoria arc (PVA, Figs. 4, 8) had a width of ca. 3000 kilometers at this stage but was now being closed by two outwardly dipping subduction zones, accelerating convergence between the two opposing arcs (Fig. 9). This convergence terminated in a Moluccan Sea-style arc-arc collision in the late Caradoc (454-450 Ma), sutured along the Red Indian Line (Figs. 2, 4, 8; van Staal et al., 1998). Laurentian-derived detritus in the late Caradoc sediments of the Badger Group that conformably overlies the PVA in Newfoundland confirms that the two arcs were welded together here by this time (McNicoll et al., 2001). Arc-arc collision also terminated the Taconic Orogeny, leaving remnant Iapetan oceanic lithosphere only in the Tetagouche-Exploits backarc basin and an oceanic seaway between Ganderia and Avalonia (Fig. 10; van Staal, 1994, 2004a).

Deformation associated with Taconic 3 arc-arc convergence and collision is represented by mélanges that mark the Red Indian Line (Figs. 2, 3; van Staal et al., 1998; McConnell et al., 2002), sinistral oblique reverse faulting, thrusting and associated metamorphism in the AAT (Lissenberg and van Staal, subm; Zagorevski et al., subm.) and to a much lesser extent in the PVA. Metamorphism locally achieved amphibolite facies conditions in the AAT, but is generally of greenschist facies or lower grade. Regional assemblages with pumpelleyite, prehnite, epidote and actinolite are common in the collision zone, both in Newfoundland and Maine (e.g. Franks, 1974; Richter and Roy, 1974), suggesting tectonic burial to intermediate depths in the order of 2 to 5 kb (Liou et al., 1985). Metamorphism in the exposed part of the Popelogan arc in New Brunswick (Wilson, 2003) never exceeded zeolite facies conditions.

Penobscot Orogeny

The Early Ordovician Penobscot orogeny overlaps chronologically with the early phase of Taconic orogenesis in the peri-Laurentian realm (Figs. 2, 4) but was recognized in and is restricted to Ganderian rocks (Neuman, 1967; Colman-Sadd et al., 1992b), which at that time were situated in the periphery of Gondwana at high southerly latitudes (Liss et al., 1994; van Staal et al., 1998) on the opposite side of the Iapetus ocean. Given that the two opposing margins were ca. 4000 km apart there cannot be any tectonic link between these two orogenies, despite its loose usage to the contrary by some workers (e.g. Pinet and Tremblay, 1995).

The nature of the Penobscot Orogeny is best understood in central Newfoundland. Upper Cambrian (ca. 494 Ma) suprasubduction zone ophiolites (Coy Pond and Pipestone Pond complexes; Figs. 1, 4) obducted onto quartz arenite of

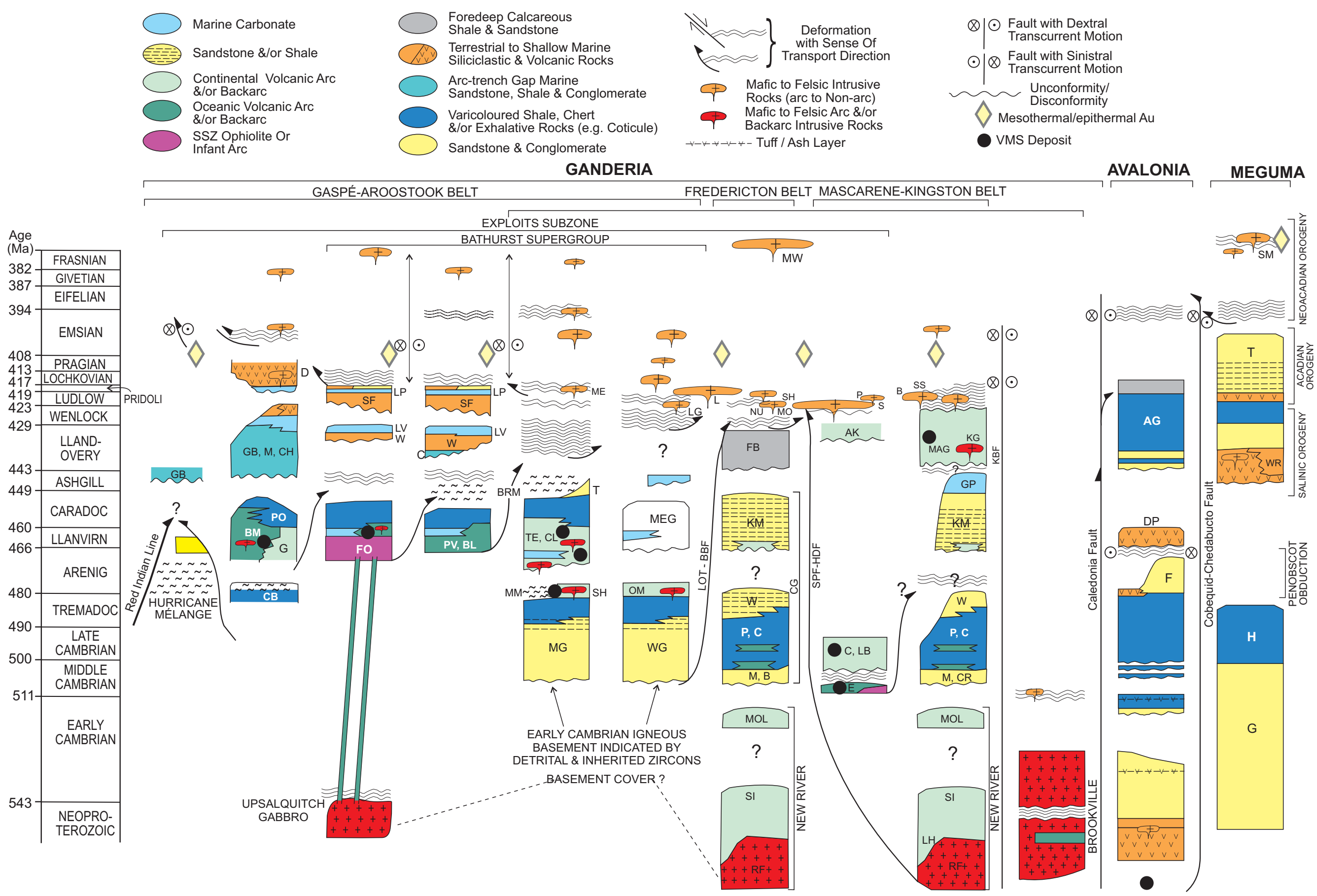

FIG. 9. Diagram showing tectonic evolution of the Popelogan/Victoria arc - Tetagouche/Exploits backarc system. Arc magmatism shuts-off in the Caradoc due to a collision with the peri-Laurentian Red Indian Lake arc. Convergence continues due to stepping back of the subduction zone into the Tetagouche/Exploits backarc basin.

the Gander margin (Colman-Sadd et al., 1992b) were stitched by Arenig (ca. 474 Ma) granite and hence, obduction must have taken place during the Tremadoc and/or earliest Arenig (van Staal, 1994). The tectonic setting of the Penobscot ophiolites is not well defined at present, but a backarc setting (Jenner and Swinden, 1993) to coeval Cambrian-early Tremadoc arc volcanic rocks in the Victoria Lake Supergroup, Wild Bight and Exploits groups (Figs. 4, 10) further to the west is most consistent with the regional geology. Such a model suggests formation of the upper plate rocks (referred to as the Penobscot arc/backarc complex) above an east-dipping subduction zone, but is opposite to the subduction polarity in the models of van Staal (1994) and MacLachlan and Dunning (1998). An overall westward younging of the Cambrian arc volcanic rocks in the Victoria Lake Supergroup (Fig. 4; Rogers et al., subm.) suggesting west-directed migration of the arc over time due to slab roll-back, is also more consistent with an east-dipping subduction polarity. The cause of the Penobscot ophiolite obduction, i.e. closure of the Penobscot backarc basin, is speculative, although the Penobscot arc remains inactive for at least 10 Ma (486-475 Ma) until its resurrection as the Victoria arc in the late Arenig (van Staal, 1994; O' Brien et al., 1997). Possibly the arc shut-off and compression in the backarc are due to the formation of a large seamount at the trench causing shallowing of the subduction angle (flat-slab subduction), which in turn increased the traction between the two plates and displaced or suppressed the asthenospheric wedge (Fig. 10). The Summerford seamount(s)-related basalts (Jacobi and Wasowski, 1985) that straddle the Red Indian Line on New World Island in northern Newfoundland also occur as large exotic blocks in the Dunnage Mélange (Wasowski and Jacobi, 1985) are in part at least Tremadoc (Kay, 1967) and may be remnants of this postulated collision (van Staal et al., 1998).

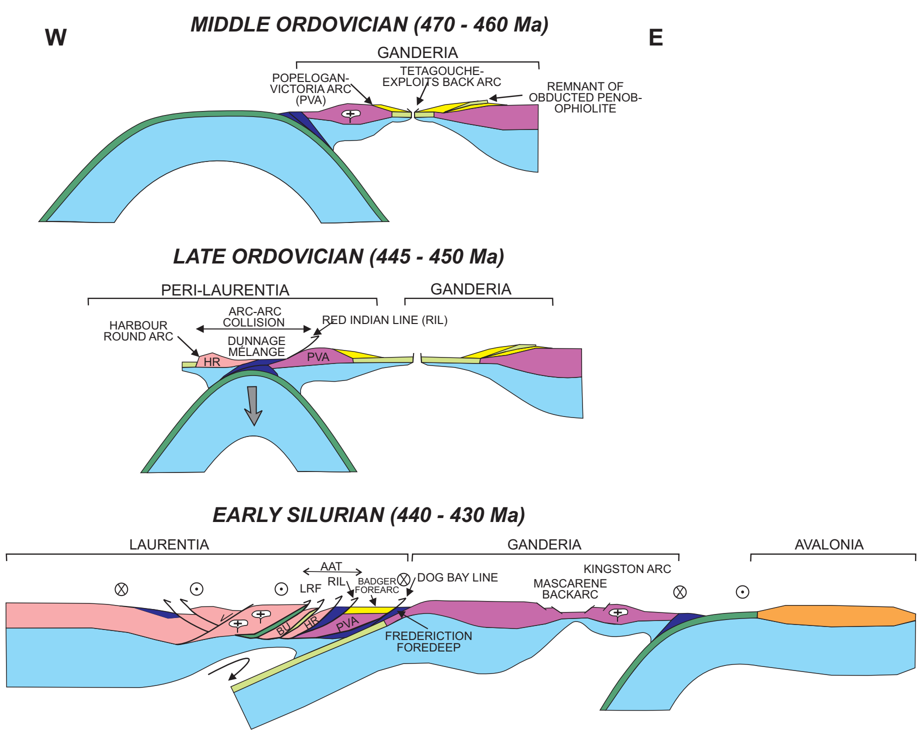

FIG.10. Tectonic history of the Penobscot arc/backarc complex.

Deformation associated with closure of the Penobscot backarc and ophiolite obduction is largely restricted to a black shale mélange containing both ultramafic and Gander Group quartzite blocks (e.g. Williams and Piasecki, 1990). Several researchers have emphasized the differences in structural intensity and complexity between the Ordovician sedimentary rocks below (Gander Group) and above (Davidsville-Baie d'Espoir groups) the obducted ophiolites and the presence of preentrainment foliations in the ultramafic exotic blocks in the mélange and conglomerates (e.g. Kennedy, 1975; Currie, 1992), suggesting that the Penobscot obduction may have caused penetrative deformation and low-grade metamorphism locally, although this needs better documentation.

Equivalents of the Penobscot complex and the orogenic effects of its emplacement are also preserved in New Brunswick and Maine (Fig. 8). Relationships with surrounding rocks are generally strongly obscured by Salinic and younger deformation (see below). The Cambrian Annidale (McLeod et al., 1992) and Ellsworth complexes in New Brunswick and Maine respectively, preserve both oceanic back-arc and arc-like rocks including locally mantle tectonites (Reusch et al., 2003) and show a spatial association with polyphase deformed Gander margin rocks (Cookson Group, Figs. 1, 8).

Salinic Orogeny

The dominantly Silurian Salinic Orogeny is a relatively newly recognized orogenic event (Dunning et al., 1990) in the Canadian Appalachians that is both kinematically and chronologically distinct from the Early Devonian Acadian Orogeny in Newfoundland and New England (van Staal, 2005). The prelude to Salinic orogenesis started in the Ashgill after the Caradoc arc-arc collision that terminated the Taconic Orogeny (see above). Sinistral-oblique convergence between Ganderia and composite Laurentia continued and was accommodated by stepping back of the west-dipping subduction zone into the Tetagouche-Exploits back arc basin (Figs. 1, 4, 8, 9; van Staal, 1994). The Tetagouche-Exploits backarc comprised a complex mosaic of small oceanic basins separated by extended continental ridges like the Sea of Japan (van Staal et al., 2003a; Valverde et al., in press). Ashgill-Llandovery (447-430 Ma) blueschists, high-pressure greenschists and mélanges occur in the east-verging Brunswick accretion/subduction complex (van Staal et al., 1990, 2003a; Currie et al., 2003). Mélanges (e.g. Llandovery Joey's Cove mélange), folds and thrust faults (Karlstrom et al., 1982; Williams et al., 1988, Elliot et al., 1991; Lafrance and Williams, 1992; Lee and Williams, 1995; Currie,

1995) are characteristic for accretion-related Salinic structures in Central Newfoundland (Fig. 4). The upwards-shallowing Badger-Botwood and Gaspé-Aroostook belts progressively filled the forearc basin (Figs. 4, 8; Pickering et al., 1988; van Staal and de Roo 1995; Kusky and Kidd, 1996; Wilson et al., 2004) of the new east-facing subduction complex (van Staal, 1994; van Staal et al., 2003a). Magmatic rocks related to this phase of subduction are represented by the third, ca. 445-435 Ma phase of the Notre Dame arc (Figs. 4, 5). This phase of the Notre Dame arc was not voluminous, which is not surprising because the backarc basin was probably not wider than 1000 km (van Staal, 1994, 2005) and hence subduction of its oceanic lithopshere was short-lived.

Lower Silurian sediments on both sides of the subduction zone remained distinct (Figs. 4, 8) and had different source areas (Williams et al., 1993; Pollock et al., 2003) until the Wenlock (ca. 425 Ma) in Newfoundland, when the basin closed along the Dog Bay Line in Newfoundland (Fig. 4, Williams et al., 1993). Terrestrial sediments were deposited on both sides of the Dog Bay Line after basin closure (Currie, 1995). Geochronological constraints on the age of structures indicate that closure was approximately coeval in New Brunswick (Bamford Brook fault system, Fig. 8) and Maine (Liberty-Orrington fault, West et al., 1992, 2003; Tucker et al., 2001). The Fredericton and Indian Island belts immediately southeast of the Salinic sutures represent marine foredeep sequences formed by tectonic loading of the backarc basin's passive margin (Davidsville-Cookson) by foreland-directed thrust sheets (Figs. 4, 5; van Staal and de Roo, 1995; Currie, 1995; Tucker et al., 2001, p. 225; Park and Whitehead, 2003). Lithological similarities between parts of the Lower Silurian forearc and foredeep sediments of the Aroostook (Central Maine belt in the USA) and Fredericton belts (e.g. Tucker et al., 2001) suggests that the forearc basin was ponded (Dickinson and Seely, 1976), i.e. sediments could spill over the forearc basin rim and be transported across the accretionary prism into the trench. Crosscutting plutons indicate that structural inversion of the Fredericton Belt in New Brunswick and Maine took place between 425-422 Ma (Fig. 8; West et al., 1992; Tucker et al., 2001), which represents the terminal phase of the Salinic collision between Laurentia and Ganderia. An inferred angular unconformity between the strongly folded, steeply dipping Lower Silurian Botwood Group and the overlying, gently dipping ca. 423 Ma Stony lake volcanics (Anderson and Williams, 1970; Dunning et al., 1990) west of the Dog Bay Line supports other evidence indicating that the Salinic Orogeny was approximately coeval in Newfoundland and New England and restricted to the Late Ordovician-Silurian. The deep crustal architecture of the Salinic orogen and the remnants of its west-dipping subduction channel have been successfully imaged on reprocessed seismic lines in Newfoundland (van der Velden et al., 2004). Deformation and metamorphism were particularly intense in the Gander Zone, both in Newfoundland, New Brunswick and southern Maine. Deformation was locally accompanied by generation of migmatites in eastern Newfoundland (Colman-Sadd et al., 1992b; D'Lemos et al., 1997; Schofield and D'Lemos, 2000) and central New Brunswick (van Staal, Fyffe and McNicoll, unpubl.). However, these parts of the Appalachians generally also underwent intense orogenesis during the Early Devonian Acadian Orogeny, obscuring relationships (Fig. 8)

The Salinic Orogeny was not restricted to the Laurentia-Ganderia collision zone, since deformed rocks occur as far west as the Humber Zone (e.g. Castonguay and Tremblay, 2003). It caused very rapid exhumation of deep levels of the Notre Dame arc in Newfoundland (Pehrsson et al., 2003), presumably involving extensional faults (although these have not been observed yet!) and west-directed thrusting and metamorphism to the rear of this arc in the internal Humber Zone (Cawood et al., 1994).

Acadian Orogeny

The Acadian Orogeny was named after the original Acadian settlements in southern New Brunswick, eastern Maine and Nova Scotia (coastal Acadia), because evidence for post Silurian, pre-Late Devonian deformation (Fig. 5) was well preserved and recognized very early on during geological investigations in these parts of the Appalachians (see Robinson et al., 1998, for a more elaborate review). Early plate tectonic models related the Acadian Orogeny to the collision between Laurentia and Avalonia (e.g. Bird and Dewey, 1970; Bradley, 1983), a causal relationship that is retained herein. However, the start and duration of the Acadian Orogeny remains a topic of discussion until today, with much of the discussion related to confusion regarding the location of the Gander -Avalon terrane boundary in Maritime Canada and New England. For example, grouping of part of Ganderia with Avalonia led some workers to include the Salinic in the Acadian Orogeny (e.g. Bradley and Tucker, 2002). Recognition that Ganderia (leading edge of Laurentia after the Salinic Orogeny, see above) has a Neoproterozoic arc-like basement that is coeval with Avalonia's (O'Brien et al., 1996; van Staal et al., 1996) is the principal culprit for most of the confusion, because it complicates delineating their boundary by first order observations. However, the former is isotopically much more evolved (e.g. Kerr et al., 1995; Sampson et al., 2000) and also has a distinctly different Late Neoproterozoic-Early Paleozoic tectonothermal history (e.g. Barr and White, 1996) than the latter, and hence the boundary between these two terranes can be mapped with some accuracy (Barr et al., 2003; van Staal et al., 2004a). It has been placed along the Hermitage Bay-Dover Fault in Newfoundland and the Caledonia Fault in Southern New Brunswick, before it is sinistrally offset by the Oak Bay fault to continue south of Grand Manan Island beneath the Gulf of Maine (Figs. 1, 4, 8). Part of the confusion is caused by the recognition of distinct late Silurian-Devonian faunal provinces (Rhenish) in Avalonia, Laurentia (Appalachian, Boucot, 1993) and part of Ganderia situated south of the Fredericton Belt (Fig. 1). However, this provinciality does not exist in the Early Silurian (R. Cocks, pers. comm., 2004) and Ashgill limestone in southern Ganderia of New Brunswick (Goss Point Formation, Fig. 8) near the Caledonia Fault contains Laurentian, mid-continent conodonts (Nowlan et al., 1997), suggesting the Late Silurian-Devonian provinciality is either climate- and/or facies-related rather than due to ocean separation.

Palaeomagnetic data show that Avalonia and Laurentia were situated within error at the same latitude during the Wenlock (ca. 425 Ma, MacNiocaill, 2000 and references therein). However, taking into account the errors involved in the plaeomagnetic data, this does not precisely constrain the timing of Avalonia-Laurentia collision (although it has to be close to this time). Time constraints are provided by syn- to late tectonic, collision-related Late Silurian-Early Devonian (420 and 400 Ma) granitoids and associated high-grade metamorphism, pervasive in eastern Laurentia (Ganderia) (Figs. 4, 5; e.g. Dunning et al., 1990; Burgess et al., 1995; Valverde-Vaquero et al., 2000, 2003; Schofield and d'Lemos, 2000), because they are coeval with cleavage development and dextral shear in the Avalonia-Ganderia boundary zone (Holdsworth, 1994; Dallmeyer and Nance, 1994) and hence postdate the onset of the Avalonia-Laurentia collision. Better time constraints are provided by geological relationships in the Kingston, Mascarene and La Poile belts and their equivalents in adjacent Maine (Fig. 1). The Kingston belt in southern New Brunswick comprises Early Silurian arc volcanic and intrusive rocks, (442-435 Ma, Doig et al., 1990; Barr et al., 2002) and continues into the coastal volcanic belt of Maine and in general, follows the Atlantic coast of the Northern Appalachian mountain belt through Cape Breton to the south coast of Newfoundland where it is truncated by the Dover-Hermitage Bay fault (Fig. 1). Hence, this arc is historically referred to as the coastal volcanic arc (e.g. Bradley, 1983). The arc rocks of the Kingston belt have been intruded by numerous mafic dikes, locally sheeted, suggesting the arc was extensional (e.g. Nance and Dallmeyer, 1993; McLeod et al., 2001). Silurian mafic dike swarms are also ubiquitous in the adjacent Mascarene belt, whose voluminous bimodal and in part consanguineous volcanic rocks generally have compositions typical of within-plate and less commonly arc environments (van Wagoner et al., 2000; McLeod, 1997) suggesting a backarc setting (Fyffe et al., 1999), with respect to the arc rocks of the Kingston belt. Hence, subduction was to the northwest beneath Laurentia (Ganderia) and Avalonia was situated on the lower plate (Fig. 9). Recent U-Pb dating of the Mascarene belt volcanic rocks, support this model since they are largely coeval (ca. 437 Ma, Miller and Fyffe, 2002) with Lower Silurian rocks in the Kingston belt, contrary to the Late Silurian-Early Devonian ages suggested by the fossils. The youngest dated volcanic rock is 423 ± 1 Ma (van Wagoner et al., 2000). Deformation and cleavage development must have take place immediately after, because the deformed Mascarene rocks are cut by the Utopia and Bocabec plutons of the St. George batholith (Figs. 1, 5; Fyffe et al., 1999), which yielded ages of 423-421 Ma, McLaughlin et al., 2003), suggesting that the whole Mascarene belt is Silurian. The Silurian La Poile basin in southern Newfoundland underwent a nearly identical tectonic history (O'Brien et al., 1991). Although arc volcanic rocks equivalent to the Kingston belt have not been recognized in southern Newfoundland, the Early Silurian Burgeo batholith (ca. 430 Ma, Dunning et al., 1990), which dominates Newfoundland's south coast, has an arc signature (Kerr et al., 1995). Silurian arc magmatic rocks in the same tectonic position occur also in Cape Breton (Barr and Jamieson, 1991; Keppie et al., 2000).

The inversion of the Mascarene and La Poile backarc basins, starting at ca. 422 Ma, therefore provides the best estimate for the onset of the Acadian Orogeny. Such an age also coincides with the latest Silurian transition from a shallow shelf to a foreland basin sequence in the Arisaig belt of Avalonia in Nova Scotia (Figs. 1, 8; Waldron et al., 1996), due to tectonic loading of Avalonia's west-facing passive margin.

The collision-related Upper Silurian-Early Devonian bimodal plutons that cut the deformed arc and back arc sequences both in New Brunswick, Cape Breton and Newfoundland, are potentially related to break-off of the oceanic slab attached to the downgoing Avalonian plate.

Neoacadian Orogeny

The Neoacadian orogeny was introduced by Robinson et al. (1998) to cover Middle Devonian to Early Carboniferous deformation and metamorphism in southern New England. These tectonic events correlate chronologically with docking and orogenesis of the Meguma terrane in Canada (Hicks et al., 1999; Keppie et al., 2002). Accretion of Meguma to Laurentia is therefore interpreted as the causative process of the Neoacadian events throughout the Northern Appalachians. Accretion was dextral oblique and largely accommodated by the Cobequid-Chedabucto fault system in Nova Scotia (Fig. 1). The provenance and drift history of Meguma are at present poorly constrained, neither is the mode of accretion well understood. At present Avalonian crust seems to be present beneath Meguma at depth, whereas upper mantle reflectors suggest a NW-dipping subduction zone was present outboard of Nova Scotia (Keen et al., 1991). Murphy et al. (1999) postulated that the dip of the subduction zone was very shallow due to interaction with a plume. I propose that Meguma transfer from the downgoing plate to the overriding Laurentian plate was accompanied by wedging of the leading (Avalonian) edge of Laurentia. Such a model also explains the absence of Devonian arc magmatism in the Laurentian upper plate.

Metallogeny

Rocks of the Canadian Appalachians are host to a large variety of mineral deposits, ranging from syngenetic volcanic-hosted massive and stockwork sulphide (VMS) deposits to chromite, PGE, gold, pluton-associated mineralization and industrial minerals (mainly asbestos, talc and building stone). Herein the mineralization specific to each of the various tectonostratigraphic zones and synorogenic belts will be described. This comprises mainly Mississippi Valley-type (Humber Zone) VMS (Dunnage and Avalon zones) and the various types of mesothermal and epithermal gold mineralization, which dominantly took place during post-Ordovician orogenic events in the tectonically active core of the orogen (central mobile belt), mainly as a result of the Silurian-Devonian accretion of the peri-Gondwanan microcontinents to Laurentia. Mineralization is commonly associated with major, accretion-related faults and/or reactivated older faults west of the Red Indian Line (Fig. 1).

The other types of mineral occurrences in the Canadian Appalachians are discussed in other contributions within this project. Extensive, relevant descriptions can be found also in Swinden and Dunsworth (1995).

Humber Zone placer and MVT Mineralization

Mineralization in the Humber Zone (pre-Appalachian mineral deposits occurring in exposed Grenvillian basement are excluded) can be divided into mineral deposits occurring in the Neoproterozoic-Cambrian rift-related sedimentary and volcanic rocks and those occurring in the overlying dominantly calcareous rocks of the passive margin phase.

Rift-related Rocks

Mineral deposits in the rift-related sandstones include marine Fe-Ti-Zr paleoplacer deposits that accumulated along the beaches and shoals of the Humber margin. They are principally known in Quebec (e.g. Ware deposit, Figs. 3, 11) and commonly associated with late Neoproterozoic rift-related volcanic rocks, which may have been an important source of the heavy minerals. Titaniferous magnetite, ilmenite, titanite, rutile, zircon, monazite and tourmaline are the principal heavy minerals found in the deposits.

The rift-related sedimentary and volcanic rocks in southern Quebec are locally also host to important Cu-mineralization (Fig. 11). Chalcopyrite and bornite are the principal ore minerals. The Harvey Hill deposit in southern Quebec has been mined and has yielded 400 000 tonnes of ore grading 1.2 % Cu and 3.6 g/t Ag. Various syngentic to epigenetic or hybrid models have been proposed to explain this mineralization.

Passive Margin-related Rocks

The Cambrian-Ordovician shelf carbonate-dominated successions of the Humber margin are host to important Zn ± Pb ± Ba mineralization, both in Newfoundland and southern Quebec (Fig. 4). The mineral deposits are generally considered to have formed by Mississippi Valley-type (MVT) metal-bearing brines generated and expelled during the Early to Late Ordovician Taconic orogeny as a result of emplacement of the large thrust sheets onto the Humber margin (Figs. 2, 3, 5). In Newfoundland Zn ± Pb mineral deposits are commonly hosted in strata that experienced extensive dolomitization, karstification and brittle fracturing. They principally occur in fractures, stylolites or veinlets in Cambrian dolostone and as disseminated to semi-massive bodies in pseudobreccias and open spaces in dolomitized Ordovician limestone. The largest and best-known deposit is the Daniel's Harbour mine (Fig. 11), which was mined between 1975 and 1990 and contained 6.6 million tones of ore grading 7.9 % Zn. Another important occurrence is the Round Pond deposit west of Hare Bay (Fig. 11) with 400 000 tonnes grading 2% Zn.

In Quebec the stratabound Upton Ba-Zn-Pb deposit (Fig. 11) with 960 000 tonnes of ore grading 46.5% Ba, 1.94 % Zn, 0.59 % Pb, 0.15 % Cu and 13.5 g/t Ag is the best-known MVT-occurrence (Paradis et al., 2004). The deposit is hosted by Lower Ordovician crinoidal limestone and the sulphides occur in disseminations and aggregates filling fractures and open spaces, along stylolites and barite and calcite grain boundaries. Basinal metal-bearing brines migrated through the margin strata during Taconic loading and sulphides were deposited when the fluids encountered H2S-rich traps in the carbonate host rock (Paradis et al., 2004). The Saint-Fabien deposit is an important MVT-occurrence (Beaudoin et al., 1989). Here the mineralization mainly occurs as stratabound barite-sphalerite-galena veins and as disseminations in cavities in partially dolomitized limestone conglomerates and sandstones of the Upper Cambrian Saint-Damase Formation (Lavoie et al., 2003).

Notre Dame Subzone VMS Deposits

The Lower to Middle Cambrian (510-501 Ma) ensimatic rocks of the LBOT are the oldest known rocks in the Notre Dame subzone (Figs. 1, 2, 12). They mainly represent the upper crustal remnants (basalts and sheeted dykes) of an

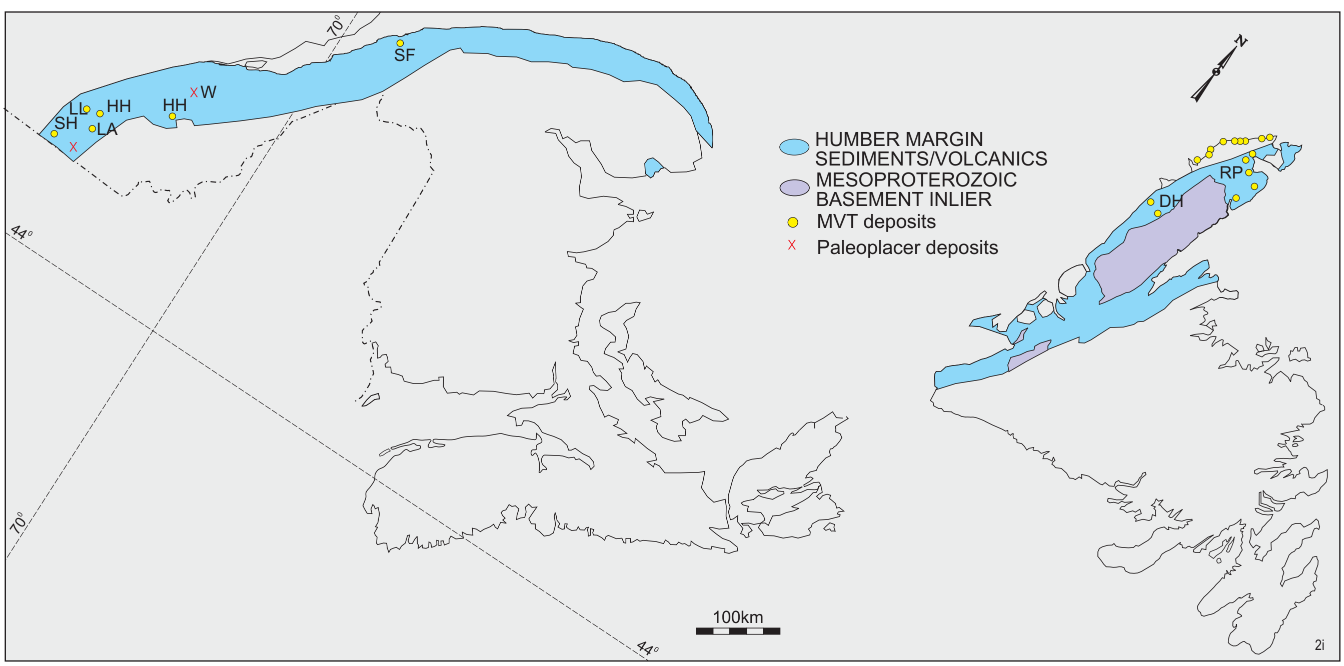

FIG.11. The Humber Zone with the distribution of the various mineral deposits discussed in the text.

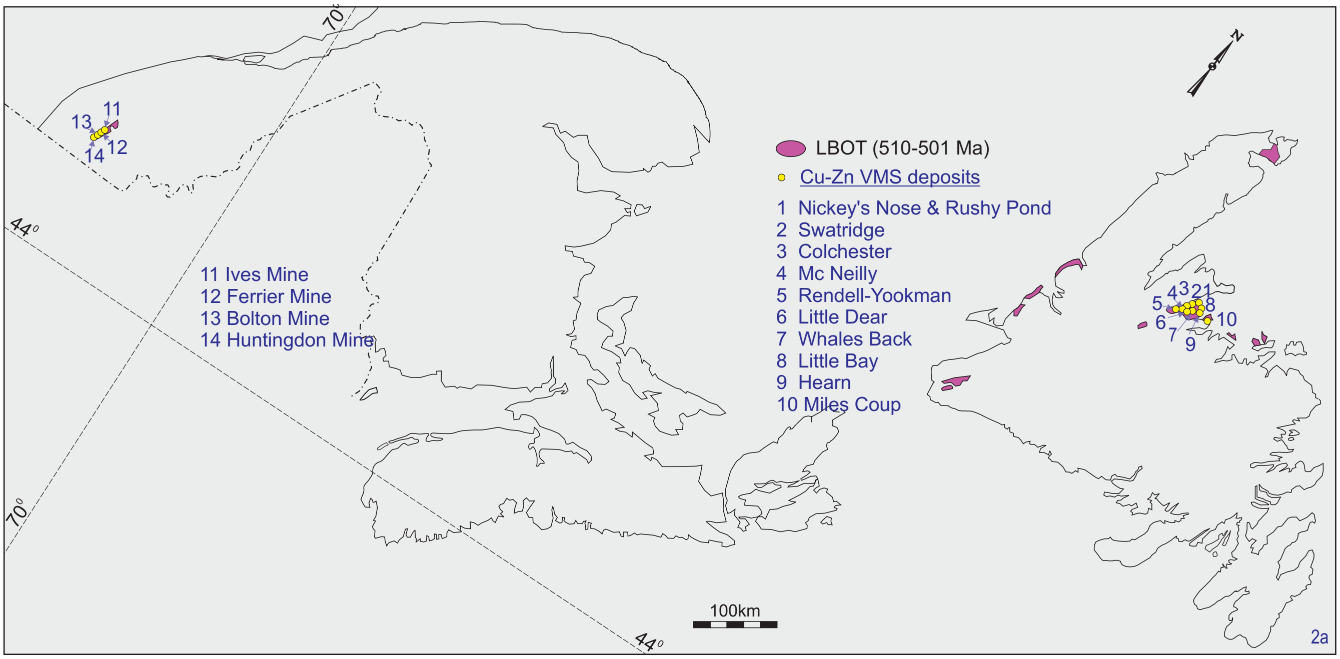

FIG. 12. VMS deposits in elements of the Lushs Bight oceanic tract.

obducted ophiolitic infant arc terrane that was emplaced on the Dashwoods microcontinent during the Late Cambrian, and where the latter was absent, directly onto the Humber margin during the Early Ordovician. The LBOT is host to numerous economically significant syngenetic Cu ± Zn ± Au VMS deposits (Fig. 12), which are commonly spatially associated with occurrences of boninitic lavas and/or dykes. In the Lushs Bight type area of northern Newfoundland, the Little Bay (>3 M tonnes of 0.8-2.5 % Cu), Whalesback (3 800 000 tonnes of ca. 1% Cu), Little Deer (ca. 75 000 tonnes of 1.3 % Cu), Swatridge, Colchester, Mcneilly and Miles Cove deposits have been mined in the past (Swinden and Dunsworth, 1995). The Chimney Cove deposit forms part of the Coastal Complex.

The only known potential equivalent of the LBOT in southern Quebec is the ca. 504 Ma Mt. Orford ophiolite complex (Figs. 1, 3, 12), which is host to four mined Cu ± Zn ± Au VMS deposits: the Huntington (1.1 000 000 tonnes of 0.9 % Cu, 0.062 g/t Au and 0.62 g/t Ag with unmined reserves of 800 000 tonnes of 0.88 % Cu), Bolton, Ferrier and Ives mines (Gauthier in Swinden and Dunsworth, 1995).

The BVOT in Newfoundland is a significantly younger Early Ordovician (ca. 489-476 Ma) belt of ophiolitic infant arc rocks with a cover consisting of arc/backarc volcanic rocks (Snooks Arm arc). The BVOT formed during Early Ordovician closure of the Humber Seaway (Fig. 5) and is mainly preserved as a fault bounded wedge along the BBL between Grand Lake and Baie Verte peninsula (Fig. 13). The

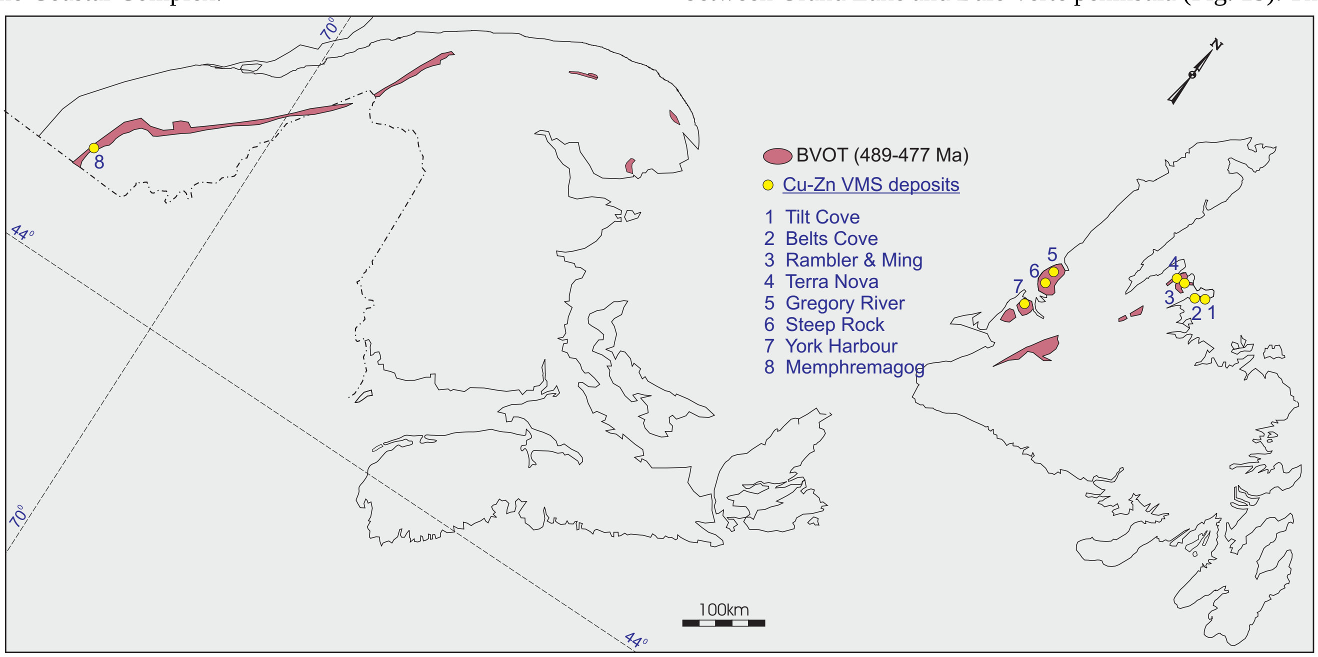

FIG. 13. VMS deposits in the Baie Verte oceanic tract.

tectonically related Bay of Islands Complex, which probably formed as a result of peri-collisional spreading in a reentrant (Fig. 6), was emplaced as large coherent allochthon (Humber Arm allochthon) onto the Humber margin during the Arenig and occurs to the west of the BBL (Figs.1, 13). The ophiolitic members of BVOT host numerous economically important Cu ± Zn ± Au ± Ag VMS deposits in Baie Verte Peninsula of which the Tilt Cove (> 8 M tonnes), Betts Cove (118 000 tonnes of 10% Cu), Rambler-Ming (4 500 000 tonnes) have been mined (Fig. 13). The VMS deposits are commonly associated with boninitic volcanic rocks. The Bay of Island ophiolite is also host to numerous cupriferous VMS deposits of which the York Harbour mine has yielded 91 000 tonnes of ore with reserves of 200 000 tonnes grading 2.68% Cu, 8.25 % Zn, 35-70 g/t Ag and < 1 g/t Au. The Gregory River, Steep Rock and Crabb Brook are related deposits (Kean et al. in Swinden and Dunsworth, 1995).

Several small cupriferous massive sulphide deposits hosted by the boninite and island arc tholeiite lavas of the Sherbrooke domain of the Ascott Complex (Tremblay et al., 1989; Tremblay, 1992) represent examples of BVOT-related VMS mineralization in southern Quebec (Gauthier in Swinden and Dunsworth, 1995).

There is no known significant, mineralization in the infrastructure of the Notre Dame arc in Newfoundland. The calc-alkaline ensialic volcanic rocks of the Middle Ordovician Ascott Complex and Weedon Formation in southern Quebec (Figs. 1, 3, 14; Tremblay et al., 1989), which represent part of the suprastructure of the second phase of the Notre Dame arc in Quebec, on the other hand are host to several important Zn ± Pb ± Cu VMS deposits of which the Eustis-Albert (ca. 1 600 000 tonnes of ore grading 2.7 % Cu), Suffield (508 000 tonnes grading 7% Zn, 0.52% Pb, 0.91% Cu), the Aldermac-Moulton hill (300 000 tonnes grading 5.32% Zn, 1.89% Pb, 1.17% Cu) and Cupra-d'Estie (2 180 000 tonnes of ore grading 2.4 % Zn, 0.2 % Pb, 1.9 % Cu, 37.7 g/t Ag and 0.5 g/t Au) were mined in the past (Gauthier in Swinden and Dunsworth, 1995).

The Middle to Upper Ordovician Magog Group, generally thought to represent the upper part of a syn-collision forearc sequence (Cousineau and St. Julien, 1992; Schroetter et al., 2003), contains several VMS deposits hosted by black shales and felsic tuffs. The largest of these is the Champagne deposit with reserves of 172 000 tonnes grading 2.68% Zn, 0.45% Pb, 0.4% Cu, 19.7g/t Ag, and 2.1g/t Au. The Bolton volcanic and sedimentary rocks in the BVOT, which occur further south (Fig. 13) near Lake Memphremagog, supposedly represent the lower part of this forearc sequence, because they occur within the St. Daniel mélange. They host the polymetallic (Zn-Cu-Pb-Sn-Sb-Ag) Memphremagog massive sulphide deposit (Trottier et al., 1991). Forearc basins, particularly those formed during obduction and collision should not be volcanically active. The igneous rocks and associated VMS deposits of the St. Daniel mélange and Magog Group are therefore better interpreted as a rift sequence, either a backarc basin (Kim et al., 2003) or a transtensional basin (Trottier et al., 1991). The latter possibly associated with slab break-off.

No VMS deposits are known in the ca. 480 Ma Annieopsquotch ophiolite belt of the AAT. The ca. 473 Ma ensialic Buchans Arc, formed during west-directed subduction beneath a tectonic sliver of Dashwoods lithosphere incorporated in the AAT (Figs. 2, 5; Zagorevski et al., 2003, subm.), is host to the important Buchans VMS deposit (Fig. 15), which yielded 16 196 876 tonnes of high grade ore (14.51% Zn, 7.56% Pb, 1.33% Cu, 126g/t Ag and 1.37g/t Au) during mining between 1928 and 1984 (Thurlow 1990). Pilley's Island, Gullbridge (3 M tonnes of ore with 1.1% Cu), Lake Bond and Shamrock (Fig. 15) are other VMS deposits in this arc sequence (Swinden and Dunsworth, 1995). The Buchans arc was rifted during the Middle Ordovician, which led to opening of a small backarc basin (Skidder backarc, Fig. 5) at ca. 465 Ma and migration of the active part of the arc trenchwards. The ensimatic Sidder basalt is host to a cupriferous VMS deposit with reserves of ca. 200 000 tonnes grading ca. 2% C and 2% Zn.

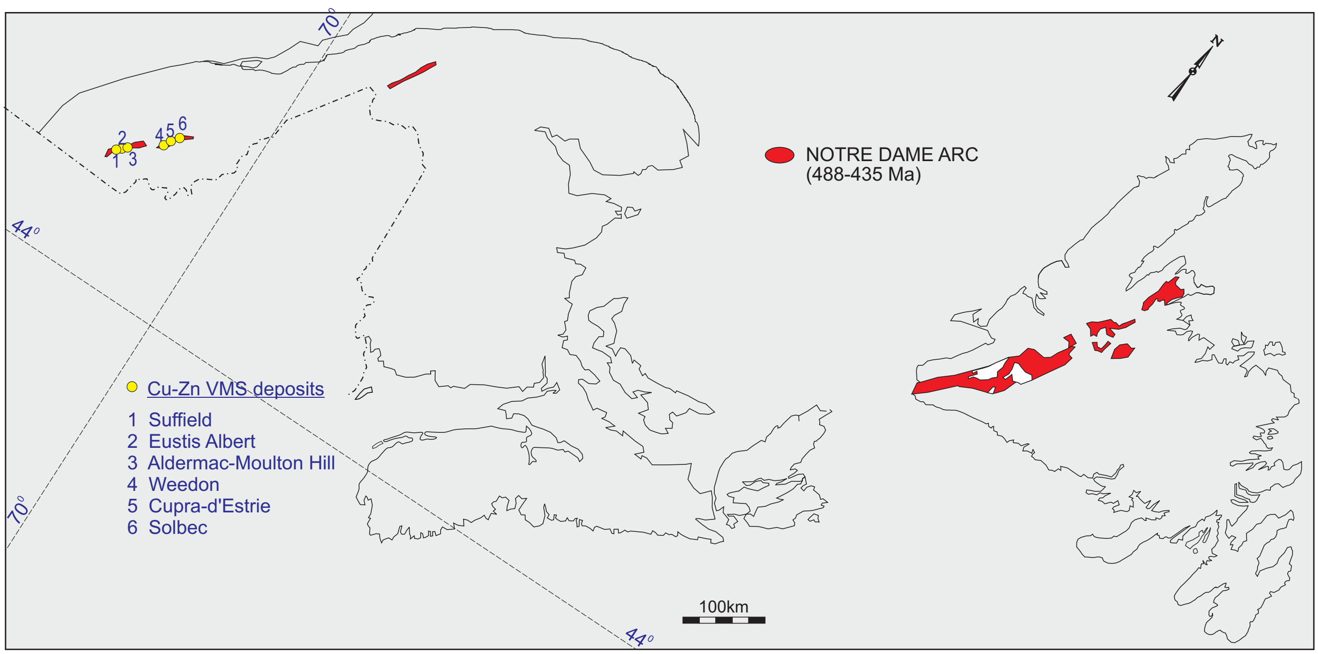

FIG. 14. VMS deposits in elements of the Notre Dame arc.

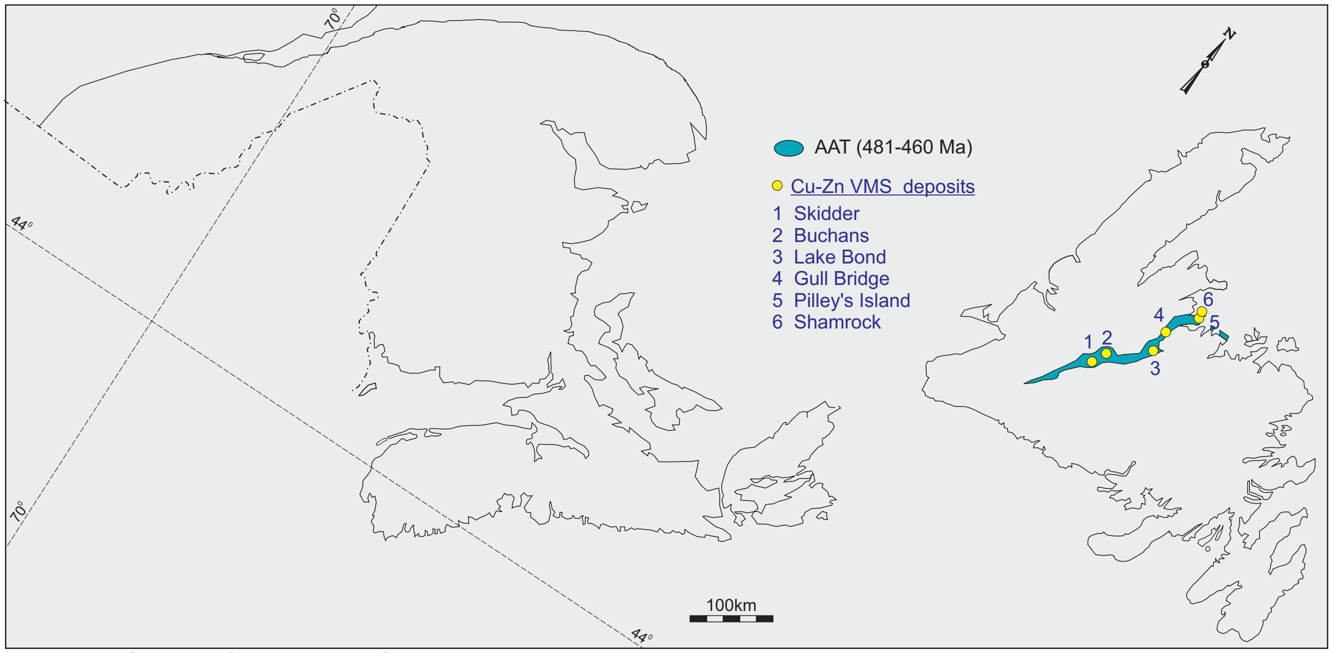

FIG. 15. VMS deposits in the Annieopsquotch accretionary tract.

Exploits Subzone VMS Deposits

The oldest known VMS deposits of the Exploits subzone occur in the Lower Cambrian (ca. 513 Ma) Tally Pond volcanic rocks (Penobscot arc) of the Victoria Lake Supergroup in central Newfoundland (Figs. 1, 4). Felsic volcanic rocks host the Duck Pond, Boundary and Burnt Pond deposits (Fig. 16), of which the Duck Pond has reserves of ca. 4 300 000 tonnes grading 3.58% Cu, 6.63% Zn, 1.05% Pb, 68.31g/t Ag, and 1g/t Au. A slightly younger phase of the Penobscot arc is represented by the Upper Cambrian, predominantly felsic volcanic rocks of the Tulks Group(ca. 498 Ma), which host the Tulks Hill, Tulks East, Daniel's Pond, Bobby Pond and Victoria Mine VMS deposits. The economically most important, the Tulks Hill deposit, contains 750 000 tonnes grading 5-6% Zn, 2% Pb, 1.3% Cu, 41g/t Ag and 0.4g/t Au. Equivalent rocks occur in the Annidale belt in southern New Brunswick, which host several cupriferous massive sulphide deposits. The Annidale belt probably formed in the Penobscot backarc basin (McLeod et al., 1992)

Early Tremadoc (488-485 Ma), predominantly mafic volcanic rocks of the Pats Pond (Victoria Lake Supergroup), the Wild Bight and Exploits groups represent the youngest phase of the Penobscot arc. The Wild Bight contains the Point Leamington, Lockport, Indian Cove and Long Pond deposits; the Exploits Group contains the Tea Arm and Strong Island deposits (Fig. 16). The Point Leamington, the largest of these deposits is hosted by rhyolite and contains 13 800 000 tonnes of massive sulphide grading 1.92% Zn,

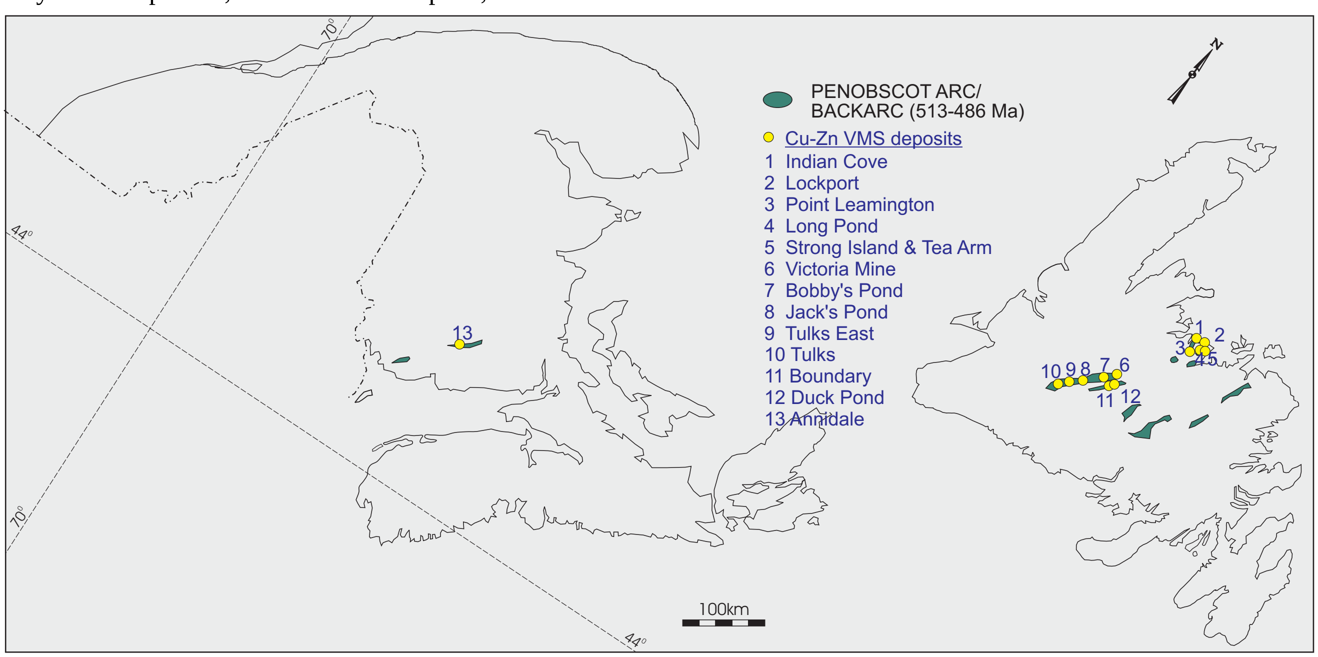

FIG. 16. VMS deposits in elements of the Penobscot arc.

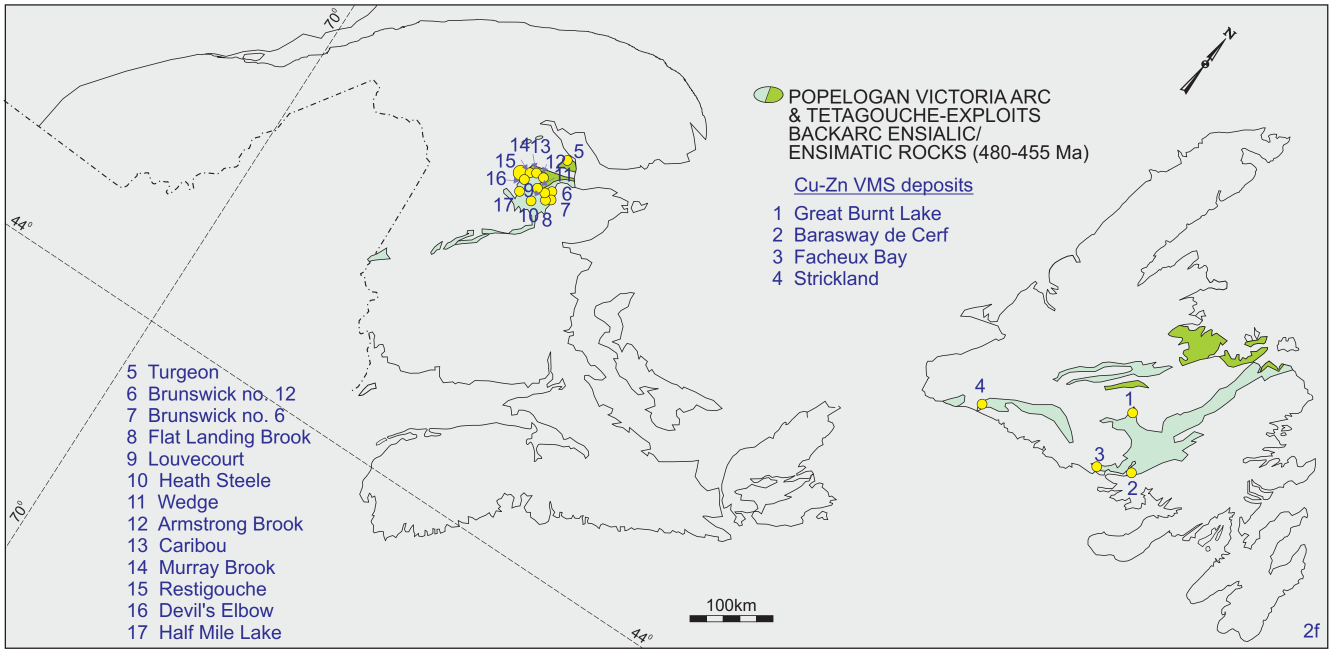

FIG. 17. VMS deposits in the elements of the Popelogan/Victoria arc - Tetagouche/Exploits backarc system.

0.48% Cu, 18.1g/t Ag, and 0.9g/t Au. The VMS deposits are generally associated with refractory volcanic rocks (Swinden and Dunsworth, 1995)

After closure of the Penobscot backarc basin, arc activity was resurrected during the Arenig both in Newfoundland and New Brunswick. Its volcanic rocks suggest that the arc was highly extensional and this phase is referred to as the Popelogan arc in New Brunswick and the Victoria arc in Newfoundland. Its products have been preserved in the stratigraphically upper parts of the Victoria Lake Supergroup, Wild Bight and Exploits groups in Newfoundland. The Oak Mountain Formation (Fig. 8; Meductic Group) and Goulette Brook Formation (Balmoral Group) represent the Popelogan arc in New Brunswick. Neither of these units contains any significant VMS mineralization. Consanguineous calc-alkaline plutons in New Brunswick however contain Cu-Mo-Au porphyry mineralization. Economically important VMS deposits are abundant in the associated Tetagouche-Exploits backarc basin, both in Newfoundland and New Brunswick. In Newfoundland these include the Strickland (260 000 tonnes grading 5.25% combined Pb and Zn), Facheux Bay and the Barasway de Cerf deposits, hosted by the Bay du Nord and Baie d'Espoir groups (Figs. 1, 4, 17). In New Brunswick they include the economically very important VMS deposits of the Bathurst Mining Camp (van Staal et al., 2003a). The giant Brunswick No. 12 Mine contained 229 0000 000 tonnes of ore grading 7.66% Zn, 3.01% Pb, 0.46% Cu, 91 ppm Ag and 0.46% Au. . The VMS deposits hosted by ensialic backarc volcanic rocks are relatively rich in Pb. Those hosted by ensimatic mafic volcanic rocks, representing remnants of backarc oceanic crust, are cupriferous. The Great Burnt Lake deposit (680 000 tonnes grading 2-3% Cu) hosted by oceanic basalts of the Cold Spring Pond Formation of central Newfoundland and the Turgeon deposits (1-2 Million tonnes grading 4% Zn and 1.5% Cu in Powerline zone) hosted by the ophiolitic Fournier Group in northern New Brunswick belong to this group (Figs, 4, 8, 17).

Pre-Silurian Mineral Deposits of the Gander Zone

The Cambrian-Ordovician sedimentary and volcanic rocks typical of Ganderia show little or no significant mineralization other than post-accretion, mesothermal gold deposits and pluton-associated mineralization that occur throughout the central mobile belt (see below). However, Ganderian Proterozoic basement rocks locally contain important mineralization that took place, presumably while it still formed part of Gondwana. The volcanic rocks enveloping the ca. 563 Ma Crippleback monzodiorite host the Burnt Pond VMS occurrence (BP in Fig. 18). In Cape Breton, Proterozoic marble in the Bras d'Or terrane host the Lime Hill stratabound sulphide deposit (LH in Fig. 18), mainly consisting of bands of massive and disseminated sphalerite, pyrrhotite and pyrite. It has reserves of 136 000 tonnes grading 9% Zn or 1 800 000 tonnes grading 2% Zn. The deposit is either a skarn or a syngenetic, carbonate-hosted massive sulphide deposit (Sangster in Swinden and Dunsworth, 1995). Polymetallic skarn deposits (Fig. 18) however are locally present in the Bras d'Or terrane where they are closely associated with latest Neoproteozoic (ca. 560 Ma) calc-alkaline plutons. Late Neoproterozoic arc plutons and volcanic rocks of the Hermitage flexure host the Hope Brook gold Mine (Fig. 19), which contained 11 200 000 tonnes of ore grading 4.54g/t Au. Gold is probably Precambrian in age.

Pre-Silurian Mineral Deposits of the Avalon Zone

Avalonia contains several types of mineral deposits that formed in this microcontinent before its late Silurian accretion to Laurentia. The oldest are several VMS deposits (Fig. 20) that are hosted by Neoproterozoic volcanic rocks, which formed during subduction processes in the periphery of

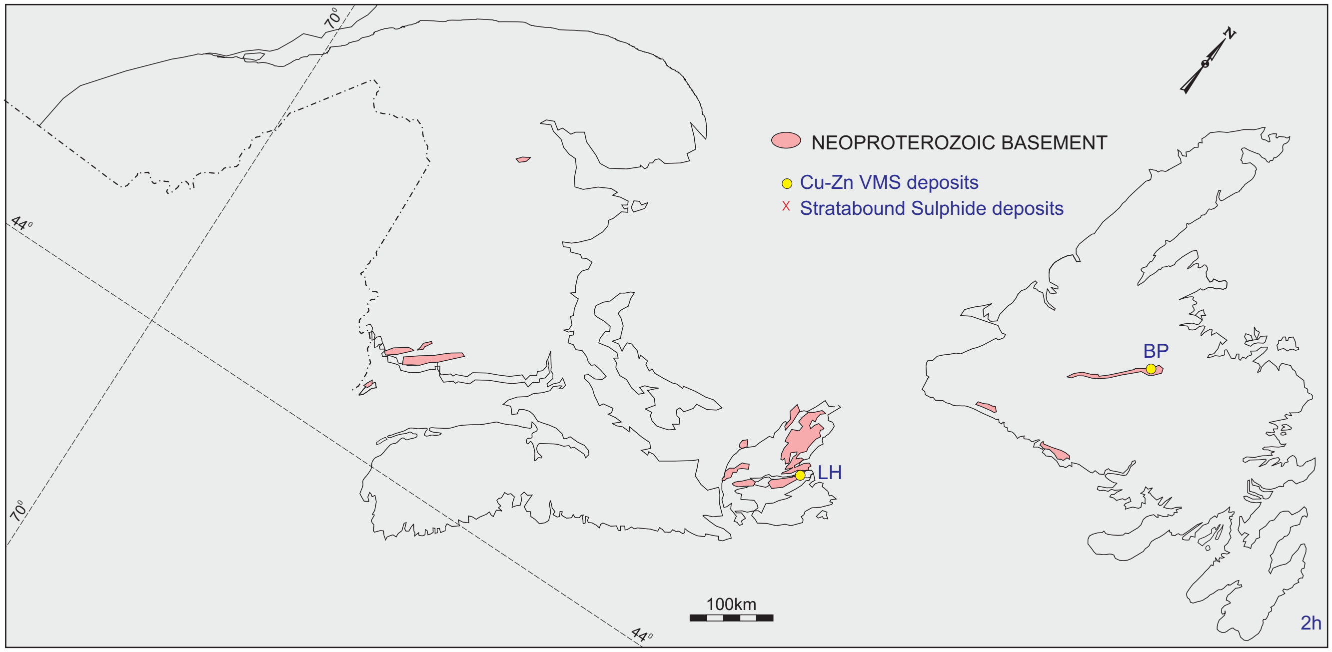

FIG. 18. Mineral deposits in Ganderian Neoproterozoic basement.

Gondwana, before opening of the Iapetus Ocean.

Avalonian VMS occurrences in Newfoundland comprise the Winter Hill and Frenchman Head deposits hosted by the ca. 680 Ma Tickle Point Formation. In Cape Breton, the coeval Stirling volcanic rocks host the Mindamar or Stirling deposit of which 1 100 000 tonnes of ore averaging 6.4% Zn, 1.5% Pb, 0.74% Cu, 75.2g/t Ag, and 1.03g/t Au were mined. In New Brunswick' s Avalon Zone, the younger, ca. 630-600 Ma Coldbrook Group host the cupriferous Teahan and Lumsden deposits (Fig. 20).

Late Neoproterozoic (ca. 620 Ma), calc-alkaline granitoids host disseminated Cu and Mo porphyry mineralization in Newfoundland (e.g. Holyrood Granite) and Cape Breton Island (e.g. Coxheath Hills pluton). Circa 620 Ma aluminous alteration zones developed in predominantly felsic volcanic rocks throughout Newfoundland's Avalon zone (Fig. 19) are associated with epithermal gold-silver mineralization (e.g. O'Brien et al., 1999).

The Lower to Middle Cambrian sedimentary strata of the Avalon zone in Newfoundland contain Mn-rich horizons, locally reaching grades of 33.35% Mn. The manganese is probably derived from the weathering of the underlying Neoproterozoic rocks (O'Driscoll in Swinden and Dunsworth, 1995). The Lower Ordovician siliciclastic rocks

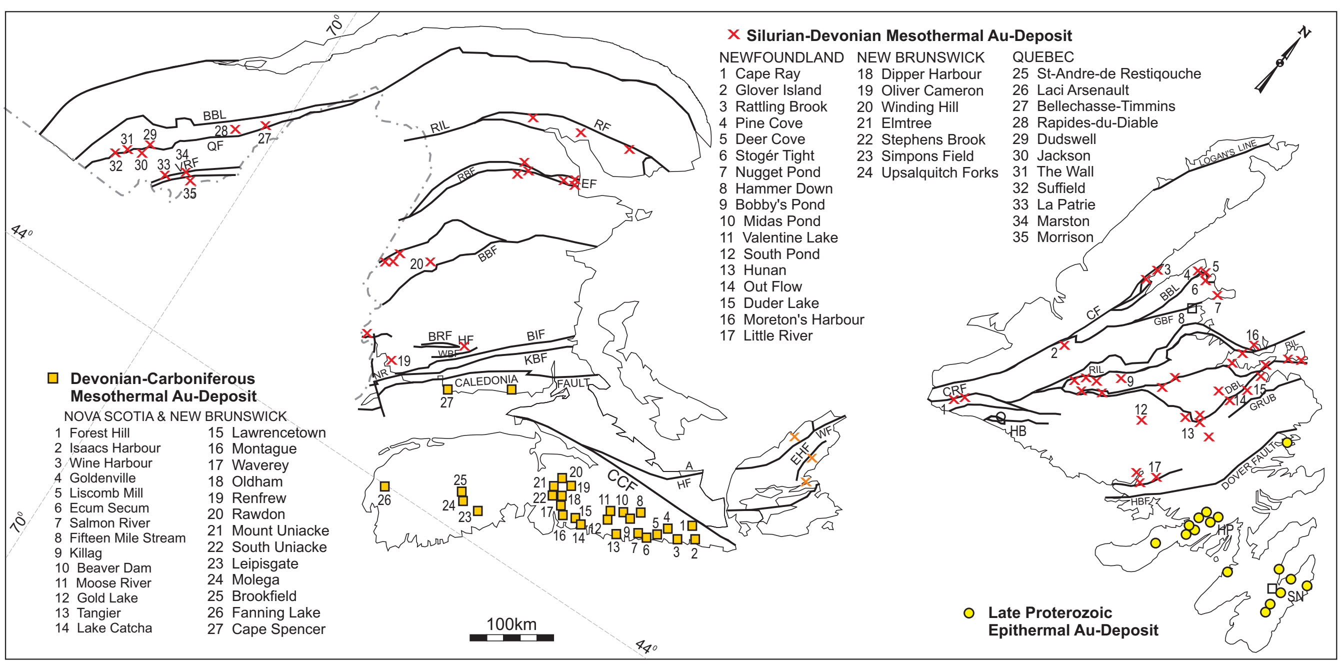

FIG. 19.Epithermal and mesothermal gold deposits in the Canadian Appalachians. HB: Hope Brook mine; HP: Hickey's Pond prospect: SN: Steep Nap prospect.

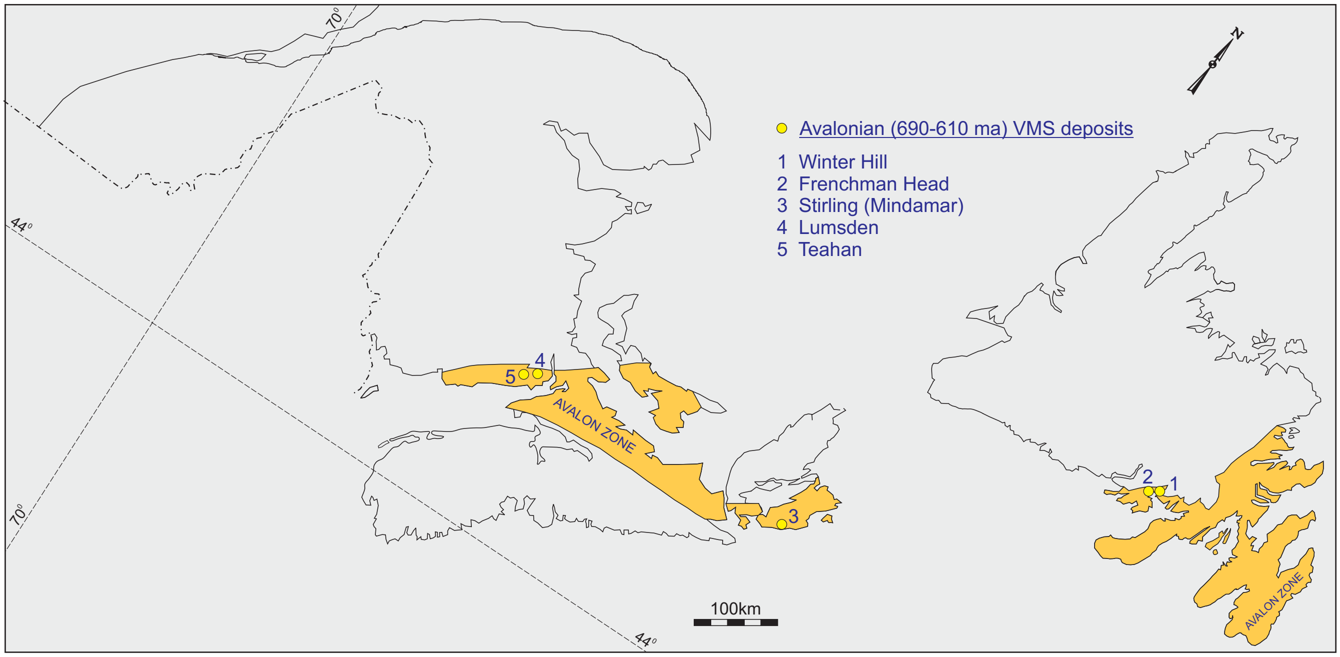

FIG. 20. Mineral deposits, gold deposits excluded, in the Avalon Zone.

of the Bell Island and Wabana groups host the Clinton-type, oolitic hematite iron deposits, which were mined between 1895 and 1966. Potential reserves beneath Conception Bay probably exceed 2 billion tones (Miller, 1983).

Pre-Devonian Mineral Deposits of the Meguma Zone

Meguma contains several types of mineral deposits that formed in this microcontinent before its late Early Devonian accretion to Laurentia. The Cambrian-Ordovician Meguma Supergroup underlies most of the exposed Meguma zone. The Meguma Supergroup is generally regarded as the remnant of a Gondwanan passive margin sequence, probably deposited off the coast of Late Proterozoic-Early Paleozoic North Africa (Schenk, 1997). The transition from the sandy Goldenville to the shaly Halifax groups contains a manganese-rich unit (Fig. 21) that is also enriched in Ba, Cu, Pb and Zn (Sangster in Swinden and Dunsworth, 1995).

Clinton-type, sedimentary iron deposits occur in the Lower Devonian Torbrook Group (Fig. 21)

Salinic-Acadian Gold Mineralization in the Central Mobile Belt

Mesothermal and to a much less extent epithermal gold deposits are common in the Dunnage and Gander zones, and also the eastern part of the Humber Zone (Fig. 19). Gold commonly occurs in sulphide-rich quartz and quartz carbonate veins or as disseminations in pervasively altered wallrock (Dubé, 1990). Gold in the Humber zone commonly occurs in veins associated with shear zones developed in the sedimentary and volcanic rocks of the Silurian Sops Arm belt, which represents part of an overstep sequence deposited above the Humber Zone and Notre Dame subzone (Williams, 1995). The shear zones are spatially associated with a splay of the Cabot fault system. The Cabot fault accommodated strike slip movements as early as the Late Ordovician (Brem et al., 2003) and remained active into the Carboniferous. Mineralization is Late Silurian or younger.

The most significant vein deposits in the Notre Dame subzone (Fig. 21) are the Cape Ray, Deer Cove, Pine Cove and Hammer Down. The mineralized veins are localized in brittle-ductile faults associated with regional Silurian to Devonian transpression (e.g. Dubé et al., 1996). The Stog'er Tight deposit in the Baie Verte Peninsula, hosted by a pervasively altered Tremadoc (ca. 483 Ma) gabbro sill (Ramezani et al., 2002) related to the Snooks Arm arc is the best example of the altered wallrock-type.

The Lac Arsenault and Saint-André-de-Restigouche are the most important mesothermal vein deposits in the Notre Dame subzone in the Quebec Gaspésie (Fig. 19). Mineralization is associated with the Grand Pabos transcurrent (dextral) fault system, which cuts Upper Ordovician to Lower Silurian siliciclastic and calcareous rocks of the Honorat and Matapedia groups of the Gaspé belt. This fault system was predominantly active during the Devonian. Skarn mineralization is also associated with this fault system. The largest vein of the Lac Arsenault deposit contains approximately 40 000 tonnes grading 15.42g/t Au, 197g/t Ag, 6.6% Pb, and 3.5% Zn (Duquette and Malo in Swinden and Dunsworth, 1995). Mesothermal deposits in southeastern Quebec are also associated with major fault zones, particularly the BBL, Guadeloupe and Victoria River fault zones (Fig. 19). The noteworthy Bellechase-Timmins deposit with estimated reserves of 12 Million tonnes of 2g/t Au occurs in quartz-carbonate veins hosted by diorite sills that had intruded the Magog Group.

Mesothermal gold deposits are common throughout the Exploits subzone and Gander zone of the Canadian Appalachians. In Newfoundland there are numerous shear zone-related auriferous veins in the Victoria Lake Supergroup. Particularly, the unconformable contact between the late Neoproterozoic plutons at the base of the Victoria Lake Supergroup and the Lower to Upper Silurian

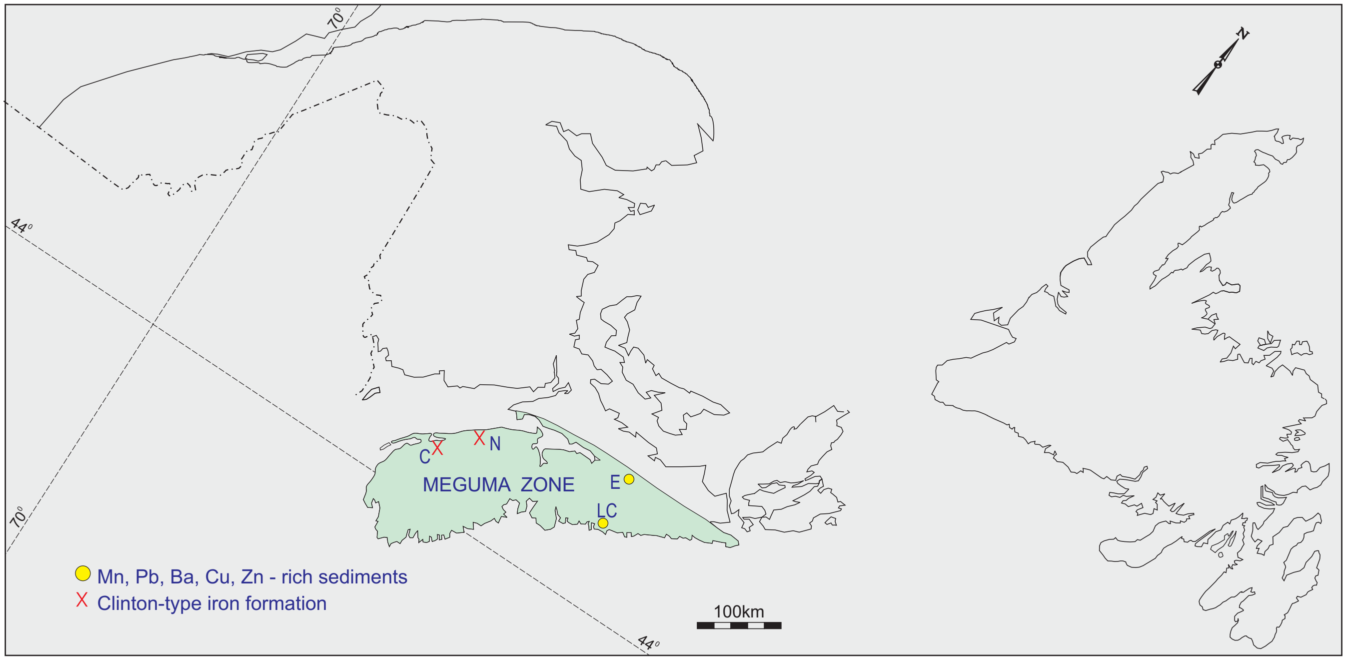

FIG. 21. Mineral deposits, gold deposits excluded, in the Meguma Zone.

Botwood Group locally was a favourable site for strain localization and formation of auriferous veins. In general, strain localization along the contacts of volcanic units in the Victoria Lake Supergroup and with the overlying Badger Group led to shear zones, intense alteration and formation of auriferous veins. The Midas gold deposit is an example of this (Fig. 19). Shearing and associated vein formation is associated with Silurian and/or Early Devonian transpression, which was accommodated both by reverse and strike-slip faults. Many of these faults are spatially associated and/or intersected by Siluro-Devonian felsic plutonic rocks. Hence, the source of the ore-bearing fluids may be partly magmatic; the fluids being channeled along the faults.

An extensive belt of auriferous veins, locally also containing antimony (e.g. Hunan deposit, Fig. 19), are associated with the Dog Bay Line or occur east of it in rocks of the Exploits subzone and Gander Zone. The veins formed mainly during latest Silurian or Early Devonian dextral transpression associated with Acadian docking of Avalonia (Holdsworth, 1994) and widespread felsic plutonism. Many of the gold occurrences have characteristics of Carlin-type deposits.

Mesothermal gold deposits in the Exploits subzone and Gander Zone of New Brunswick are mainly associated with segments or splays of the Rocky Brook-Millstream, Woodstock, Bamford Brook, Honeydale, Basswood Ridge and Wheaton Brook fault systems (Fig. 1). An example is the relatively large Elmtree deposit in northern New Brunswick, which comprises quartz-carbonte auriferous veins hosted by sheared and altered Ordovician gabbro affected by the Elmtree fault, a splay of thre Rocky Brook-Millstream fault. The deposit contains 350 000 tonnes grading 4.46g/t Au (Tremblay and Dubé, 1991). Most of the above mentioned faults accommodated significant transcurrent and reverse movements during Acadian dextral transpression (van Staal and de Roo, 1995). Auriferous quartz veins occur also in the Gander Zone of Cape Breton Island (Aspy Zone), associated with Acadian transpression localized in fault zones such as the Eastern Highlands shear zone and the Wilkie Brook fault.

Neoacadian Gold Mineralization in Meguma

Mesothermal, gold-bearing veins in Meguma generally occur in the Goldenville Group (Fig. 19) where relatively thick beds of fine-grained sulphidic shale are interlayered with sandstones. The veins have been mined since 1862. The gold-bearing veins occur in several orientations but preferentially occur in the hinges of anticlines that were modified during a late-stage amplification of the regional upright folding synchronous with ca. 370 Ma granite plutonism and low-pressure regional metamorphism (Keppie et al., 2002).

Siluro-Devonian (Acadian) Pluton-related Mineralization

The Central Mobile belt of the Canadian Appalachians, particularly the Exploits subzone and the Gander Zone, contains a large volume of Late Silurian-Early Devonian (422-395 Ma) felsic to intermediate and minor mafic plutons. Plutons of this age range are rare or absent in the Notre Dame subzone. They have a broad spectrum of compositions and not surprisingly also produced a wide variety of mineral deposits (Fig. 22).

In Newfoundland peraluminous granites in the Gander Zone and adjacent Exploits subzone, such as the large North Bay batholith (Fig. 22), which comprises several distinct intrusive phases, are associated with molybdenite and scheelite-bearing quartz veins and/or pegmatites, and veins containing barite-galena and sphalerite. In New Brunswick, large batholiths like the Early Devonian Pokiok are associated with quartz veins containing various combinations of stibnite, native antimony, gold and scheelite (e.g. Lake George deposit). Others like the North Pole granite contain base metal sulphide veins. Some high-level, subvolcanic granite stocks (e.g. Benjamin River and Upsalquitch forks) contain

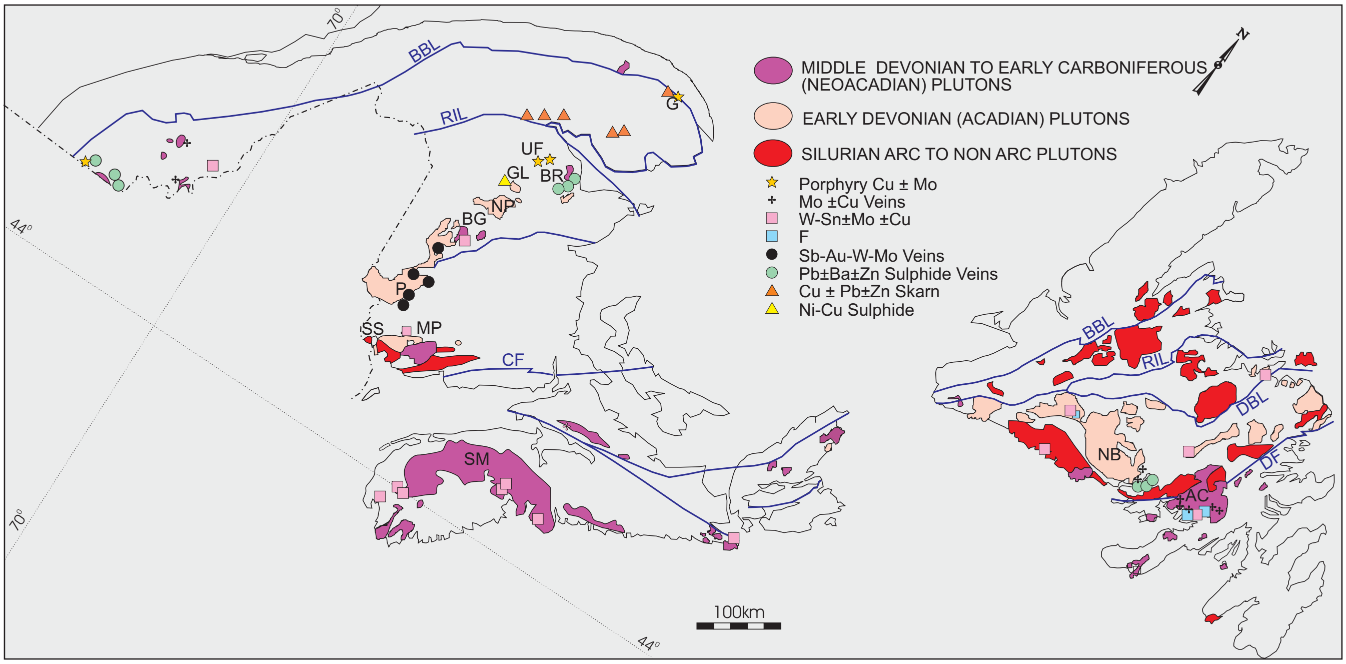

FIG. 22. Mineral deposits associated with the Acadian and Neoacadian plutons. AC: Ackley granite; NB: North Bay batholith; P: Pokiok batholith; BG: Burnthill granite; NP: North Pole granite, MP: Mt. Pleasant; SS: St. Stephens gabbro; GL: Goodwin Lake gabbro; BR: Benjamin River porphyry; UF: Upsalquitch Forks porphyry; G: Gaspé Mine; BBL: Baie Verte-Brompton Line; RIL: Red Indian Line; DBL: Dog Bay Line; DF: Dover fault; CF: Caledonia fault;

porphyry Cu-Mo mineralization. Early Devonian layered mafic-ultramafic intrusions in New Brunswick, such as the St. Stephen and Goodwin Lake gabbroic bodies, locally contain appreciable Ni-Cu sulphides deposits.

Middle Devonian to Early Carboniferous (Neoacadian) Pluton-related Mineralization

Neoacadian plutons, predominantly granitic, occur in all tectonostratigraphic zones of the Canadian Appalachians but are most voluminous in the Meguma, Avalon and Gander zones. Their petrogenesis is linked to the tectonic processes responsible for Meguma's accretion and subsequent convergence that led to final closure of the Rheic Ocean (e.g. Murphy et al., 1999).

The large, Upper Devonian Ackley granite in Newfoundland, which stitches the Gander-Avalon boundary (Figs. 1, 4, 22), contains several economically interesting molybdenite occurrences hosted by aplite-pegmatite phases. Fluorite, scheelite and tin mineralization is generally associated with the most evolved, silica-rich granite phases.

In Nova Scotia, the most evolved phases of the voluminous, Upper Devonian South Mountain batholith (Meguma Zone) and other smaller coeval plutons host several deposits rich in Sn, W, Mo, Cu, U, F, As, Ta and Nb (Fig. 22).

The Upper Devonian-Lower Carboniferous phases of the Saint George batholith in southern New Brunswick host several significant Sn, W, Mo and Bi deposits (e.g. Mt. Pleasant). The Burnthill, Trouth Hill and Dungarvon granites in central New Brunswick are host to W, Sn, Mo, Be, Mo, F deposits, which mainly occur in quartz veins or as disseminations near the margins or the contact aureole of the plutons.

Cu-rich orebodies in the form of skarns (e.g. Needle Mountain at Gaspé Mine), mesothermal veins (e.g. Madeleine) and porphyry-type (e.g. Copper Mountain at Gaspé Mine) mineralization are related to the Middle Devonian McGerrigle Pluton and related sattelite bodies in the Gaspésie of the Quebec Appalachians. The Gaspé Mine produced ca. 124 million tones of ore with 0.64% Cu and recoverable Mo, Ag, Bi, Se and Au between 1955-and 1991.

Mineralization related to Neoacadian granites is also present in southeastern Quebec mainly involving Mo-Cu, Mo-Bi-Ag- Pb-Zn, Ag-Pb-Zn-Cu and W-Ag-Au-Bi-Pb-Zn bearing veins that mainly occur in the contact aureole.

References

Anderson, F.D, and Williams, H., 1970, Gander Lake (West Half), Newfoundland: Geological Survey of Canada, Map 1195A (final map with descriptive notes).

Astini, R.A., and Thomas, W.S., 1999, Origin and evolution of the Precordillera terrane of western Argentina: a drifted Laurentian orphan; in Ramos, V.A. and Keppie, J.D., eds., Laurentia-Gondwana connections before Pangea: Geological Society America Special Paper 336, p.1-20.

Barr S.M., and Jamieson, R.A., 1991, Tectonic setting and regional correlation of Ordovician-Silurian rocks of the Aspy terrane, Cape Breton Island, Nova Scotia: Canadian Journal of Earth Sciences, 28, p. 1769-1779.

Barr, S.M., and Kerr, A., 1997, Late Precambrian plutons in the Avalon terrane of New Brunswick, Nova Scotia and Newfoundland. in Sinha, A.K., Whalen, J.B., and Hogan, J.P., eds., The Nature Of Magmatism In The Appalachian Orogen: Geological Society of America Memoir 191, p. 45-74.

Barr, S.M., and White, C.E., 1996, Contrasts in Late Precambrian-Early Paleozoic tectonothermal history between Avalon Composite terrane sensu stricto and other possible Peri-gondwanan terranes in southern New Brunswick and Cape Breton. in Nance, R.D., and Thompson, M.D., eds., Avalonian and Related Peri-Gondwanan Terranes of the Circum-North Atlantic: Geological Society of America, Special Paper 304, p. 95-108.

Barr, S.M., Raeside, R.P., and White, C.E., 1998, Geological correlations between Cape Breton Island and Newfoundland, northern Appalachian orogen: Canadian Journal of Earth Science 35, p. 1252-1270.

Barr S.M., White, C.E. and Miller, B.V., 2002, The Kingston Terrane, southern New Brunswick, Canada: evidence for an Early Silurian volcanic arc: Geological Society of America Bulletin 114, p. 964-982.

Barr S.M., White, C.E. and Miller, B.V., 2003, Age and geochemistry of Late Neoproterozoic and Early Cambrian igneous rocks in southern New Brunswick: similarities and contrasts: Atlantic Geology, 39, p. 55-73.

Beaudoin, G., Schrijver, K., Marcoux, F., Calvez, J.Y., 1989, A vein and disseminated Ba-Zn-Pb deposit in the Appalachian thrust belt, St. Fabien, Quebec: Economic Geology, 84, p. 799-816.

Bédard, J.H., and Kim, J., 2002, Boninites in the NE Appalachian Notre Dame Subzone ophiolites: tectonic models for Iapetus terranes: Geological Society of America, Abstracts with Programs, 34, p. A60.

Bédard, J.H., Lauziere, K., Tremblay, A. and Sangster, A.L., 1998, Evidence for forearc seafloor spreading from the Betts Cove ophiolite, Newfoundland: oceanic crust of boninitic affinity: Tectonophysics 248, p. 233-245.

Bédard, J.H., Lauziere, K., Tremblay, A., Sangster, A.L., Douma, S., and Dec., T., 2000, Betts Cove ophiolite and its cover rocks, Newfoundland: Geological Survey of Canada, Bulletin, 550, 76p.

Berdan, J.M., 1971. Silurian to Early Devonian Ostracodes of European aspect from the Eastport quadrangle, Maine: Geological Society of America, Abstracts with Programs, 3, No. 1, p. 18.

Bird, J.M., and Dewey, J.F., 1970, Lithosphere plate-continental margin tectonics and the evolution of the Appalachian Orogen: Geological Society of America Bulletin, 81, p. 1031-1060.

Boucot, A.J, 1993, Comments on Cambrian-to-Carboniferous biogeography and its implications for the Acadian orogeny; in Roy, D.C., and Skehan, J.W., eds., The Acadian Orogeny: Recent studies in new England, Maritime Canada, and the Autochthonous Foreland: Geological Society of America Special Paper 275, p. 41-49.

Boucot, A.J., Dewey, J.F., Dineley, D.L., Fletcher, R., Fyson, W.K., Griffin, J.G., Hickox, C.J., McKerrow, W.S., and Zeigler, A.M., 1974, Geology of the Arisaig area, Antigonish County, Nova Scotia: Geological Society of America Special Paper 139, 191p.

Bouyx, E., Blaise, J., Brice, D., Degardin, J. M., Goujet, D., Gourvennec, R., Le Menn, J., Lardeux, H., Morzadec, P. et Paris, F., 1997, Biostratigraphie et paléobiogeographie du Siluro-Dévonien de la Zone de Meguma (Nouvelle-Écosse, Canadian): Canadian Journal of Earth Science 34, p. 1295-1309.

Bradley, D.C., 1983, Tectonics of the Acadian Orogeny in New England and adjacent Canada: Journal of Geology, 91, p. 381-400.

Bradley, D.C. and Tucker, R.D., 2002, Emsian synorogenic paleogeography of the Maine Appalachians: Journal of Geology, 110, p. 483-492.

Brem, A.G., Lin, S., van Staal, C.R., 2003, Structural relationships south of Grand Lake Newfoundland; in Current Research 2002: Newfoundland Department of Mines and Energy, Geological Survey Report 2002-1, p. 1-13.

Buchan, K.L., Ernst, R.E. and Kumarapeli, P.S., 2004, Paleomagnetism of the Grenville diabase dyke swarm and implications for the mid Vendian paleolatitude of Laurentia: AGU spring meeting, Montreal. - p.

Burgess, J.L., Brown, M., Dallmeyer, R.D. and van Staal, C.R., 1995, Microstructure, metamorphism, thermochronology and P-T-t deformation history of the Port aux Basques gneisses, south-west Newfoundland, Canada: Journal of Metamorphic Geology, 13, p. 751-776.

Casey, J.F. and Dewey, J.F., 1984, Initiation of subduction zones along transform and accreting plate boundaries, triple junction evolution and forearc spreading centers - implications for ophiolitic geology and obduction; in Gass, I.G., Lippard, S.J., and Shelton, A.W., eds., Ophiolites and oceanic lithosphere: Geological Society of London Special Paper, 13, p. 131-144.

Castonguay, S., and Tremblay, A., 2003, Tectonic evolution and significance of Silurian-Early Devonian hinterland-directed deformation in the internal Humber Zone of the southern Quebec Appalachians: Canadian Journal of Earth Sciences, 40, p. 255-268.

Castonguay, S., Ruffet, G., Tremblay, A. and Feraud, G., 2001, Tectonometamorphic evolution of the southern Quebec Appalachians: $^{40}Ar/^{39}Ar$ evidence for Middle Ordovician crustal thickening and Silurian-Early Devonian exhumation of the internal Humber zone: Geological Society of America Bulletin 113, p. 144-160.

Cawood, P.A., and Suhr, G., 1992, Generation and obduction of ophiolites: constraints from the Bay of Islands Complex, Western Newfoundland: Tectonics, 11, p. 884-897.

Cawood, P.A., McCausland, P.J.A. and Dunning, G.A., 2001, Opening Iapetus: Constraints from the Laurentian margin in Newfoundland: Geological Society of America Bulletin, 113, p. 443-453

Cawood, P.A., Dunning, G.A., Lux, D., and van Gool, J.A.M., 1994, Timing of peak metamorphism and deformation along the Appalachian margin of Laurentia in Newfoundland: Silurian, not Ordovician: Geology, 22, p. 399-402.

Chandler, F. W., 1982, Sedimentology of two Middle Paleozoic terrestrial sequences, King George IV Lake area, Newfoundland and some comments on regional paleoclimate; in Current Research, Part A: Geological Survey of Canada, Paper 82-1A, p. 213-219.

Chorlton, L.B., Williams, H., and Wilton, D.H.C., 1995, Cape Ray Belt; in Williams, H., ed., The Appalachian/Caledonian Orogen: Canada and Greenland; Geology of Canada, no. 6: Geological Survey of Canada (also Geological Society of America, the Geology of North America, v. F-1), p. 397-403.

Colman-Sadd, S.D., Stone, P., Swinden, H.S. and Barnes, R.P., 1992a. Parallel geological development in the Dunnage Zone of Newfoundland and the Lower Paleozoic terranes of southern Scotland: an assesment. Transactions of the Royal Society of Edinburgh, Earth Sciences, 83, p. 571-594

Colman-Sadd, S.P., Dunning, G.R., and Dec, T., 1992b. Dunnage-Gander relationships and Ordovician orogeny in central Newfoundland: a sediment provenance and U/Pb study: American Journal of Science 292, p. 317-355.

Cousineau, P.A. and St. Julien, P., 1992, The Saint-Daniel Melange: evolution of an accretionary complex in the Dunnage Terrane of the Quebec Appalachians: Tectonics, 11, p. 898-909.

Culshaw, N., and Reynolds, P., 1997, $^{40}Ar/^{39}Ar$ age of shear zones in the southwest Meguma Zone between Yarmouth and Meteghan, Nova Scotia: Canadian Journal of Earth Sciences, 34, p. 848-853.

Currie, K.L., 1995, The northeastern end of the Dunnage Zone in Newfoundland: Atlantic Geology, 31, p. 25-38.

Currie, K L., 1992, A new look at Gander-Dunnage relations in Carmanville map area, Newfoundland; in Current Research, part D: Geological Survey of Canada, Paper 92-1D, p. 27-33.

Currie, K. L., van Staal, C.R., Peter, J. and Rogers, N., 2003, Conditions of metamorphism of the main massive sulfide deposits and surrounding host rocks in the Bathurst Mining Camp: Economic Geology Monograph 11, p. 65-78.

Dallmeyer, R.D., and Nance, R.D., 1994, $^{40}Ar/^{39}Ar$ whole rock phyllite ages from Late Precambrian rocks of the Avalon composite terrane, New Brunswick: evidence of Silurian-Devonian thermal rejuvenation: Canadian Journal of Earth Sciences 31, p. 818-824.

Dallmeyer, R.D., and Williams, H., 1975, $^{40}Ar/^{39}Ar$ ages from the Bay of Islands metamorphic aureole: their bearing on the timing of Ordovician ophiolite obduction: Canadian Journal of Earth Sciences 12, p. 1685-1690.

David, J., and Marquis, R. 1994, Géochronologie U-Pb dans les Appalaches du Quebec: Application aux roches de la zone de Dunnage: La Revue Géologique 1, p. 16-20.

David, J. and Gariepy, C., 1990, Early Silurian orogenic andesites from the central Quebec Appalachians: Canadian Journal of Earth Sciences 27, p. 632-643.

Dewey, J.F., 2002, Transtension in Arcs and Orogens: International Geology Reviews, 44, p. 402-439.

Dickinson, W.R., and Seely, D.R., 1979, Structure and stratigraphy of forearc regions: American Association of Petroleum Geologists Bulletin, 63, p. 2-31.

d'Lemos, R.S., Schofield, D.I., Holdsworth, R.E., and King, T.R., 1997, Deep crustal and local rheological controls on the siting and reactivation of fault and shear zones, northeastern Newfoundland: Journal of the Geological Society, London, 154, p. 117-121.

Doig, R., Nance, R.D., Murphy, J.B., and Casseday, R.P., 1990, Evidence for Silurian sinistral accretion of Avalon composite terrane in Canada: Journal of the Geological Society, London, 147, p. 927-930.

Dubé, B., 1990, Contrasting styles of gold: only deposits in western Newfoundland (a preliminary report); in Current Research, Part B, Geological Survey of Canada, Paper 90-1B, p. 77-90.

Dubé, B., Dunning, G. R., Lauziere, K., and Roddick, J.C., 1996, New insights into the Appalachian Orogen from geology and geochronology along the Cape Ray fault zone, southwest Newfoundland: Geological Society of America Bulletin, 108, p. 101-116.

Dunning, G.R., and Cousineau, P.A., 1990, U/Pb ages of single zircons from Chain Lakes Massif and a correlative unit in ophiolitic mélange in Quebec: Geological Society of America, Abstracts with Programs, NE-section, 22, p. 13.

Dunning, G.R. and Krogh, T.E. 1985, Geochronology of ophiolites of the Newfoundland Appalachians: Canadian Journal of Earth Sciences, 22, p. 1659-1670.

Dunning, G.R., and O'Brien, S.J., 1989, Late Proterozoic-Early Paleozoic crust in the Hermitage flexure, Newfoundland Appalachians: U/Pb ages and tectonic significance: Geology, 17, p. 548-551.

Dunning, G.R. and Pedersen, R.B., 1988, U/Pb ages of ophiolites and arc-related plutons of the Norwegian Caledonides: Implications for the development of Iapetus: Contributions to Mineralogy and Petrology, 98, p. 13-23.

Dunning, G., O'Brien , S. J., Colman-Sadd, S. P., Blackwood, R., Dickson, W.L., O'Neill, P.P. and Krogh, T.E., 1990, Silurian orogeny in the Newfoundland Appalachians: Journal of Geology 98, p. 895-913.

Dunning, G.R., Swinden, H.S. Kean, B.F., Evans, D.T.W., and Jenner, G.A. 1991, A Cambrian island arc in Iapetus: geochronology and geochemistry of the Lake Ambrose volcanic belt, Newfoundland Appalachians: Geological Magazine, 128, p. 1-17.

Durling, P.W., Bell, J.S. and Fader, G.B.J., 1987, The geological structure and distribution of Paleozoic rocks on the Avalon platform offshore, Newfoundland: Canadian Journal of Earth Sciences, 24, p. 1412-1420.

Elliott, C.G., Dunning, G.R. and Williams, P.F., 1991, New constraints on the timing of deformation in eastern Notre Dame Bay, Newfoundland, from U/Pb zircon ages of felsic intrusions: Geological Society of America Bulletin, 103, p. 125-135.

Evans, D.T.W., Kean, B.F. and Dunning, G.R. 1990, Geological Studies, Victoria Lake Group, Central Newfoundland: Current Research, Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 90-1, p. 131-144.

Fox, D., and van Berkel, J.T., 1988, Mafic-ultramafic occurrences in metasedimentary rocks of southwestern Newfoundland; in Current Research, Part B: Geological Survey of Canada, Paper 88-1B, p. 41-48.

Fortey, R.A., and Cocks, L.R., 2003, Palaeontological evidence bearing on global Ordovician-Silurian continental reconstructions: Earth Science Reviews 61, p. 245-307.

Fyffe, L.R., Pickerill, R.K. and Stringer, P., 1999, Stratigraphy, sedimentology and structure of the Oak Bay and Waweig formations, Mascarene basins: implications for the Paleotectonic evolution of southwestern New Brunswick: Atlantic Geology 35, p. 59-84.

Franks, S.G., 1974, Prehnite-Pumpellyite facies metamorphism of the New Bay Formation, Exploits Zone, Newfoundland: Canadian Mineralogist 12, p. 456-462.

Fryer, B.J., Kerr, A., Jenner, G.A., and Longstaffe, F.J., 1992, Probing the crust with plutons: Regional isotopic geochemistry of granitoid intrusions across insular Newfoundland; in Current Research: Newfoundland Department of Mines and Energy, Geological Surveys Branch, Report 92-1, p. 119-139.

Gerbi, C., Johnson, S., Aleinikoff, J., Bedard, J., Dunning, G. and Fanning, subm. Early paleozoic orogenesis in the Maine-Quebec Appalachians 11: Development of the Boundary Mountain region: Candian Journal of Earth Sciences, -, p. --,---

Gibbons, W. and Horak, J.M., 1996, The evolution of the Neoproterozoic Avalonian subduction system: Evidence from the British Isles; in Nance, R.D., and Thompson, M.D., eds., Avalonian and Related Peri-Gondwanan Terranes of the Circum-North Atlantic: Geological Society of America, Special Paper 304, p. 269-280.

Hacker, B.R., 1991, The role of deformation in the role of metamorphic field gradients: Ridge subduction beneath the Oman ophiolite: Tectonics, 10, p. 458-473.

Hall, L. and van Staal, C.R., 1999, Geology of Southern End of Long Range Mountains (Dashwoods Subzone), Newfoundland: Geological Survey of Canada, Open file, scale 1: 50 000.

Hamilton, M.A., and Murphy, J.B., 2004, Tectonic significance of a Llanvirn age for the Dunn Point volcanic rocks, Avalon terrane, Nova Scotia, Canada: implications for the evolution of the Iapetus and Rheic oceans: Tectonophysics 379, p. 199-209.

Harris, R.A., 1992, Peri-collisional extension and the formation of Oman-type ophiolites in the Banda arc and Brooks Range; in Parson, L.M., Murton, B.J., and Browning, P., eds., Ophiolites and their modern oceanic analogues: Geological Society Special Publication 60, p. 301-325.

Hibbard, J., and Williams, H., 1979, Regional setting of the Dunnage mélange in the Newfoundland Appalachians: American Journal of Science 279, p. 993-1021.

Hicks, R.J., Jamieson, R.A., and Reynolds, P., 1999, Detrital and metamorphic $^{40}Ar/^{39}Ar$ ages from muscovite and whole-rock samples, Meguma Supergroup, southern Nova Scotia: Canadian Journal of Earth Sciences 36, p. 23-32.

Hicks, R.J., Jamieson, R.A., and Reynolds, P., 1998, Detrital and metamorphic $^{40}Ar/^{39}Ar$ ages from muscovite and whole-rock samples, Meguma Supergroup, southern Nova Scotia: Canadian Journal of Earth Sciences 36, p. 23-32.

Hodych, J.P. and Buchan, K.L., 1998, Palaeomagnetism of the ca. 440 Ma Cape St. Mary's sills of the Avalon peninsula of Newfoundland: implications for Impetus closure: Geophysical Journal International 135, p. 155-164.

Hodych, J.P., Cox, R.A., and Kosler, J., 2004, An equatorial Laurentia at 550 Ma confirmed by Grenvillian inherited zircons dated by LAM ICP-MS in the Skinner Cove volcanics of western Newfoundland: implications for inertial interchange true polar wander: Precambrian Research 129, p. 93-113.

Holdsworth, R.E., 1994, Structural evolution of the Gander-Avalon terrane boundary: a reactivated transpression zone in the NE Newfoundland Appalachians: Journal of the Geological Society, London, 151, p. 629-646.

Huot, F., Hébert, R. and Turcotte, B., 2002, A multistage magmatic history for the genesis of the Orford ophiolite (Quebec, Canada): a study of the Mont Chagnon massif: Canadian Journal of Earth Sciences 39, p. 1201-1217.

Hutchinson, D.R., Klitgord, K.D., Lee, M.W., and Trehu, A.M., 1988. U.S. Geological Survey deep seismic reflection profile across the Gulf of Maine: Geological Society of America Bulletin 100, p. 172-184.

Ingersoll, R.V., 1988, Tectonics of sedimentary basins: Geological Society of America Bulletin 100, p. 1704-1719.

Jamieson, R.A., 1988, Metamorphic P-T-t data from western Newfoundland and Cape Breton - implications for Taconian and Acadian tectonics: Geological Society of Canada, Program with Abstracts, 13, p. A60.

Jacobi, R.D., 1981, Peripheral bulge-A causal mechanism for the Lower/Middle Ordovician unconformity along the western margin of the northern Appalachians: Earth and Planetary Science Letters 56, p. 245-251.

Jacobi, R.D., and Wasowski, J.J., 1985, Geochemistry and plate-tectonic significance of the volcanic rocks of the Summerford Group, north-central Newfoundland: Geology, 13, p. 126-130.

James, N.P., Stevens, R.K., Barnes, C.R., and Knight, I., 1989, Evolution of a lower Paleozoic continental margin carbonate platform, northern Canadian Appalachians; in Controls on carbonate platform and basin development: The Society of Economic Paleontologists and Mineralogists, Special Publication 44, p. 123-146.

Jenner, G.A., and Swinden, H.S., 1993, The Pipestone Pond Complex, central Newfoundland: complex magmatism in an eastern Dunnage Zone ophiolite: Canadian Journal of Earth Sciences, v. 30, p. 434-448.

Jenner, G.A., Dunning, G.R., Malpas, J., Brown, M., and Brace,T., 1991, Bay of islands and Little Port complexes revisited: age, geochemical and isotopic evidence confirm suprasubduction zone origin: Canadian Journal of Earth Sciences 28, p. 1635-1652.

Johnson, R.J.E., and van der Voo, R., 1986, Paleomagnetism of the late Precambrian Fourchu Group, Cape Breton Island, Nova Scotia: Canadian Journal of Earth Sciences, 23, p. 1673-1685.

Johnson, R.J.E., van der Pluijm, B.A. and van der Voo, R., 1991, Paleomagnetism of the Moreton's Harbour Group, northeastern Newfoundland Appalachians: evidence for an Early Ordovician island arc near the Laurentian margin of Iapetus: Journal of Geophysical Research, 96, p. 11689-11701.

Johnson, S.C., 2001, Contrasting geology in the Pocologan River and Long Reach areas: implications for the New River belt and correlations in southern New Brunswick and Maine: Atlantic Geology 37, p. 61-79.

Johnson, S.C., and McLeod, M.J., 1996, The New River Belt: A unique segment along the western margin of the Avalon composite terrane, southern New Brunswick, Canada; in Nance, R.D., and Thompson, M.D., eds., Avalonian And Related Peri-Gondwanan Terranes Of The Circum-North Atlantic: Geological Society of America Special Paper 304, p. 149-164.

Kamo, S.L., Gower, C.F. and Krogh, T.E., 1989, Birthdate for the Iapetus Ocean? A precise U-Pb zircon and baddeleyite age for the Long Range dikes, southeast Labrador: Geology, 17, p. 602-605.

Karlstrom, K., van der Pluijm, B.A., and Williams, P.F, 1982, Structural interpretation of the eastern Notre Dame Bay area, Newfoundland: regional post-Middle Silurian thrusting and asymmetrical folding: Canadian Journal of Earth Sciences, 19, p. 2325-2341.

Karson, J. and Dewey, J.F., 1978, Coastal complex, western Newfoundland: an Early Ordovician fracture zone: Geological Society of America Bulletin 89, p.1037-1049.

Kay, M., 1967, Stratigraphy and structure of northeast Newfoundland bearing on drift in North Atlantic: American Association of Petroleum Geologists Bulletin, 51, p. 579-600.

Kean, B.A., Evans, D.T.W. and Jenner, G.A., 1995, Geology and mineralization of the Lushs Bight Group. Newfoundland Department of Natural Resources, Report 95-2, 204p.

Keen, C.E., Kay, W.A., Keppie, D., Marillier, F., Pe-Piper, G., and Waldron, J.W.F., 1991, Deep seismic reflection data from the Bay of Fundy and Gulf of Maine: tectonic implications for the northern Appalachians: Canadian Journal of Earth Sciences, 28, p. 1096-1111.

Kennedy, M.J., 1975, Repetitive orogeny in the northeastern Appalachians - New plate models based upon Newfoundland examples: Tectonophysics, 28, p. 39-87.

Keppie, J.D. and Krogh, T.E., 2000, 440 Ma igneous activity in the Meguma terrane, Nova Scotia, Canada: part of the Appalachian overstep sequence? American Journal of Science 300, p. 528-538.

Keppie, J.D., Dostal, J., Dallmeyer, R.D., and Doig, R., 2000, Superposed Neoproterozoic and Silurian magmatic arcs in central Cape Breton Island, Canada: geochemical and geochronological constraints: Geological Magazine, 137, p. 137-153.

Keppie, D.F., Keppie, J.D., and Murphy, J.B., 2002, Saddle reef auriferous veins in a conical fold termination (Oldham anticline, Meguma terrane, Nova Scotia, Canada): reconciliation of structural and age data: Canadian Journal of Earth Sciences, 39, p. 53-63.

Kerr, A., Jenner, G.J., and Fryer, B.J., 1995, Sm-Nd isotopic geochemistry of Precambrian to Paleozoic granitoid suites and the deep-crustal structure of the southeast margin of the Newfoundland Appalachians: Canadian Journal of Earth Sciences, 32, p. 224-245.

Kim, J., Coish, R., Evans, M., and Dick, G., 2003, Supra-subduction zone extensional magmatism in Vermont and adjacent Quebec: Implications for Early Paleozoic Appalachian tectonics: Geological Society of America Bulletin 115, p. 1552-1569.

King, L.H., Fader, G.B.J., Jenkins, W.A.M. and King, E.L. 1986, Occurrence and regional geological setting of Paleozoic rocks on the Grand Banks of Newfoundland: Canadian Journal of Earth Sciences 23, p. 504-526.

King, M.S. and Barr, S.M., 2004, Magnetic and gravity models across terrane boundaries in southern New Brunswick, Canada: Canadian Journal of Earth Sciences 41, p. 1027-1047.

Knight, I., James, N.P. and Lane, T.E., 1991, The Ordovician St. George Unconformity, northern Appalachians: the relationship of plate convergence at the St. Lawrence promontory to the Sauk/Tippecanoe sequence boundary: Geological Society of America Bulletin 103, p. 1200-1225.

Krogh, T.E., and Keppie, J.D., 1990. Age of detrital zircon and titanite in the Meguma Group, southern Nova Scotia, Canada, clues to the origin of the Meguma Terrane: Tectonophysics, 177, p. 307-323.

Kurth, M., Sassen, A., Suhr, G. and Mezger, K., 1998, Precise ages and isotopic constraints for the Lewis hills (Bay of Islands ophiolite): preservation of an arc-spreading ridge intersection: Geology, 26, p. 1127-1130.

Kusky, T.M., and Kidd, W.S.F., 1996, Tectonic implications of Early Silurian thrust imbrication of the northern Exploits Subzone, Central Newfoundland: Journal of Geodynamics 22, p. 229-265.

Lafrance, B. and Williams, P.F., 1992, Silurian deformation in eastern Notre Dame Bay, Newfoundland: Canadian Journal of Earth Sciences, 29, p. 1899-1914.

Laird, J., Trzcienski, W.E., Jr. and Bothner, W.A., 1993, High pressure Taconian and subsequent polymetamorphism of southern Quebec and northern Vermont: Department of Geology and Geography, University of Massachusetts, Contribution 67-2, p.1-32.

Landing, E., 1996, Avalon: Insular continent by the latest Precambrian; in Nance, R. D., and Thompson, M. D., eds., Avalonian and Related Peri-Gondwanan Terranes of the Circum-North Atlantic: Geological Society of America, Special Paper 304, p. 29-63.

Lavoie, D., Burden, E. and Lebel, D., 2003, Stratigraphic framework for the Cambrian-Ordovician rift and passive margin successions from southern Quebec to western Newfoundland: Canadian Journal of Earth Sciences 40, p. 177-205.

Lee, C.B. and Williams, H., 1995, The Teakettle and Carmanville mélanges in the Exploits Subzone of northeast Newfoundland: recycling and diapiric emplacement in an accretionary prism; in Hibbard, J, van Staal, C.R. and Cawood, P., eds., Current Perspectives in the Appalachian-Caledonian orogen: Geological Association of Canada Special Paper, 41, p. 147-160.

Liou, J.G., Maruyama, S., and Cho, M., 1985, Phase equilibria and mineral parageneses of metabasites in low-grade metamorphism. Mineralogical Magazine, 49, p. 321-333.

Liss, M.J., van der Pluijm, B.A., and van der Voo, R., 1994, Avalonian proximity of the Ordovician Miramichi terrane, northern New Brunswick, northern Appalachians: Paleomagnetic evidence for rifting and back-arc basin formation at the southern margin of Iapetus: Tectonophysics, v. 227, p. 17-30.

Lissenberg, C.J. and van Staal, C.R., subm., Feedback between deformation and magmatism in the Lloyd's River Fault zone, Central Newfoundland: an example of episodic fault reactivation in an accretionary setting: Tectonics, , - , p. -- - ---.

Lissenberg, C.J and van Staal, C.R., 2002, The relationships between the Annieopsquotch ophiolite belt, the Dashwoods block and the Notre Dame arc in southwestern Newfoundland; in Current Research 2001: Newfoundland Department of Mines and Energy, Geological Survey Report 2001-1, p. 145-154.

Lissenberg, C.J., van Staal, C.R., Bédard, J.H. and Zagorevski, A., in press, Geochemical constraints on the origin of the Annieopsquotch ophiolite belt, southwest Newfoundland: Geological Society of America Bulletin, - , p. -- - ---.

Lissenberg, J., McNicoll, V.J., and van Staal, C.R., 2004, P-T-t constraints on accretion of ophiolites along the Lloyd's river Fault zone, SW Newfoundland; in Geological Society of America, 39th Annual Meeting, NE-section, Abstracts with Programs, p. 91.

Ludman, A., Hopeck, J.T. and Brock, P.C., 1993, Nature of the Acadian Orogeny in eastern Maine; in Roy, D.C., and Skehan, J.W., eds., The Acadian Orogeny: Recent studies in New England, Maritime Canada, and the Autochthonous Foreland: Geological Society of America Special Paper 275, p. 67-84.

MacLachlan, K. and Dunning, G.R., 1998, U-Pb ages and tectonomagmatic relationships of Early Ordovician low-Ti tholeiites, boninites and related plutonic rocks in central Newfoundland, Canada: Contributions to Mineralogy and Petrology, 133, p. 235-258.

MacDonald, L.A., Barr, S.M., White, C.E., and Ketchum, J.W. F., 2002, Canadian Journal of Earth Sciences 39, p. 259-277.

MacNiocaill, C., 2000, A new Silurian paleolatitude for eastern Avalonia and evidence for crustal rotations in the Avalonian margin of southwestern Ireland: Geophysical Journal International, 141, p. 661-671.

MacNiocaill, C. and Smethurst, M., 1994, Paleozoic palaeogeography of Laurentia and its margins: a reassessment of Palaeomagnetic data: Geophysical Journal International, 116, p. 715-725.

Malo, M., Cousineau, P.A., Sacks, P.E., Riva, J.F.V., Asselin, E. and Gosselin, P., 2001, Age and composition of the Ruisseau Isabelle Mélange along the Shickshock sud fault zone: constraints on the timing of mélanges formation in the Gaspé peninsula: Canadian Journal of Earth Sciences 38, p. 21-42.

McConnell, B.J., O'Brien, B.H., and Nowlan, G.S., 2002, Late Middle Ordovician olisostrome formation and magmatism along the Red Indian Line, the Laurentian arc-Gondwana arc boundary at Sops Head, Newfoundland: Canadian Journal of Earth Sciences 39, p. 1625-1633.

McLaughlin, R. J., Barr, S.M., Hill, M. D., Thompson, M. D., Ramezani, J. and Reynolds, P. H., 2003, The Moosehorn plutonic suite, southeastern Maine and southwestern New Brunswick: age, petrochemistry, and tectonic setting: Atlantic Geology 39, p. 123-146.

McLeod, M. J., 1997, Redefinition of the Queen Brook Formation of southern New Brunswick and preliminary geochemistry; in Carroll, B.M.W., ed., Current Research 1996: New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 97-4, p. 175-190.

McLeod, M. J., Ruitenberg, A.A., and Krogh, T.E., 1992, Geology and U-Pb geochronology of the Annidale Group, southern New Brunswick: Lower Ordovician volcanic and sedimentary rocks formed near the southeastern margin of Iapetus Ocean: Atlantic Geology 28, p. 181-192.

McLeod, M. J., Pickerill, R. K., and Lux, R. D., 2001, Mafic intrusions on Campobello Island: implications for New Brunswick-Maine correlations: Atlantic Geology 37, p. 17-40.

McNamara, A. K., MacNiocaill, C., van der Pluijm, B. A., and van der Voo, R., 2001, West African proximity of the Avalon terrane in the latest Precambrian: Geological Society America Bulletin 113, p. 1161-1170.

McNicoll, V., van Staal, C.R. and Waldron, J. W. F., 2001, Accretionary history of the Northern Appalachians: SHRIMP study of Ordovician-Silurian syntectonic sediments in the Canadian Appalachians; in Abstract Volume, GAC/MAC Annual meeting, St. John's Nfld., p.100.

Meert and Torsvik, 2003, The making and unmaking of a supercontinent: Rodinia revisited: Tectonophysics 375, p. 261-288.

Miller, B.V. and Barr, S.M., 2000, Petrology and isotopic composition of a Grenvillian basement fragment in the Northern Appalachian Orogen: Blair River Inlier, Nova Scotia, Canada: Journal of Petrology 41, p. 1777-1804.

Miller, B.V. and Fyffe, L. R., 2002, Geochronology of the Letete and Waweig formations, mascarene Group, southwestern New Brunswick: Atlantic Geology 38, p. 29-36.

Miller, H.G., 1983, Geophysical constraints on the size and extent of the Wabana hematite deposit: Economic Geology, 78, p. 1017-1021.

Monzier, M., Danyushevsky, L.V., Crawford, A.J., Bellon, H., and Cotton, J., 1993, High-Mg andesites from the southern termination of the New Hebrides island arc (SW Pacific): Journal of Volcanology and Geothermal Research, 57, p. 193-217.

Muller, R.D., Gaina, C., Roest, W.R., and Hansen, D.L., 2001, A recipe for microcontinent formation: Geology 29, p. 203-206.

Murphy, J.B., and Keppie, J.D., 1995, Arisaig Belt; in Williams, H., ed., The Appalachian/Caledonian Orogen: Canada and Greenland; Geology of Canada, no. 6: Geological Survey of Canada (also Geological Society of America, the Geology of North America, v. F-1), p. 360-365.

Murphy, J.B., van Staal, C.R. and Keppie, J.D., 1999, Middle to Late Paleozoic Acadian Orogeny in the northern Appalachians: a Laramide-style plume-modified orogeny: Geology 27, p. 653-656.

Murphy, J.B., Nance, R.D., and Keppie, J.D., 2002, Discussion and reply: West African proximity of the Avalon terrane in the latest Precambrian: Geological Society America Bulletin 114, p. 1049-1052.

Nance, R.D., and Dallmeyer, RD., 1993, ^{40}Ar/^{39}Ar amphibole ages from the Kingston Complex, New Brunswick: Evidence for Silurian-Devonian tectonothermal activity and implications for the accretion of the Avalon composite terrane: Journal of Geology 101, p. 375-388.

Neuman, R.B., 1967, Bedrock geology of the Shin Pond and Stacyville quadrangles, Maine. U.S: Geological Survey, Professional Paper 524-1, 47 p.

Nowlan, G.S. and Neuman, R.B., 1995, Palaeontological contributions to Paleozoic paleogeographic and tectonic reconstructions; in Williams, H., ed., Geology of the Appalachian-Caledonian Orogen in Canada and Greenland; Geology of Canada, no. 6: Geological Survey of Canada, (also Geological Society of America, The Geology of North America, v. F1), p. 817-842.

Nowlan, G.S., McCracken, A.D. and McLeod, M.J., 1997, Tectonic and paleogeographic significance of Late Ordovician conodonts in the Canadian Appalachians: Canadian Journal of Earth Sciences 34, p. 1521-1537.

O'Brien, B., O'Brien, S., and Dunning, G. R., 1991, Silurian cover, Late Precambrian - Early Ordovician basement, and the chronology of Silurian orogenesis in the Hermitage Flexure (Newfoundland Appalachians): American Journal of Science 291, p. 760-799.

O'Brien, B., O'Brien, S., Dunning, G.R., and Tucker, R.D., 1993, Episodic reactivation of a Late Precambrian mylonite zone of the Gondwanan margin of the Appalachians, southern Newfoundland: Tectonics, v. 12, p. 1043-1055.

O'Brien, S.J., O'Brien, B.H., Dunning, G.R. and Tucker, R.D., 1996, Late Neoproterozoic Avalonian and related peri-Gondwanan rocks of the Newfoundland Appalachians; in Nance, R.D., and Thompson, M.D., eds., Avalonian and Related Peri-Gondwanan Terranes of the Circum-North Atlantic: Geological Society of America, Special Paper 304, p. 9-28.

O'Brien, B., Swinden, H.S., Dunning, G.R., Williams, S.H., and O'Brien, F., 1997, A peri-Gondwanan arc-back arc complex in Iapetus: Early-Mid Ordovician evolution of the Exploits Group, Newfoundland: American Journal of Science 297, p. 220-272.

O'Brien, S.J., Dubé, B., and O'Driscoll, C.F., 1999, High-sulphidation, epithermal-style hydrothermal systems in Late Neoproterozoic Avalonian rocks on the Burin Peninsula, Newfoundland: implications for gold exploration; in Current Research: Newfoundland Department of Mines and Energy, Geological Survey, Report 99-1, p. 275-296.

O'Neill, P.P., 1991, Geology of the Weir's Pond area, Newfoundland (NTS 2E/1): Newfoundland Department of Mines and Energy, Geological Survey Branch Report 91-3, 144 p.

Paradis, S., Chi, G., and Lavoie, D., 2004, Fluid inclusions and isotopic evidence for the origin of the Upton Ba-Zn-Pb deposit, Quebec Appalachians, Canada: Economic Geology 99, p. 807-817.

Park, A.F. and Whitehead, J., 2003, Structural transect through Silurian turbidites of the Fredericton Belt southwest of Fredericton, New Brunswick: the role of the Fredericton Fault in late Iapetus convergence: Atlantic Geology 39, p. 227-237.

Pe-Piper, G., and Jansa, L.F., 1999, Pre-Mesozoic basement rocks offshore Nova Scotia, Canada: New constraints on the accretion history of the Meguma terrane: Geological Society America Bulletin, 111, p. 1773-1791.

Pearce, J.A., Lippard, S.J., and Roberts, S., 1984, Characteristics and tectonic significance of supra-subduction zone ophiolites; in Kokelaar, B.P., and Howells, M.F., eds., Marginal Basin Geology: Geological Society of London, Special Publication 16, p. 77-94.

Pehrsson, S., van Staal, C.R., Herd, R.K., McNicoll, V., 2003, The Cormacks Lake complex, Dashwoods Subzone: a window into the deeper levels of the Notre Dame Arc; in Current Research 2002: Newfoundland Department of Mines and Energy, Geological Survey Report 2002-1, p.115-125.

Pincivy, A., Malo, M., Ruffet, G., Tremblay, A., and Sacks, P.E., 2003, Regional metamorphism of the Appalachian Humber zone of Gaspe Peninsula: ^{40}Ar/^{39}Ar evidence for crustal thickening during the Taconian orogeny: Canadian Journal of Earth Sciences 40, p. 301-315.

Pickering, K.T., Bassett, M.G., and Siveter, D.J., 1988, Late Ordovician - Early Silurian destruction of the Impetus Ocean: Newfoundland, British Isles and Scandinavia - a discussion: Transactions of the Royal Society of Edinburgh, Earth Sciences 79, p. 361-382.

Pinet, N. and Tremblay, A., 1995, Tectonic evolution of the Quebec-Maine Appalachians: from oceanic spreading to obduction and collision in the northern Appalachians: American Journal of Science, 295, p. 173-200.

Pollock, J.C., Morrissey, K.D., Wilton, D.H.C., van Staal, C.R. and Tubrett, M.N., 2003, Laser ablation U-Th-Pb geochronology of detrital zircons from the Botwood and Indian Islands Belts: Accretionary tectonic evolution of the northeast Exploits subzone, Dunnage Zone, Newfoundland Appalachians: Geological Society of America, 38th Annual Meeting, NE-section, Abstracts with Programs, p. 79.

Price, J.R., Barr, S.M., Raeside, R.P., and Reynolds, P.H., 1999, Petrology, tectonic setting, and $^{40}Ar/^{39}Ar$ (hornblende) dating of the Late Ordovician-Early Silurian Belle Cote Road orthogneiss, western Cape Breton Highlands, Nova Scotia: Atlantic Geology 35, p. 1-17.

Ramezani, J., Dunning, G.R., and Wilson, M.R., 2002, Geologic setting, geochemistry of alteration, and U-Pb age of hydrothermal zircon from the Silurian Stog'er Tight gold prospect, Newfoundland Appalachians, Canada. Exploration and Mining Geology, 9, p. 171-188.

Reusch, D., van Staal, C.R. and Barr, S., 2003, Ultramafic and sedimentary dikes, Penobscot Bay: Cambrian extension and Ordovician accretion along southeastern Ganderia; in Abstracts with Programs, Geological Society of America, 38th Annual Meeting, NE-section, p. 78.

Richter, D.A. and Roy, D.C., 1974, Sub-greenschist metamorphic assemblages in northern Maine: Canadian Mineralogist 12, p. 469-474.

Robinson P., Tucker R.D., Bradley D., Berryl, V.H.N., and Osberg P.H ., 1998, Paleozoic orogens in New England, USA. Geologiska Föreningens Stockholm Forhandlingar 120, 119-148.

Rogers, N., van Staal, C.R., McNicoll, V., Pollock, J., Zagorevski, A., Whalen, J. and Kean, B. subm. Neoproterozoic and Cambrian arc magmatism along the eastern margin of the Victoria Lake Supergroup: a remnant of Ganderian basement in central Newfoundland? Precambrian Research. --, p. ------.

Samson, S.D., Barr, S.M, and White, C.E., 2000, Nd isotopic characteristics of terranes within the Avalon Zone, southern New Brunswick: Canadian Journal of Earth Sciences 37, p. 1039-1052.

Schenk, P.E., 1997, Sequence stratigraphy and provenance on Gondwana's margin: The Meguma zone (Cambrian to Devonian) of Nova Scotia, Canada: Geological Society America Bulletin, 109, p. 395-409.

Schofield, D. I., and D'Lemos, R.S., 2000, Granite petrogenesis in the Gander Zone, NE Newfoundland: mixinbg of melts from multiple sources and the role of lithospheric delamination: Canadian Journal of Earth Sciences 37, p. 535-547.

Schroetter, J.M., Pagé, P., Bédard, J.H., Tremblay, A. and Bécu, V., 2003, Forearc extension and seafloor spreading in the Thetford Mines ophiolite complex; in Dilek, Y. and Robinson, P.T., eds., Ophiolites in Earth History, Geological Society London, Special Publication 218, p. 231-251.

Seaman, S.J., Wobus, R.A., Wiebe, R.A., Lubick, N. and Bowring, S.A., 1995, Volcanic expression of bimodal magmatism: the Cranberry Island-Cadillac Mountain complex, coastal Maine: Journal of Geology 103, p. 301-311.

Stern, R.J., and Bloomer, B.S.H., 1992, Subduction zone infancy: examples from the Eocene Izu-Bonin-Mariana and Jurassic California arcs: Geological Society of America Bulletin, 104, 1621-1636.

Suhr, G., and Edwards, S.J., 2000, Contrasting mantle sequences exposed in the Lewis hills massif: Evidence for the early, arc-related history of the Bay of Islands ophiolite; in Dilek, Y., Moores, E.M., Elthon, D., and Nicolas, A., eds., Ophiolites and oceanic crust: new insights from field studies and the Ocean Drilling Program: Geological Society of America, Special Paper 349, p. 433-442.

Swinden, H.S., 1996, Geochemistry of volcanic rocks in the Moreton's Harbour-Twillingate area, Notre Dame Bay; in Current Research, Newfoundland Department of Mines and Energy, Geological Surveys Branch, Report 96-1, p. 207-226.

Swinden, H.S., and Dunsworth, S.M., 1995, Metallogeny; Chapter 9, in Williams, H., ed., The Appalachian/Caledonian Orogen: Canada and Greenland, Geology of Canada, no. 6: Geological Survey of Canada (also Geological Society of America, the Geology of North America, v. F-1), p. 681-814.

Swinden, H.S., Jenner, G.A. and Szybinski, Z.A., 1997, Magmatic and tectonic evolution of the Cambrian-Ordovician laurentian margin of Impetus: Geochemical and isotopic constraints from the Notre Dame subzone, Newfoundland; in Sinha, K., Whalen, J.B., and Hogan J.P., eds., The Nature of Magmatism in the Appalachian Orogen: Geological Society of America Memoir 191, p. 367-395.

Szybinski, Z.A., 1995, Paleotectonic and structural setting of thye western Notre Dame Bay area, Newfoundland Appalachians: Unpublished PhD thesis, Memorial University of Newfoundland. St. John's, Newfoundland, 690p.

Thomas, W.A., 1977, Evolution of Appalachian-Ouachita salients and recesses from reentrants and promontories in the continental margin: American Journal of Science 277, p. 1233-1278.

Thurlow, J.G., 1990, Geology of the Buchans orebodies - A 1990 summary; in Swinden, H.S., Evans, D.T.W., and Kean, B.F., eds., Metallogenic Framework of Base and Precious Metal Deposits, Central and Western Newfoundland, 8th IAGOD symposium, Field trip no. 1, Guidebook: Geological Survey of Canada, Open File 2156, p. 84-91.

Tremblay, A., 1992, Tectonic and accretionary history of Taconian oceanic rocks of the Quebec Appalachians: American Journal of Science 292, p. 229-252.

Tremblay, A., and Dubé, B., 1991, Structural relationships between some gold occurrences and fault zones in the Bathurst area, northern New Brunswick; in Current Research, Part D, Geological Survey of Canada, Paper 90-1D, p. 89-100.

Tremblay, A., Hebert, R., and Bergeron, M., 1989, Le Complexe d'Ascot des Appalaches du sud du Quebec - petrologie et geochimie: Canadian Journal of Earth Sciences, 26, p. 2407-2420.

Tremblay, A., Lafleche, M.R., McNutt, R.H. and Bergeron, M., 1994, Petrogenesis of Cambro-Ordovician subduction-related granitic magmas of the Quebec Appalachians, Canada: Chemical Geology 113, p. 205-220.

Tremblay, A., Malo, M., and St. Julien, P., 1995, Dunnage Zone-Quebec; in Williams, H. ed., Chapter 3 of Geology of the Appalachian-Caledonian Orogen in Canada and Greenland,Geology of Canada, no. 6: Geological Survey of Canada (also Geological Society of America, The Geology of North America, v. F1), p. 179-197

Trench, A., Torsvik, T. H. and McKerrow, W. S., 1992, The palaeogeographic evolution of southern Britain during early Paleozoic times: a reconciliation of palaeomagnetic and biogeographic evidence: Tectonophysics 201, p. 75-82.

Trottier, J., Brown, A. C., and Gauthier, M., 1991, An Ordovician rift environment for the Memphremagog polymetallic massive sulphide deposit, Appalachian Ophiolite Belt, Quebec: Canadian Journal of Earth Sciences, 28, p. 1887-1904.

Tucker, R.D., Osberg, P.H. and Berryl, V.H.N., 2001, The geology of a part of Acadia and the nature of the Acadian orogeny across central and eastern Maine: American Journal of Science 301, p. 205-260.

Valverde, P., Dunning, G and van Staal, C.R., 2000, The Margaree orthogneiss (Port aux basques Complex, SW Newfoundland)evolution of a peri-Gondwanan, Mid Arenig-Early Llanvirn, mafic-felsic igneous complex: Canadian Journal of Earth Sciences 37, 1691-1710.

Valverde-Vaquero, P, van Staal, C.R., and van der Velden, A., 2003, Acadian orogenesis and high grade metamorphism in the Central Mobile Belt of central Newfoundland; in Abstracts with Programs, Geological Society of America, 38th Annual Meeting, NE-section, p. 23.

Valverde-Vaquero, P., van Staal, C.R., McNicoll, V. and Dunning, G., in press, Middle Ordovician magmatism and metamorphism along the Gander margin in Central Newfoundland: Journal of the Geological Society London, - , p. -- - --.

Van der Velden, A. J., van Staal, C.R. and Cook, F. A., 2004, Crustal structure, fossil subduction and the tectonic evolution of the Newfoundland Appalachians: Evidence from a reprocessed seismic reflection survey: Geological Society of America Bulletin, v. 116, p.1485-1498.

Van der Voo, R., and Johnson, R. J. E., 1985, Paleomagnetism of the Dunn Point Formation (Nova Scotia): high paleolatitudes for the Avalon terrane in the Late Ordovician: Geophysical Research Letters 12, p. 337-340.

Van Staal, C.R. 1994, The Brunswick subduction complex in the Canadian Appalachians: record of the Late Ordovician to Late Silurian collision between Laurentia and the Gander margin of Avalon: Tectonics, 13, p. 946-962.

Van Staal, C.R., 2005, The Northern Appalachians; in Selley, R.C., Robin, L., Cocks, M., and Plimer, I.R., eds., Encyclopedia of Geology: Elsevier, Oxford, Vol. 4, p. 81-91.

Van Staal, C.R. and de Roo, J.A., 1995, Mid-Paleozoic tectonic evolution of the Appalachian Central Mobile Belt in northern New Brunswick, Canada: Collision, extensional collapse, and dextral transpression; in Hibbard, J., van Staal, C.R., and Cawood, P., eds., Current Perspectives in the Appalachian-Caledonian Orogen: Geological Association of Canada, Special Paper 41: p. 367-389.

Van Staal, C.R. and Fyffe, L.R. 1995, The New Brunswick Dunnage Zone; in Williams, H., ed., The Appalachian/Caledonian Orogen: Canada and Greenland, Geology of Canada, no. 6: Geological Survey of Canada (also Geological Society of America, the Geology of North America, v. F-1), p. 166-178.

Van Staal, C.R. and Williams, H., 1991, Dunnage Zone-Gander Zone relationships in the Canadian Appalachians. Geological Society of America, Northeastern Section, 26th annual meeting; Southeastern Section, 40th annual meeting, Baltimore, MD. Abstracts with Programs, 23; 1, p. 143.

Van Staal, C.R., Sullivan, R.W., and Whalen, J.B., 1996, Provenance and tectonic history of the Gander Margin in the Caledonian/Appalachian Orogen: implications for the origin and assembly of Avalonia; in Nance, R.D., and Thompson, M.D., eds., Avalonian and Related Peri-Gondwanan Terranes of the Circum-North Atlantic: Geological Society of America, Special Paper 304, p. 347-367.

Van Staal, C.R., Dewey, J.F., MacNiocaill, C. and McKerrow, S., 1998, The Cambrian-Silurian tectonic evolution of the northern Appalachians: history of a complex, southwest Pacific-type segment of Iapetus; in Blundell, D.J. and Scott, A.C., eds., Lyell: the Past is the Key to the Present: Geological Society Special Publication 143, p. 199-242.

Van Staal, C.R., Wilson, R.A., Fyffe, L.R., Langton, J.P., McCutcheon, S.R., Rogers, N., McNicoll, V., and Ravenhurst, C.E., 2003a, Geology and tectonic history of the Bathurst Supergroup and its relationships to coeval rocks in southwestern New Brunswick and adjacent Maine - a synthesis; in Goodfellow, W.D., McCutcheon, S.R., and Peter, J.M., eds., Massive Sulfide Deposits of the Bathurst Mining Camp, New Brunswick, and Northern Maine: Economic Geology Monograph 11, p. 37-60

Van Staal, C.R., Whalen, J.B., Pehrson, S and McNicoll, V., 2003b, Tectonic evolution of the Notre Dame magmatic arc, Newfoundland Appalachians. AGU fall meeting, Vol. 84, no. 46, p. F1579.

Van Staal, C.R., McNicoll, V., Valverde-Vaquero, P., Barr, S., Fyffe, L.R., Reusch, D.N., 2004a, Ganderia, Avalonia, and the Salinic and Acadian orogenies; in Geological Society of America, 39th Annual Meeting, NE-section, Abstracts with Programs, p. 128-129.

Van Staal, C.R., Lissenberg, C.J., Zagorevski, A., McNicoll, V., Whalen, J., Bedard, J., and Pehrsson, S., 2004b, A new look at the tectonic processes involved in the Ordovician Taconic Orogeny in the Northern Appalachians: evidence for multiple accretion of (infant) arc terranes; in Geological Society of America, 39th Annual Meeting, Denver, Abstracts with Programs,

Van Wagoner, N.A., Leybourne, M. I., Dadd, K.A., Huskins, M.L.A., 2000, The Silurian (?) Passamaquoddy Bay mafic dyke swarm, New Brunswick: petrogenesis and tectonic implications: Canadian Journal of Earth Sciences, 38, p. 1565-1578.

Van Wagoner, N.A., Leybourne, M. I., Dadd, K.A., Baldwin, D.K. and McNeil, W., 2002, Late Silurian bimodal volcanism of southwestern New Brunswick, Canada: Products of continental extension: Geological Society of America Bulletin 114, p. 400-418.

Waldron, J.W.F. and van Staal, C.R., 2001, Taconic Orogeny and the accretion of the Dashwoods block: a peri-Laurentian microcontinent in the Iapetus Ocean: Geology 29, p. 811-814.

Waldron, J.W.F., Murphy, J.B., Melchin, M.J., and Davis, G., 1996, Silurian tectonics of Western Avalonia: strain-corrected subsidence history of the Arisaig Group, Nova Scotia: Journal of Geology 104, p. 677-694.

Walker, J.A. and McCutcheon, S.R., 1995, Siluro-Devonian stratigraphy of the Chaleur Bay synclinorium, northern New Brunswick; in Merlini, S.A.A., ed., Current Research 1994: New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Miscellaneous Report 18, p. 225-244.

Wasoski, J.J. and Jacobi, R.D., 1985, Geochemistry and tectonic significance of the mafic volcanic blocks in the Dunnage mélange, north central Newfoundland: Canadian Journal of Earth Sciences, 22, p. 1248-1256.

West, D.P., Beal, H.,M, and Grover, T., 2003, Silurian deformation and metamorphism of Ordovician arc rocks of the Casco Bay Group, south-central Maine: Canadian Journal of Earth Sciences, 40, p. 887-905.

West, D.P., Ludman, A. and Lux, D.R., 1992, Silurian age for the Pocomoonshine Gabbro-Diorite, southeastern Maine and its regional tectonic implications: American Journal of Earth Sciences 292, p. 253-273.

Whalen, J. B., 1989, The topsails igneous suite, western Newfoundland: an Early Silurian subduction-related magmatic suite? Canadian Journal of Earth Sciences 26, p. 2421-2434.

Whalen, J B., McNicoll, V., van Staal, C.R., 2003, Plutonic geochemical and isotopic evidence for a transition from arc (ca. 489-435 Ma) to within plate (ca. 430 Ma) magmatism within the Notre Dame arc; in Abstracts with Programs, Geological Society of America, 38th Annual Meeting, NE-section, p. 33.

Whalen, J.B., Currie, K. l., and van Breemen, O., 1987, Episodic Ordovician-Silurian plutonism in the Topsails terrane, western Newfoundland: Transactions of the Royal Society of Edinburgh, Earth Sciences, 78, p. 17-28.

Whalen, J.B., Jenner, G.A., Longstaffe, F.J., and Gariépy, C., 1996, Geochemical and Isotopic (O, Nd, Pb and Sr) constraints on A-type granite petrogenesis based on the topsails igneous suite, Newfoundland Appalachians: Journal of Petrology, 37, p. 1463-1489.

Whalen, J.B., Jenner, G.A., Longstaffe, F.J., Gariépy, C., and Fryer, B. J., 1997a, Implications of granitoid geochemical and isotopic (Nd, O, Pb) data from the Cambrian-Ordovician Notre Dame arc for the evolution of the Central Mobile belt, Newfoundland Appalachians; in Sinha, K., Whalen, J.B., and Hogan, J.P., eds., The Nature of Magmatism in the Appalachian Orogen: Geological Society of America, Memoir 191, p. 367-395

Whalen, J.B., van Staal, C.R., Longstaffe, F.J., Gariepy, C. and Jenner, G.A. 1997b, Insights into tectonostratigraphic zone identification in southwestern Newfoundland based on isotopic (Nd, O, Pb) and geochemical data: Atlantic Geology 33, 231-241

Whitehead, J., Dunning, G.R. and Spray, J.G., 2000, U-Pb geochronology and origin of granitoid rocks in the thetford mines ophiolite, Canadian Appalachians: Geological Society of America Bulletin, 112, p. 915-928.

Whitehead, J., Reynolds, P.H., and Spray, J.G., 1996, $^{40}Ar/^{39}Ar$ age constraints on Taconian and Acadian events in the Quebec Appalachians: Geology 24, p. 359-362.

Williams, H., 1979, Appalachian Orogen in Canada: Canadian Journal of Earth Sciences 16, p. 792-807.

Williams, H., 1992, Melanges and coticule occurrences in the Northeast Exploits Subzone, Newfoundland: Geological Survey of Canada, Current Research, Part D, Eastern Canada and national and general programs, Paper, p. 121-127.

Williams, H., editor, 1995, Geology of the Appalachian-Caledonian Orogen in Canada and Greenland; Geology of Canada, no. 6: Geological Survey of Canada (also Geological Society of America, The Geology of North America, v. F1).

Williams, H. and Grant, A.C., 1998, Tectonic Assemblages map scale 1:3000000, Atlantic Region, Canada: Geological Survey of Canada, Open File 3657.

Williams, H. and Hiscott, R.N., 1987, Definition of the Impetus rift-drift transition in western Newfoundland: Geology 15, p. 1044-1047.

Williams, H., and O'Brien, S.J., 1995, Fortune Belt; in Williams, H., The Appalachian/Caledonian Orogen: Canada and Greenland, Geology of Canada, no. 6: Geological Survey of Canada (also Geological Society of America, the Geology of North America, v. F-1), p. 423-425.

Williams, H. and Payne, J. G., 1975, The Twillingate granite and nearby volcanic groups: an island arc complex in northeast Newfoundland: Canadian Journal of Earth Sciences, 12, p. 982-995.

Williams, H. and Piasecki, M.A.J., 1990, The Cold Spring Melange and a possible model for Dunnage-Gander zone interaction in central Newfoundland: Canadian Journal of Earth Sciences, 27, p. 1126-1134.

Williams, H. and St. Julien, P., 1982, The Baie Verte Brompton Line: Early Paleozoic continent ocean interface in the Canadian Appalachians; in St. Julien, P., and Beland, J., eds., Major Structural zones and faults of the northern Appalachians: Geological Association of Canada , Special Paper 24, p.177-208.

Williams H, Currie K L and Piasecki, M.A.J, 1993, The Dog Bay Line: A major Silurian tectonic boundary in northeast Newfoundland: Canadian Journal of Earth Sciences 30, p. 2481-2494.

Williams, H., Colman-Sadd, S.P. and Swinden, H.S., 1988, Tectonicstratigraphic subdivisions of central Newfoundland, in Current Research, Part B: Geological Survey of Canada Paper 88-1B, p. 91-98.

Williams, H., Lafrance, B., Dean, P.L., Williams, P.F., Pickering, K.T. and van der Pluijm, B.A., 1995, Badger Belt; in Williams, H., ed., The Appalachian/Caledonian Orogen: Canada and Greenland, Geology of Canada, no. 6: Geological Survey of Canada (also Geological Society of America, The Geology of North America, v. F-1), p. 403-413.

Wilson, R., 2003, Geochemistry and petrogenesis of Ordovician arc-related volcanic rocks in the Popelogan Inlier, northern New Brunswick: Canadian Journal of Earth Sciences 40, p. 1171-1189.

Wilson, R., Burden, E.T., Bertrand, R., Asselin, E., and McCracken, A.D., 2004, Stratigraphy and tectono-sedimentary evolution of the Late Ordovician to Middle Devonian Gaspe belt in northern New Brunswick: evidence from the Restigouche area: Canadian Journal of Earth Sciences 41, p. 527-551.

Zagorevski, A., Rogers, N. and van Staal, C.R., 2003, Tectono-stratigraphic relationships in the Lloyd's River and Tulks Brook valleys, central Newfoundland: a geological link between Red Indian and King George IV lakes; in Current Research 2002: Newfoundland Department of Mines and Energy, Geological Survey Report 2002-1, p. 167-178.

Zagorevski, A., van Staal, C.R., McNicoll, V. and Rogers, N., 2004, Pats Pond and Wigwam Brook groups: Record of episodic Peri-Gondwanan Upper Cambrian-Caradoc island arc activity in the Exploits Subzone of Central Newfoundland; in Abstracts with Programs: Geological Society of America, 39th Annual Meeting, NE-section, p. 129.

Zagorevski, N. Rogers, C.R. van Staal, V. McNicoll, C.J. Lissenberg, and P. Valverde-Vaquero, subm., Lower to Middle Ordovician evolution of peri-Laurentian arc and back-arc complexes in the Iapetus: constraints from the Annieopsquotch Accretionary Tract, Central Newfoundland: Geological Society of America Bulletin, p. --,---.