5th International Symposium on the Silurian System
5th Annual Meeting of the IGCP 591 - The Lower to Middle Paleozoic Revolution

Gaspe, July 3 – 7, 2015

Pre-Conference Excursion

THE LOWER PALEOZOIC ROCKS OF THE GASPÉ PENINSULA

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with the participation of
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IGCP 591: The Early to Middle Paleozoic Revolution
5th Annual Meeting
July 8-11, 2015
Québec, Canada

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PREAMBLE

The Paleozoic succession in eastern Quebec consists of Cambrian-Upper Ordovician deep marine passive margin to foreland continental slope deposits. After the Middle-Late Ordovician Taconian Orogeny, sedimentation during the Early Silurian to Early Devonian was dominated by clastic deposits with however, two major shallow marine carbonate successions rich in cryptomicrobial and metazoan fauna and local reefs.

The excursion will allow observing the various types of faunal-rich, platform-derived limestone conglomerates that are used to correlate the thick fine-grained dominated Cambrian-Upper Ordovician deep-water succession. The Silurian carbonate facies will be a highlight of the trip with exquisite examples of diverse cryptomicrobial constructions as well as deep stromatactis-rich mud mounds and fringing reefs. The field trip will be concluded with a visit at the Museum of Miguasha Park, a world heritage UNESCO site with its spectacular collection of Late Devonian fishes.

We would like to acknowledge the significant sponsorphip of these organizations for their contributions to this field trip: Project 591 of the International Geoscience Program (IGCP), International Subcommission on Silurian Stratigraphy (ISSS), Hydrocarbures Anticosti, Junex and Pétrolia. Finally, Félix-Antoine Comeau from INRS-ETE is gratefully acknowledged for his meticulous work for the preparation of the field guide.

FROM IAPETAN RIFT TO ACADIAN FORELAND

A SUMMARY FROM QUEBEC APPALACHIANS

1. INTRODUCTION

A regional synthesis of the Appalachians in Canada (Williams, 1995) and in the USA (Hatcher *et al.*, 1989) were published as separate volumes, part of the centennial Geological Society of America Decade of North America Geology (DNAG) synthesis endeavour. The information synthesized our knowledge of this mobile belt in the mid to late 80's period. These volumes are still a source of invaluable information as they present the most complete and detailed account of the entire Appalachian Orogen.

Since publication, critical new research results have become available and allowed a refining of our understanding of this mobile belt. In the Canadian section of the Appalachians, for example, hydrocarbon exploration in the mid/late 90's in the lower and middle Paleozoic successions (Cooper *et al.*, 2001; Lavoie and Bourque, 2001), a major deep-seismic project (Lithoprobe East, Quinlan, 1998), NATMAP (Canada NATional geoscience MAPping program) regional mapping and thematic studies (Maritimes Basin; 1993-1998, Forelands and Platform; 1999-2004), two Targeted Geoscience Initiative projects (Red Indian Line; 2000-2003; Appalachian Energy; 2003-2005) and the overarching Secure Canadian Energy Supply program (2005-2010; Lavoie *et al*., 2009, Dietrich *et al*., 2011) prompted some new research activities and resulted in improved understanding of the northern Appalachians (Lynch, 2001; Lavoie *et al.*, 2003a; 2004; van Staal, 2005; Lavoie, 2008). In a global effort of synthesis, Hibbard *et al*. (2006) have produced a new compilation map of the entire North American Appalachians.

This contribution presents an overview of the lower to middle Paleozoic stratigraphic architecture, paleogeographic scenarios and relative sea-level history for the evolving sedimentary basins that resulted in the actual northern Appalachians.

2. REGIONAL GEOLOGICAL SETTING

Rocks ranging from the Neoproterozoic to Cretaceous are found in the Appalachians of North America (Figure 1). This orogenic belt has been shaped by several major tectonic events as well as by local, less severe, but critical tectonic phases (Figure 2). Six significant orogenic/deformation events are documented in the Appalachians and are related to the accretion of volcanic arcs, oceanic crust, microcontinents and continents to the progressively more and more composite margin of Laurentia (van Staal *et al.*, 1998; van Staal, 2005; Ettensohn, 2008; van Staal *et al*., 2009). These events are 1) the late Cambrian Penobscot Phase (Cambrian oceanic units-Gander) and the coeval Lushs Bight Oceanic Tract-Dashwoods accretion, 2) the end-Middle Ordovician Taconian Orogeny (volcanic arcs-Laurentia), 3) the Silurian Salinic Orogeny (Ganderia-Laurentia), 4) the late Early Devonian Acadian Orogeny (Avalonia-Laurentia), 5) the end-Middle to Late Devonian Neoacadian Orogeny (Meguma-Laurentia) and 6) the end-Carboniferous - Permian Alleghanian Orogeny (Gondwana-Laurentia), all these events leading to the formation of Pangea (Miall and Blakey, 2008). In this contribution, we discuss the first four of these events and their tectonostratigraphic effects on the Canadian Appalachian Orogen (Figure 2).

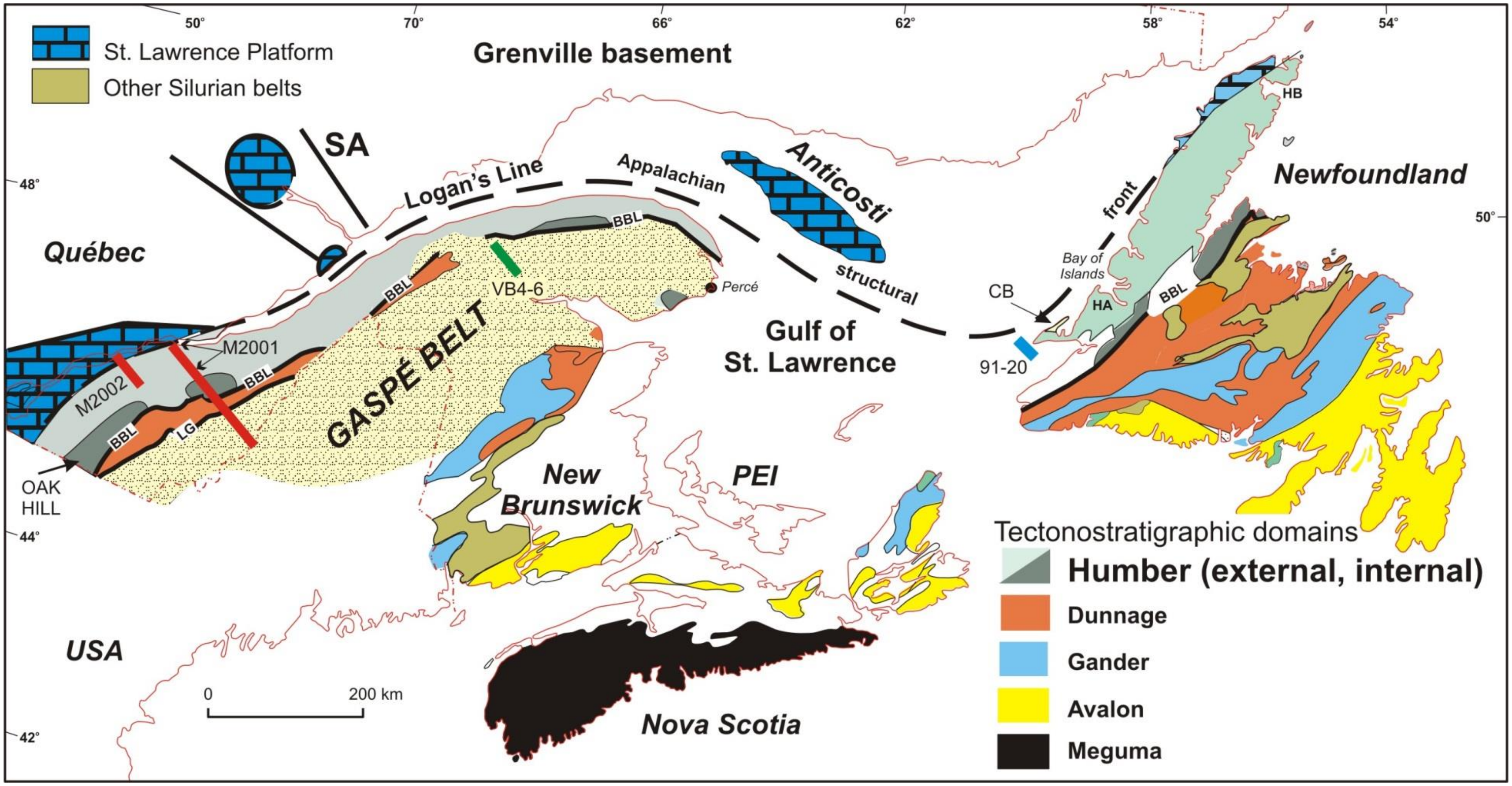


Figure 1. Taconian tectonostratigraphic domains and the Silurian-Devonian basin (Gaspé Belt) of the Canadian Appalachians. The tectono-stratigraphic divisions of the Gaspé Belt are shown on Figure 15. Thick red lines refer to the position of seismic lines shown in Figures 4 (southern Quebec), 5 (Western Newfoundland) and 19 (Gaspé Belt). Note the position of the Early Cambrian shallow-marine sediments of the Oak Hill Group in southern Québec. BBL: Baie Verte – Brompton Line, SA: Saguenay Graben. Tectonostratigraphic nappes of the Taconian Humber Zone are detailed in Lavoie et al (2003b). CB: Silurian Clam Bank Belt. Modified from Williams (1995) and Lavoie et al. (2003b).

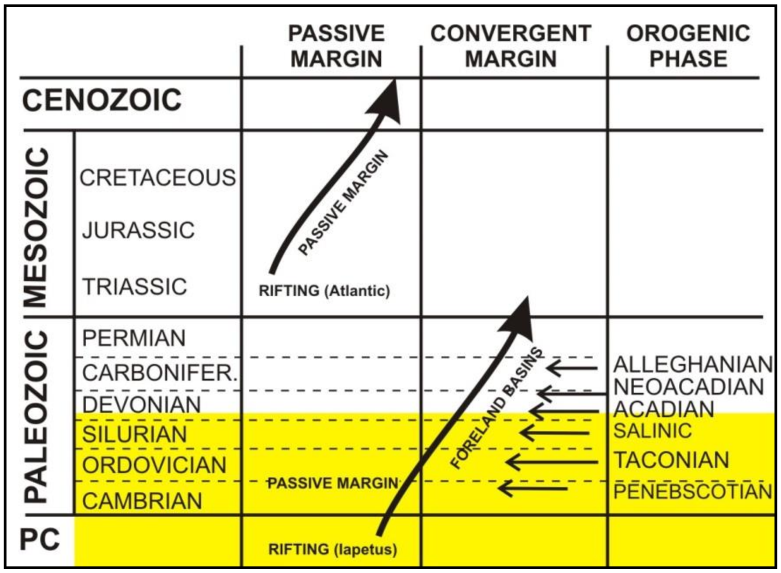


Figure 2. Tectonic cycles recorded along the ancient continental margin of Laurentia in eastern North America. Major orogenic phases are outlined. The shaded box shows the stratigraphic interval covered in this contribution. Modified from Sanford (1993)..

3. TECTONOSTRATIGRAPHIC DOMAINS OF THE APPALACHIANS

The tectonostratigraphic domains of the evolving orogenic belt are used to divide the Appalachians into workable packages for geological consideration. The Lower Paleozoic tectonostratigraphic zones (Williams, 1979) include the Humber (Laurentia's continental domain), Dunnage (peri-Laurentia and peri-Gondwana oceanic domains), the Gander and Avalon zones (peri-Gondwana oceanic and continental domains, respectively), and the Meguma Zone (a late-accreted peri-Gondwana continental terrane) (Figure 1). These belts record the complex evolution of the Cambrian and Ordovician orogenies (Figure 2; van Staal, 2005) and were affected by post-Taconian events that shaped up the Appalachians. The first part of this contribution focuses primarily on the Laurentian Humber Zone. The post-Taconian to syn-Acadian basins are developed over the Taconian zones (Figure 1); the best known of these basins is the Gaspé Belt that is preserved in various tectonostratigraphic assemblages: the Connecticut Valley–Gaspé synclinorium, the Aroostook–Percé anticlinorium and the Chaleurs Bay synclinorium. The Early Devonian Acadian Orogeny is the main phase that shaped these elements (Malo and Bourque, 1993; Williams, 1995). The expression of the Silurian Salinic Orogeny (Dunning *et al.*, 1990; Cawood *et al.*, 1994; van Staal, 2005) varies along strike in the Appalachians (Waldron *et al.*, 1998; Malo, 2001; Tremblay and Castonguay, 2002; Tremblay and Pinet, 2005; Lavoie, 2008; Ettensohn, 2008). Alleghanian deformation recorded in the pre-Acadian units in the Gaspé Peninsula is restricted to some extensional faulting (Bourque *et al.*, 1995; Jutras *et al.*, 2003).

4. THE TACONIAN-DEFORMED BASINS – THE HUMBER ZONE

An irregularly-shaped continental margin with recesses and salients characterized the southern edge of Laurentia following break-up of Rodinia in Neoproterozoic time (Figure 3; Thomas, 1977, 1991; Miall and Blakey, 2008; Allen *et al*., 2009, 2010). The irregular shape of the margin played a key role in the evolution of the early Paleozoic foreland platform in Canada (Stenzel *et al.*, 1990; Lavoie 1994; Sharma *et al.*, 2003; Allen *et al*., 2009, 2010) and in the USA (Quinlan and Beaumont, 1984; Ettensohn, 2008).

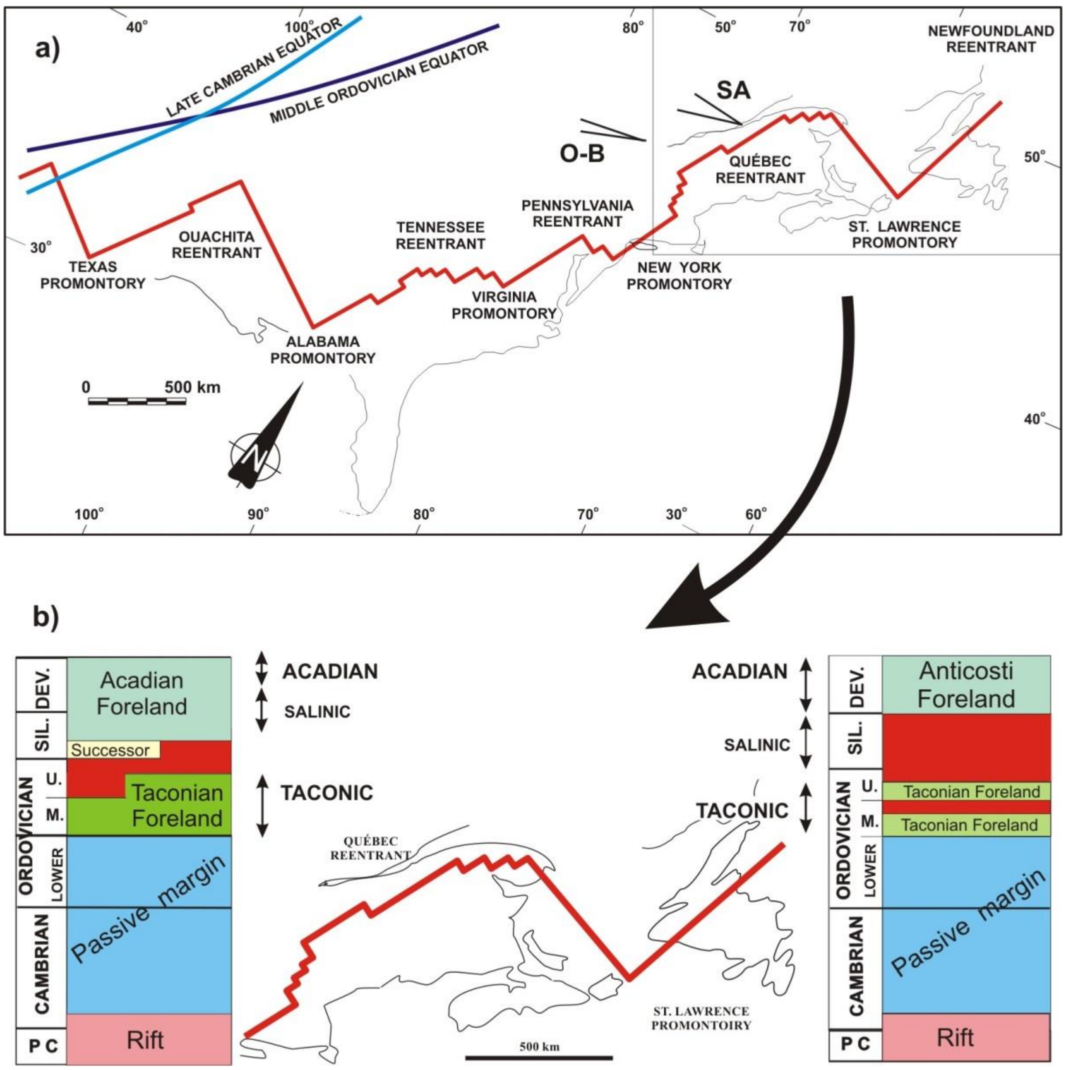


Figure 3. a) The Early Paleozoic continental margin of Laurentia with the distribution of reentrants and promontories. O-B: Ottawa – Bonnechère Graben, SA: Saguenay Graben. Modified from Thomas (1977). b) General event-stratigraphic framework for the Québec Reentrant (left column) and St. Lawrence Promontory (right column) together with the most significant tectonic events.

Detailed information on the rift, passive-margin and foreland-basin evolution of the shallow-marine early Paleozoic continental-margin platform is available for western

Newfoundland (James *et al.*, 1989) and southern Quebec – eastern Ontario (Bernstein, 1992; Lavoie, 1994, 1995a; Salad Hersi and Dix, 1997; Lavoie and Asselin, 1998; Salad Hersi *et al.*, 2002a, 2003; Salad Hersi and Dix, 2006; Dix and Al Rodhan, 2006; Lavoie, 2008, Lavoie et al., 2012). The coeval slope succession has been studied in detail in western Newfoundland (James and Stevens, 1986; James *et al.*, 1989; Waldron and Palmer, 2000; Palmer *et al.*, 2001; Burden *et al.*, 2001; Waldron *et al.*, 2003) and eastern Québec (Lebel and Kirkwood, 1998; Lavoie, 1997, 1998, 2001, 2002; Cousineau and Longuépée, 2003; Longuépée and Cousineau, 2005), and a regional integrated framework for this time interval has been proposed (Lavoie *et al.*, 2003b; Lavoie, 2008).

The term Humber Zone (Williams, 1976) was given for the north-westernmost tectonostratigraphic domain of the Taconian orogenic belt (Figure 1). First defined in western Newfoundland, this belt was later recognized and extended on the Canadian mainland down to the northern US segment of the Appalachians (Williams, 1978). In the Humber Zone, stacks of tectonic slices of Neoproterozoic basement and Lower Cambrian to Upper Ordovician rocks of Laurentian continental affinity (St. Lawrence Platform and coeval slope and rise sediments) are deformed and thrusted over the St. Lawrence cratonic platform in a thin- to thick-skinned tectonic scenario (St-Julien and Hubert, 1975; Williams, 1978; van Staal *et al.*, 1998; Waldron *et al.*, 1998, 2003; Stockmal *et al.*, 1998; Séjourné *et al.*, 2003; Stockmal *et al.*, 2004; Séjourné *et al.*, 2005;

Figure 4 and Figure 5). The Humber zone is bordered to the west by the St. Lawrence Platform (Sanford, 1993); the limit is the westernmost transported tectonic slices (Globensky, 1987; Waldron *et al.*, 1998). This limit in southern Québec is commonly referred to as the Logan's line, or as the Champlain Thrust in northern Vermont. Seismic data however, indicate that the St. Lawrence Platform records significant Taconian (?) compressive deformation (

Figure 4), which include triangle zone and blind thrusts found in the central segment of the St. Lawrence Platform in southern Québec (Castonguay *et al.*, 2003, 2006; 2010). Therefore in Québec, the Appalachian structural front does not coincide with Logan's line. To the east, the Humber Zone is bordered by the Dunnage Zone, which consists of various oceanic rocks; the western limit of the Humber Zone consists of faults that form the Baie Verte – Brompton Line (Figure 2; Tremblay *et al.*, 1995; van Staal, 2005). Differences in the degree of deformation and metamorphism led St-Julien and Hubert (1975) to divide the Taconian deformed Laurentia continental rocks of the Québec Reentrant into two domains (Figure 2): a western external domain with low deformation and low-grade metamorphism that passes eastward to an internal domain with higher-grade metamorphic rocks as well as polyphase tectonic deformation (Pinet *et al.*, 1996; Waldron *et al.*, 1998; Castonguay *et al.*, 2001; Temblay and Castonguay, 2002).

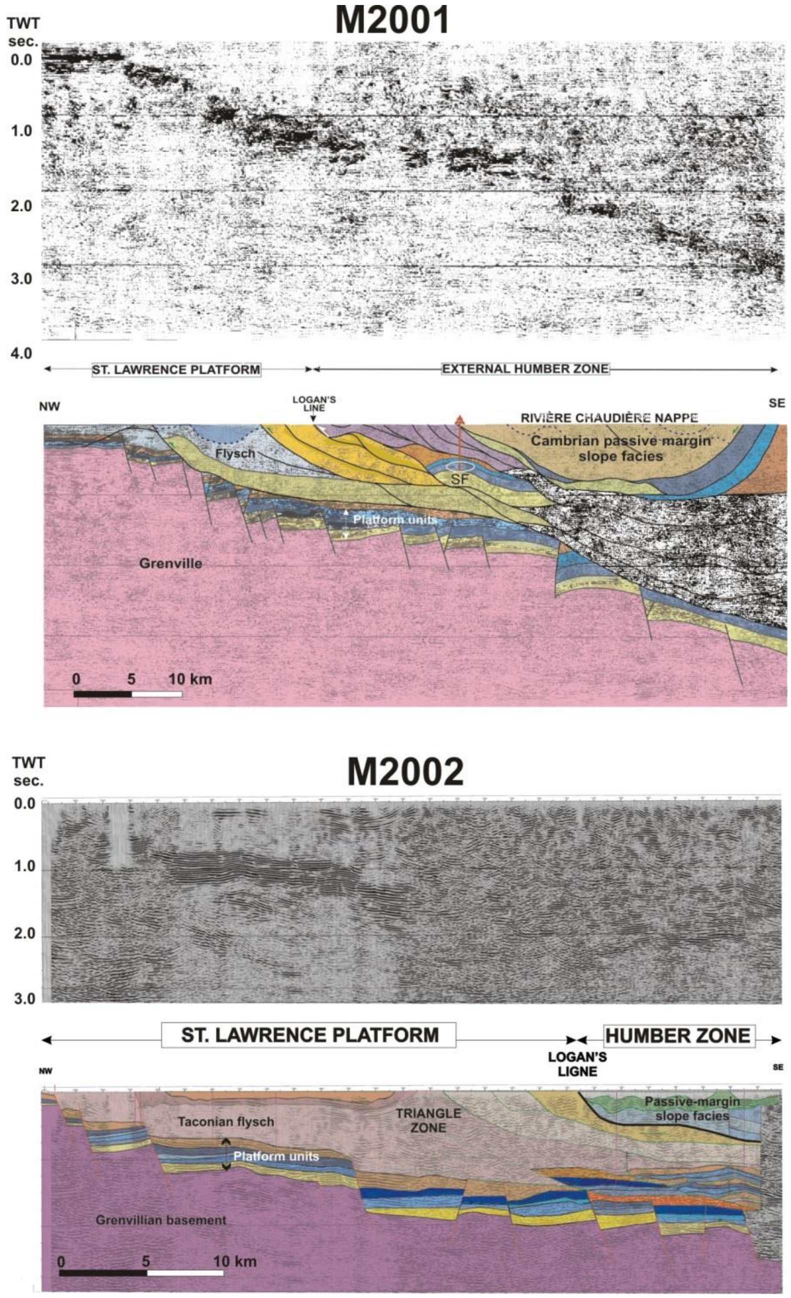


Figure 4 - Seismic lines M2001 and M2002 in southern Quebec imaging the St Lawrence Platform, the Appalachian structural front and the stack of nappes in the Humber domain. Only the northwestern segment of line M2001 is shown. Note the development of significant compressive structures west of the Logan's line, in particular, a shallow triangle zone on M2002. The position of the Saint-Flavien gas field is shown on the M2001 line. The deformation is thin-skinned. Modified from Castonguay *et al.* (2010). Location of the lines in southern Quebec is shown by the red lines on Figure 1.

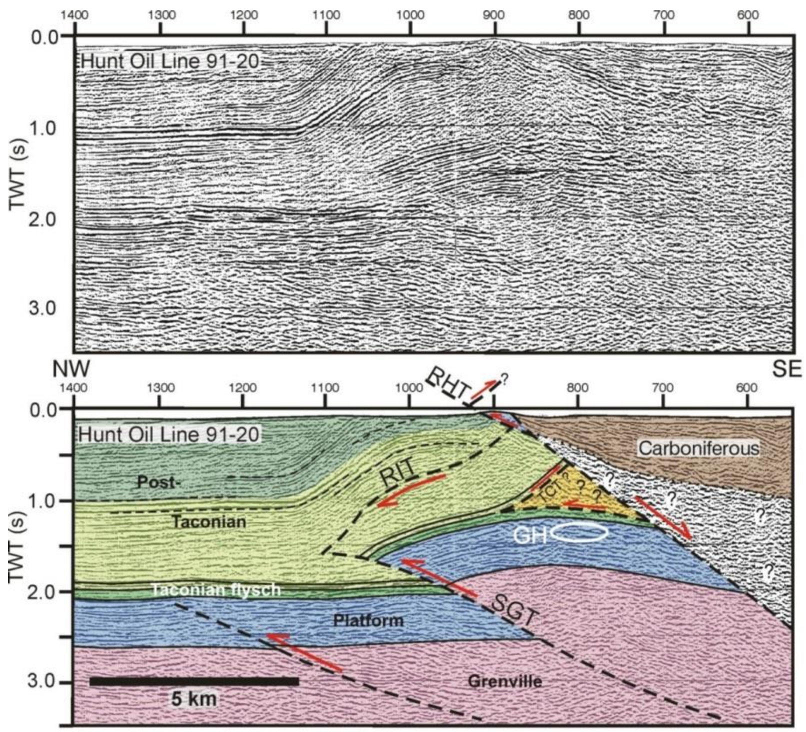


Figure 5. Seismic line 91-20 offshore western Newfoundland imaging the platform and foreland-basin successions involved in thick-skinned deformation with basin inversion along the Round Head Thrust Fault (RHT) and the development of a triangle zone. The projected position of the onshore Garden Hill (GH) oil field is shown. Modified from Stockmal *et al.* (1998). RIT: Red Island Thrust; SGT: St. George Thrust; TCT: Tea Cove Thrust. Location of the line is shown by the blue line on Figure 1.

The relative timing of obduction of the oceanic seafloor units onto the continental margin in the Québec Reentrant has been traditionally indirectly determined by the biostratigraphic age of the successions that under- and overlie the accreted units of the Dunnage Zone (St-Julien and Hubert, 1975). Recent ^{40}Ar/^{39}AR and K/Ar metamorphic ages confirm the "classic" Middle to Late Ordovician Taconian age (Castonguay *et al.*, 1997; Pincivy *et al.*, 2003; Glasmacher *et al.*, 2003; Malo *et al.*, 2008) for the ophiolite obduction onto the continental slope margin successions. At the St. Lawrence Promontory in western Newfoundland, the obduction of the Bay of Island ophiolite and the associated Humber Arm Allochthon onto the continental margin of Laurentia was long considered to be Middle Ordovician in age (Williams, 1975). This "classic" Taconian age is supported by the biostratigraphic ages of the Taconian flysch and of the overlying units. However, detailed geochronology, structural studies and industry seismic data (Figure 5) indicate that the emplacement of oceanic-domain units over the shallow segment of the continental margin started in Silurian (Dunning *et al.*, 1990; Cawood *et al.*, 1994) and ended prior to the Viséan (Carboniferous), likely in Middle Devonian (Cawood, 1993; Waldron *et al.*, 1998; Stockmal *et al.*, 1998; 2003; 2004). The "Taconian" event near the St. Lawrence Promontory resulted from the emplacement of the oceanic seafloor and composite terranes on distal deep marine continental slope succession (van Staal *et al.*, 1998; Waldron and van Staal, 2001). It has been proposed that subduction near the continental margin of Laurentia started in the lastest Cambrian with the obdcution of the Lushs Bight Oceanic Tract (Swinden *et al.*, 1997) over the Dashwoods microcontinent (Waldron and van Staal, 2001), the latter being lately detached from Laurentia (Waldron and van Staal, 2001). The accretion of the new composite terrane along the continental margin at the St. Lawrence Promontory marks the onset of the Taconian orogeny there (van Staal, 2005).

4.1. End rift–early drift

In western Newfoundland, the oldest rift-related event is dated at 615 Ma (Kamo *et al.*, 1989), however, Cawood *et al.* (2001) documented that significant rifting only started at 570 Ma with a last pulse at 555-550 Ma (van Staal *et al.*, 1998; Waldron and van Staal, 2001; van Staal, 2005). For the western Newfoundland platform succession, James *et al.* (1989) identified the end rift – early drift episode as the "pre-platform shelf" which is recorded by the Lower Cambrian Labrador Group. This event coincides with the Sauk I sub-sequence of the Early Cambrian (Sloss, 1963).

In Québec, dike-swarm tholeiites in the Grenvillian province give a 590 Ma age (Kamo *et al.*, 1995). Rift-related alkaline basalts and comendites of the Tibbit Hill Formation in southern Québec gave 554 Ma (Kumarapeli *et al.*, 1989). Similar rift basalts are found in the Caldwell and Shickshock groups and the Montagne Saint-Anselme Formation in southern Québec, Gaspé Peninsula and eastern Québec, respectively. U-Pb dating of the volcanic rocks at the Montagne Saint-Anselme yields an age of 561 ± 7 Ma, whereas basalts of the Shickshock Group at the Lac Matapédia (Gaspé Peninsula) yield ages of 565 ± 6 Ma and 556 ± 5 Ma (Cox *et al.*, 2005). A felsic phase within the Caldwell lavas gave a radiometric age of 562 ± 2 Ma (J. Bédard, pers. comm., 2003). There is no unequivocal preserved record of Early Cambrian facies on the St. Lawrence Platform. The Potsdam Group unconformably overlies Precambrian basement; the lower formation (Covey Hill Formation) is assigned an Early Cambrian age (Sanford, 1993) without supporting faunal elements although more recently Late Cambrian medusa have been reported from the top of the Covey Hill Formation (Lacelle *et al.*, 2008). At the eastern end of the Humber Zone (Figure 2), tectonic stacks of the shallow-marine Oak Hill Group (Charbonneau, 1980) overlie rift volcanics (Kumarapeli *et al.*, 1989; Castonguay *et al.*, 2001). The Cheshire (sandstone) and Dunham (carbonate) formations have yielded Early Cambrian faunal elements (Clark, 1936: Clark and McGerrigle, 1944).

4.1.1. The St. Lawrence Promontory (western Newfoundland)

The Lower Paleozoic continental margin of Laurentia preserved in western Newfoundland was built on the St. Lawrence Promontory (Figure 3) (Thomas, 1977, 1991; Miall and Blakey, 2008; Allen *et al.*, 2009, 2010). Autochthonous and transported rocks are preserved. The best known of the allochthons is the Humber Arm Allochthon (Williams, 1975). Its sedimentary rock package forms the Humber Arm Supergroup (Stevens, 1970).

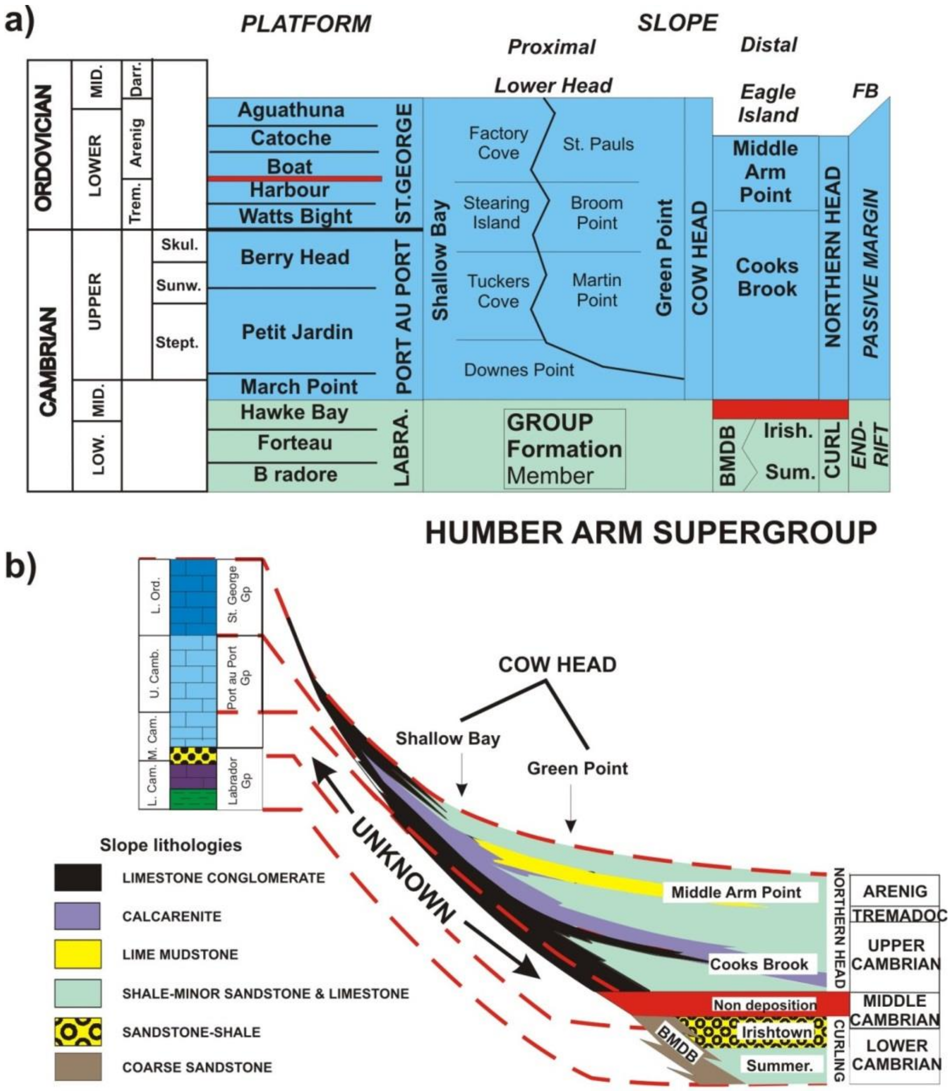


Figure 6. a) End-rift (green-coloured) and passive margin (blue-coloured) stratigraphic correlation of platform succession and Humber Zone continental-slope sediments in Western Newfoundland. The Humber Arm Supergroup consists of the lower Curling Group and the laterally equivalent Cow Head and Northern Head groups. Designation of units as follows: **GROUP, Formation**, Member. Foreland-basin units are in italic. Step: Steptoan, Sunw: Sunwaptan, Skull: Skullrockian, Trem: Tremadocian, Darr: Darriwilian. b) General lateral relationship of stratigraphic units from platform to distal slope. BMDB: Blow Me Down Brook Formation, Summer: Summerside Formation. Red-coloured intervals represent a hiatus. Not to scale. Modified from James *et al.* (1989) and Lavoie *et al.* (2003b).

The current framework includes a Neoproterozoic (?) - Lower Cambrian Curling Group (Summerside, Irishtown, and Blow Me Down Brook formations), a Middle Cambrian - mid Arenigian Northern Head Group (Cooks Brook and Middle Arm Point formations) and the coeval, laterally correlative Cow Head Group (Shallow Bay and Green Point formations) (Figure 6). The lower assemblage (the Curling Group) has no equivalent below the Cow Head Group

(Figure 6). The slope and rise sediments of the end-rift episode are recorded in the Curling Group (Lavoie *et al.*, 2003b).

The Neoproterozoic to Lower Cambrian Summerside Formation consists of slates with subordinate meta-sandstones and conglomerates (Stevens, 1965, 1970; Waldron and Palmer, 2000; Palmer *et al.*, 2001; Waldron *et al.*, 2003). The overlying Lower Cambrian Irishtown Formation consists of slates with sandstones and limestone conglomerates (Palmer *et al.*, 2001). The upper Lower Cambrian Blow Me Down Brook Formation (Botsford, 1988; Lindholm and Casey, 1990; Burden *et al.*, 2001) consists of parallel and cross-laminated, quartz-rich feldspathic sandstone with shale (Waldron and Palmer, 2000; Buchanan *et al.*, 2001; Waldron *et al.*, 2001, 2003).

The Curling Group is time-correlative with the Lower Cambrian shallow marine Labrador Group (James *et al.*, 1989; Figure 6). Microfaunal correlations have been proposed between the Curling Group and the Forteau Formation (Labrador Group) (Burden *et al.*, 2001; Normore, 2001). The upper unit of the Labrador Group, the Hawke Bay Formation, records a major sea-level lowstand (James *et al.*, 1989). It has been proposed that massive sandstone and conglomerate in the upper part of the Irishtown Formation represents the slope record of that major lowstand (James *et al.*, 1989; Palmer *et al.*, 2001; Lavoie *et al.*, 2003b).

4.1.2. The Québec Reentrant (Eastern Québec)

In eastern Québec, the Lower Paleozoic continental margin of Laurentia was built in the Québec Reentrant (Figure 3) (Thomas, 1977, 1991; Miall and Blakey, 2008; Allen *et al.*, 2009, 2010). The Humber succession in the Québec Reentrant occurs in a number of stacked structural nappes (Figure 2), for which stratigraphic nomenclatures were only recently synthesized (Lavoie *et al.*, 2003b) (Figure 2 and Figure 7).

At the base of the Humber succession, the undated Saint-Roch Group (and correlative units; Figure 7) consists of mudstone with subordinate sandstone and rift volcanics (Lavoie, 1997). A distinctive unit of massive, pebbly green sandstone with red and green mudstone of late Early Cambrian age (Saint-Nicolas – “green sandstone” and correlative units; Figure 7) overlies the basal succession (Sweet and Narbonne, 1993; Lavoie *et al.*, 2003b; Burden, 2003). This distinctive massive sandstone unit is a regional marker. It has been proposed that this coarse-grained unit represents the deep-marine expression of a significant late Early Cambrian sea-level lowstand (Lavoie *et al.*, 2003b).

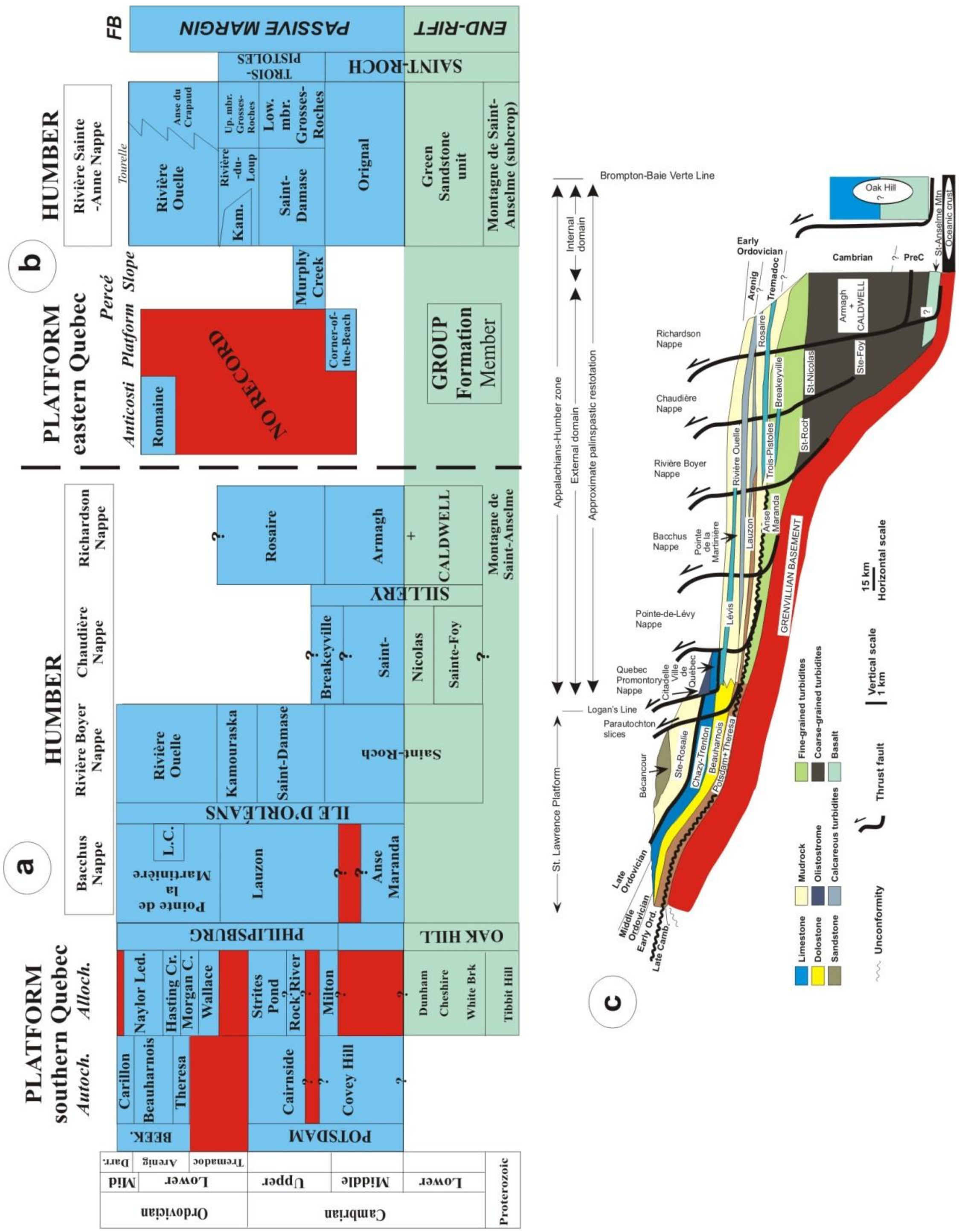


Figure 7. End-rift (green-coloured) and passive-margin (blue-coloured) stratigraphic correlations of platform and Humber Zone continental-slope sediments in the Québec Reentrant in (a) southern Québec and (b) eastern Québec - Gaspé. See Figure 6 for unit status. Autoch: Autochthonous units of the St. Lawrence Platform. Alloch: Allochthonous platform thrusts in the Humber Zone. BEEKMAN: Beekmantown Group, Hasting Cr: Hasting Creek Formation, Naylor Led: Naylor Ledge Formation, Kam: Kamouraska Formation, L.C.: Lévis Formation conglomerate. Red-coloured intervals are for hiatus. c) Schematic composite diagram of the St. Lawrence Platform and Humber Zone illustrating the assumed palinspastically restored lateral relationships

of some tectonostratigraphic nappes. Note the thickening of the sedimentary pile toward the east. The Early Cambrian platform units of the Oak Hill Group are part of a distinct tectonic nappe. Vertical exaggeration 15x. Modified from Lebel and Kirkwood (1998).

4.1.3 Correlation western Newfoundland – Québec

Following the late Neoproterozoic initiation of spreading and eruption of basalts with associated coarse-grained sedimentation (Wood Island Lavas, Bradore, Saint-Anselme and Tibbit Hill formations, Caldwell and Shickshock groups), the ensuing relative sea-level rise led to shallow-marine carbonate-siliciclastic sedimentation on local horst structures (Forteau and Dunham formations), whereas in the graben and slope settings, fine- and coarse-grained sediments were deposited as proximal and distal submarine fans (Summerside, Irishtown, Blow Me Down Brook, Sainte-Foy and Armagh formations, lower beds of Saint-Roch Group) (Figure 8 and Figure 9a). A major sea-level lowstand is recognized in late Early Cambrian and marks the end of the Sauk I sub-sequence (James *et al.*, 1989; Lavoie *et al.*, 2003b). This lowstand is recorded in prograding shallow-marine sandstone such as the Hawke Bay (Newfoundland; Knight and Boyce, 1987) and Monkton (Vermont; Landing *et al.*, 2002) formations. This event is expressed in the deep-marine sandstone and conglomerate found in the upper part of the Irishtown, in the Blow Me Down Brook and Saint-Nicolas formations and the “green sandstone” unit of the Saint-Roch Group (Figure 8 and Figure 9b).

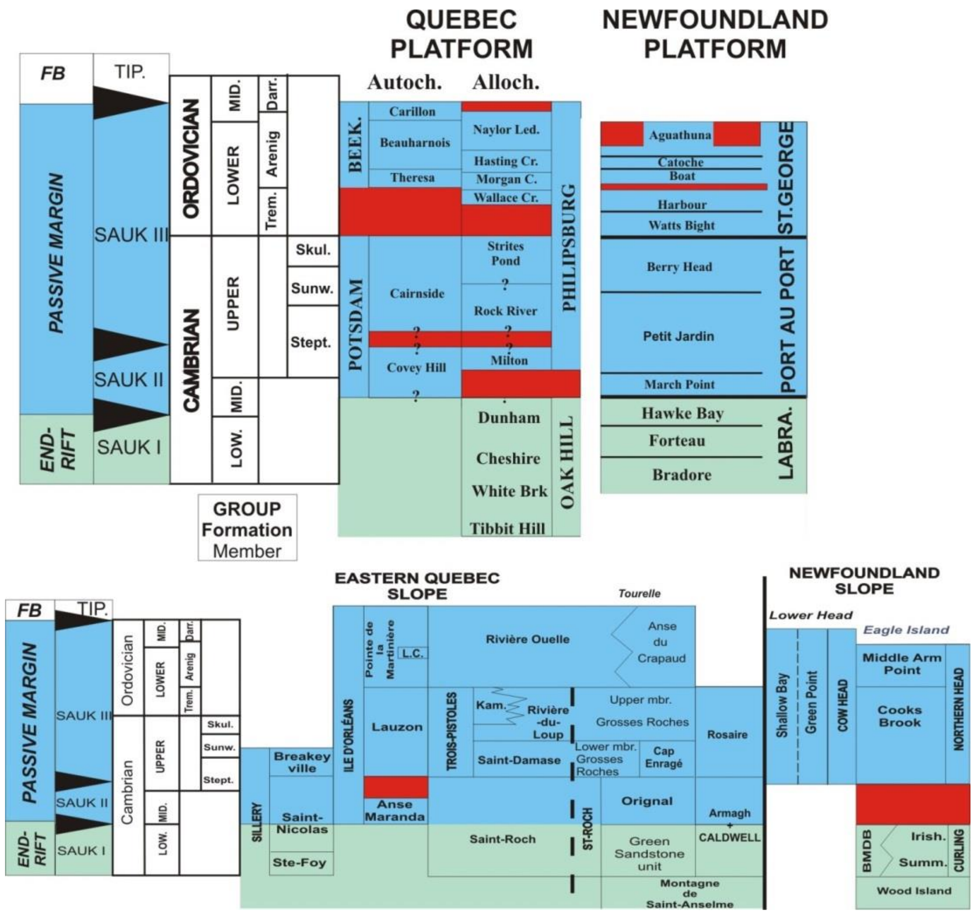


Figure 8. Stratigraphic correlation of the end-rift (Sauk I sub-sequence; green-coloured) and passive-margin (Sauk II and III; blue-coloured) successions in the Québec Reentrant and at the St. Lawrence Promontory. Correlations for platform and slope rock units are proposed; see text for details. Red-coloured intervals are for hiatus. See Figure 6 and Figure 7 for unit status and acronyms. Modified from Lavoie *et al.* (2003b).

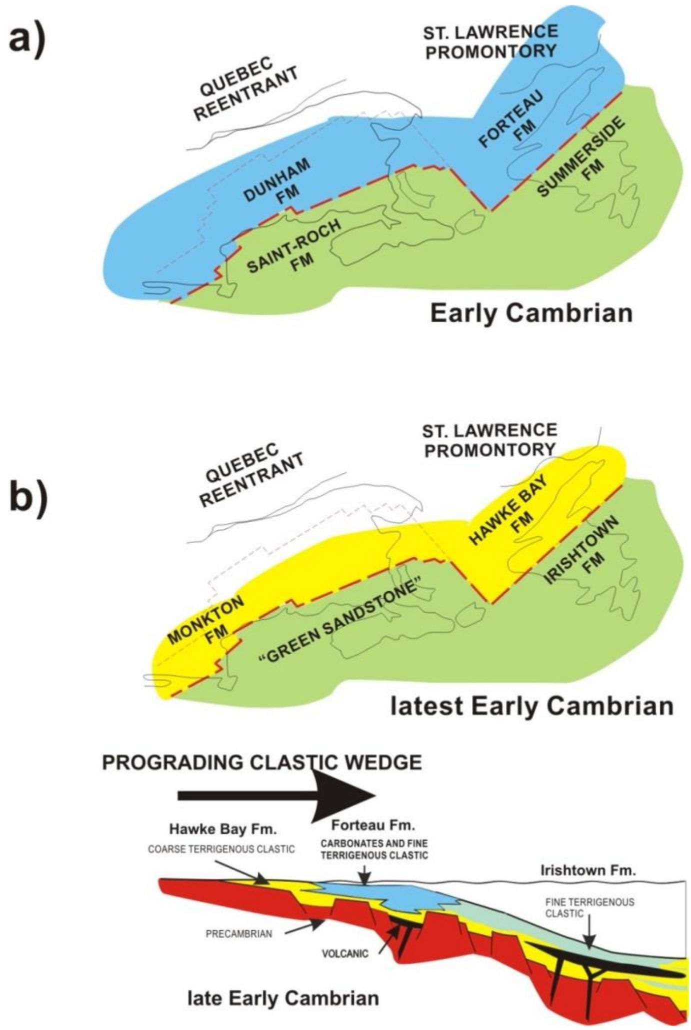


Figure 9. a) Interpreted paleogeographic reconstruction of the Laurentian continental margin in Early Cambrian. Geographically restricted carbonate platforms (Forteau / Dunham) are located on rift-related horsts, while intervening deep grabens are filled by coarse- to fine-grained slope sediments (Armagh / Saint-Roch / Summerside). The thick dashed line represents the assumed position of the continental shelf edge. b) Paleogeographic reconstruction in late Early Cambrian at the time of the "Hawke Bay event" (first major sea level lowstand) that marks the end-rift episode. Shallow-marine quartzite (Monkton / Hawke Bay) prograded towards the shelf break while deeper slope environments were fed by coarse-grained sediments ("Green Sandstone" / Irishtown) from the prograding clastic wedge. Modified from Lavoie *et al.* (2003b). The cartoon illustrates the late Early Cambrian paleoenvironmental model; the progradation of the clastic wedge (Hawke Bay Formation) responds to the major sea-level lowstand. Cartoon modified from James *et al.* (1989).

4.2. The passive margin

In western Newfoundland, the late Early Cambrian shallow-marine clastics were flooded by the transgressive sea level that marks the initiation of the Sauk II sub-sequence (James *et al.*, 1989). The carbonate-dominated passive-margin consisted in a Middle-Late Cambrian narrow, high-energy carbonate platform (Port au Port Group) that evolved into an Early-earliest Middle Ordovician wide, low-energy carbonate platform (St. George Group) (Figure 6; James *et al.*, 1989). The passive-margin period ended with onset of significant sea-floor subduction, and the migration of a tectonic peripheral bulge on the margin in earliest Middle Ordovician (Jacobi, 1981; Knight *et al.*, 1991; Lavoie *et al.*, 2012). This event coincides with the end of the Sauk sequence, the beginning of the Tippecanoe sequence and the inception of the Taconian foreland basin (Figure 1, Figure 2 and Figure 3).

In the Québec Reentrant (Figure 7), the oldest known passive-margin, shallow-marine platforms are the upper Middle Cambrian Corner-of-the-Beach Formation (Kindle, 1942; Lavoie, 2001) and the shallow-marine carbonate platform of the Upper Cambrian Strites Pond Formation (Salad Hersi and Lavoie, 2001a; Salad Hersi *et al.*, 2002b). These two formations are facies-wise similar to the Port au Port Group (Lavoie, 2001; Salad Hersi and Lavoie, 2001a; Salad Hersi *et al.*, 2002b; Lavoie *et al*., 2012). The shallow-marine record of the Sauk II and III sub-sequences is best expressed in the extensive Lower Ordovician carbonates of the Beekmantown and Philipsburg groups of southern Québec (Globensky, 1987; Bernstein, 1992; Salad Hersi *et al.*, 2002a, 2002b, 2003; Salad Hersi, 2012; Dix, 2012) as well as of the Romaine Formation on Mingan Islands (Desrochers, 1988; Desrochers *et al*., 2012). The Lower Ordovician units are truncated by the unconformity resulting from the migration of the peripheral bulge (Knight *et al.*, 1991; Lavoie, 1994).

4.2.1. The St. Lawrence Promontory (western Newfoundland)

The slope record of the passive margin consists of two laterally correlative rock packages: 1) the Middle Cambrian-lowermost Middle Ordovician proximal Cow Head Group and 2) the coeval, but more distal, succession of the Northern Head Group (Figure 6). These deep-marine successions are well-dated; limestone fragments in the conglomerates that punctuate the succession are rich in shallow-marine fauna, whereas the intervening fine-grained sediments are dated by graptolites and acritarchs.

The Cow Head Group has been extensively studied (James and Stevens, 1986; Coniglio, 1986; James *et al.*, 1989) and consists of two laterally correlative formations, the proximal Shallow Bay and the distal Green Point formations (Figure 6). Seven distinctive rock assemblages (defined as members) of alternating shales, sandstones and fine to coarse-grained limestones are recognized in the Shallow Bay (four members) and Green Point (three members) formations (Figure 6). The biostratigraphy allows correlation between both formations, with the shallow-marine platform and with the Cambrian Grand Cycles framework (James and Stevens, 1986; James *et al.*, 1989).

The Northern Head Group (Botsford, 1988) consists of the Cooks Brook and Middle Arm Point formations (Figure 6). The limestone and shale succession of the upper Middle Cambrian to Lower Ordovician Cooks Brook Formation disconformably overlies the upper Lower Cambrian Irishtown Formation (Figure 6). The Middle Arm Point Formation consists of mudstone with subordinate silty dolostone and limestone that carry Tremadocian to Arenigian age graptolite.

The passive-margin succession in western Newfoundland consists of proximal (Cow Head Group) and distal (Northern Head Group) depositional assemblages (Figure 6). The detailed work by James and Stevens (1986) and James *et al.* (1989) correlates the evolution of the Cow Head Group with that of the coeval shallow-marine Port au Port and St. George groups (Figure 6). Two major T-R cycles (Sauk II and III sub-sequences) are recorded in the Cow Head Group. Correlation of the Cow Head Group with the Northern Head Group is also proposed (Figure 6) (Lavoie *et al.*, 2003b).

4.2.2. The Québec Reentrant (Eastern Québec)

The first passive-margin sediments that overlie the upper Lower Cambrian green sandstone unit consist of a thick succession of upper Lower Cambrian to lower Middle Cambrian mudstone with glauconite- and quartz-rich sandstone (Orignal Formation and correlative units; Figure 7). A distinctive coarse-grained unit (Saint-Damase Formation and correlative units; Figure 7) overlies this fine-grained dominated interval. This unit consists of channel-fill carbonate conglomerate, feldspathic and siliceous sandstone and minor mudstone (Lavoie, 1998). The matrix of the conglomerate is Late Cambrian and embedded fragments consist of Early to early Late Cambrian nearshore to shallow marine platform margin limestone facies together with meter-sized sandstone, basalt fragments and basement-derived gneiss and orthoquartzite (Lavoie, 1997, 1998).

The coarse-grained interval is overlain by a succession of uppermost Cambrian to lowermost Ordovician mudstone with subordinate sandstone (Rivière-du-Loup Formation and correlative units; Figure 7) with discontinuous thick channel-fill quartz arenite (Kamouraska Formation; Figure 7).

The youngest passive margin unit (Rivière-Ouelle Formation and correlative units; Figure 7) consists of variegated mudstone with subordinate sandstone, ribbon limestone, calcarenite and limestone conglomerate of Early Ordovician age (Landing and Benus, 1985; Landing *et al.*, 1986; Bernstein *et al.*, 1992; Maletz, 1992, 2001; Asselin and Achab, 2004).

4.2.3. Correlation Newfoundland – Québec

The passive-margin history consists of two major T-R cycles identified as the Sauk II and III sub-sequences (Figure 8). The initial Sauk II transgressive and early highstand sea-level (Middle Cambrian) resulted in the sedimentation of the lower part of the Port au Port Group with no preserved slope record until the late Middle Cambrian (Cooks Brook Formation). In eastern Québec, the Corner-of-the-Beach Formation indicates that the Middle Cambrian platform locally extended into the more outer part of the Québec Reentrant; the slope record consists only of mudstone and sandstone (e.g., Orignal Formation and equivalent units). A sea-level lowstand is recognized near the base of the Late Cambrian (Steptoan) and correlates with the end of Grand Cycle A (Chow and James, 1987; Cowan and James, 1993), whereas the slope record of the marine lowstand is found in limestone conglomerates at the base of the Shallow Bay and Cooks Brook formations. These conglomerates consist of limestone fragments derived from late highstand to lowstand shedding of platform-margin facies (James *et al.*, 1989). In Québec, no record of lower Upper Cambrian platform rocks is known, but the widespread lower Upper Cambrian (Steptoan) slope limestone conglomerates (Saint-Damase Formation and correlative units) indicate the former presence of this platform. These thick conglomerates correlate with the end of the Sauk II sub-sequence.

Presence of the pre-Upper Cambrian fragments in the conglomerate makes the Upper Cambrian conglomerates of the Québec Reentrant different from the Newfoundland time-correlatives. Simple late-highstand to lowstand shedding of platform-margin clasts cannot alone explain the presence of fragments of Neoproterozoic (basement) to Late Cambrian age. The thickest and best developed conglomerate successions are found in eastern Quebec, adjacent to the Saguenay Graben (Aulacogene of Kumarapeli and Saull, 1966; Figure 2 and Figure 10a) and a Late Cambrian reactivation of this failed Neoproterozoic rift has been proposed as causal mechanism (Lavoie *et al.*, 2003b). This erosion of the continental margin ended with the final exhumation of basement rocks through erosion of the carbonate, clastic and volcanic succession deposited during and after the rift episode. The exact cause for the reactivation of the Saguenay Graben is still unclear; however, the first accretionary events recorded in circum-Iapetus terranes occurred in late Middle Cambrian (Miall and Blakey, 2008). This is well-documented by the Penobscotian Phase in the units of the peri-Gondwana Gander terrane (Neuman, 1967) and in the obduction of the peri-Laurentia Bushs Bight Oceanic Tract over the Dashwoods microcontinent (van Staal *et al.*, 2004). The latter accretion occurred in the neighbourhood of Laurentia and could have been the trigger for late Cambrian tectonic instability in the Quebec Reentrant.

At the onset of the Sauk III sub-sequence (Figure 8), a sea-level highstand is recorded in the Grand Cycle C and is dated as late Steptoan. On the Newfoundland platform, this marine highstand is recorded in the Berry Head Formation (Port au Port Group); in the slope environment, the finer-grained units of the Cow Head Formation record this high sea level. No carbonate platform of that age is known in the Québec Reentrant, but a fine-grained siliciclastic slope record (Rivière-du-Loup Formation and equivalents units) likely correlates with the Newfoundland slope succession. This highstand was followed by another sea-level lowstand in latest Cambrian (early Skullrockian), which marks the end of the Port au Port Group in western Newfoundland. In the slope environment, the fine-grained succession of the Cow Head Group passes into a more conglomeratic section. In southern Québec, the platform carbonates of the Strites Pond Formation are dated as latest Cambrian (Skullrockian), and it is capped by an erosive subaerial unconformity, which separates it from the outer-shelf facies of the upper Tremadocian Wallace Creek Formation (Salad Hersi and Lavoie, 2001a; Salad Hersi *et al.*, 2002b; Lavoie *et al.*, 2012). The coeval slope record of this erosive event is the thick channel-fill quartz sands of the Kamouraska Formation.

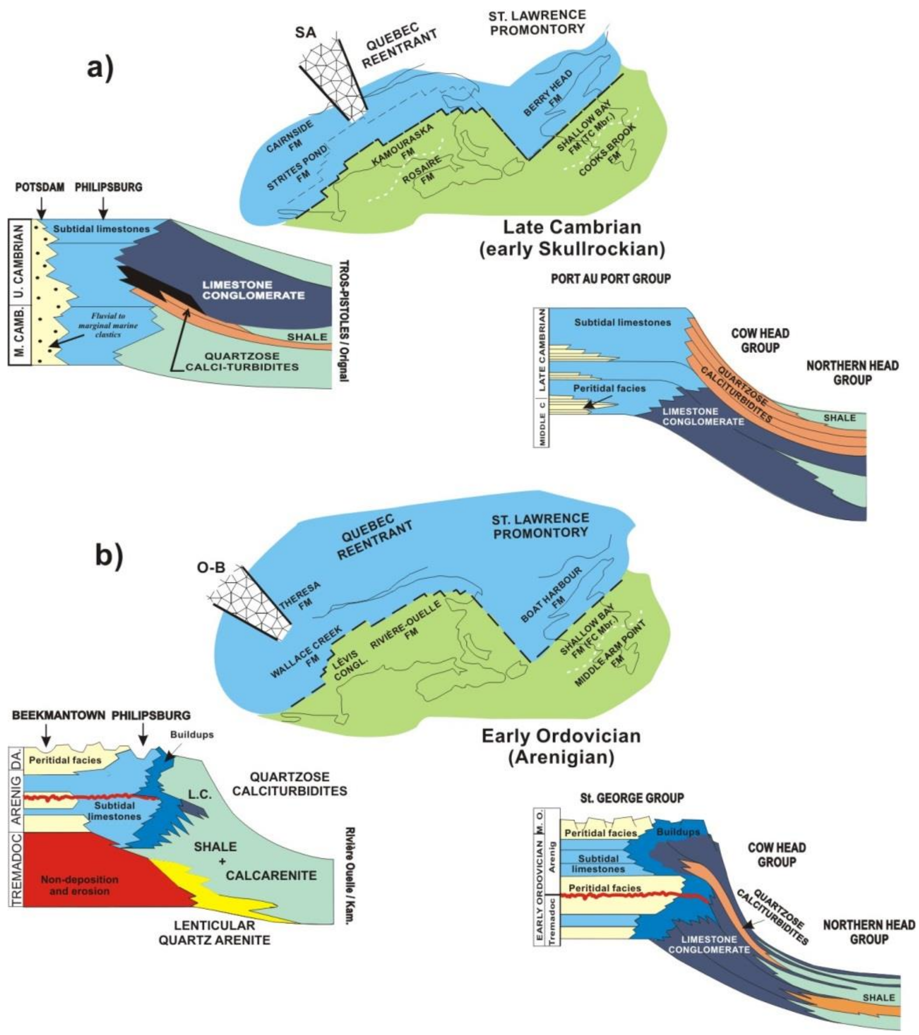


Figure 10. a) Interpreted paleogeographic reconstruction of the Laurentian continental margin in Late Cambrian (Skullrockian). Lateral relationship between the Cairnside and Strites Pond formations is discussed in Salad Hersi *et al.* (2002a, 2002b). The thickest succession of the Upper Cambrian conglomerates (Saint-Damase and correlative units) with older basement and platform rocks are found in the Lower St. Lawrence Valley, near the Saguenay Graben (SA). The two cartoons illustrate the depositional settings and lateral platform – slope relationships in Middle-Late Cambrian. Not to scale. b) Interpreted paleogeographic reconstruction of the Laurentian continental margin in Early Ordovician (Arenigian). The lateral relationship between the Theresa and Wallace Creek formations is discussed in Salad Hersi *et al.* (2002b, 2003). Thick white dashed lines represent the hypothetical facies transition from proximal to distal slope facies. The diachronism in Early Ordovician sea level lowstands (Tremadocian-Arenigian in Western Newfoundland and mid-Arenigian in southern Québec) is interpreted to have been related to the tectonic influence of the Ottawa – Bonnechère Graben (O-B). The two cartoons illustrate the depositional settings and lateral platform – slope relationships in Early Ordovician. Not to scale.

The Early Ordovician was marked by craton-wide transgression leading to the deposition of the St. George Group in western Newfoundland (Pratt and James, 1986), the Romaine Formation on Mingan and Anticosti islands (Desrochers, 1988; Brennan-Alpert, 2001: Desrochers *et al*., 2012) and the Beekmantown Group in southern Québec and eastern Ontario

(Bernstein, 1992; Salad Hersi *et al.*, 2002a, 2003; Salad hersi, 2012; Dix 2012) (Figure 8). Two T-R depositional cycles are recognized; the mid Boat Harbour Formation unconformity (Tremadocian-Arenigian boundary) separates these two cycles (James *et al.*, 1989) as does the slightly younger (mid-Arenigian) Theresa – Beauharnois formation contact (Salad Hersi *et al.*, 2003; Dix and Salad Hersi, 2004; Dix and Al Rodhan, 2006). In western Newfoundland, the first cycle covers the Tremadocian; the second cycle is Arenigian to Darriwilian in age. In southern Quebec and eastern Ontario, the T-R cycles are seemingly younger; the first cycle is upper Tremadocian to mid-Arenigian whereas the second one is mid-Arenigian to Darriwilian in age (Dix and Salad Hersi, 2004). Tectonic instability associated with the Ottawa – Bonnechère Graben has been proposed to explain the diachronism in the sea level fluctuations, conversely imprecise biostratigraphic data could also be envisaged (Dix and Salad Hersi, 2004; Dix and Al Rodhan, 2006). In the coeval slope succession, these limits of the T-R cycles are expressed in shedding of major limestone conglomerates in the Shallow Bay (James *et al.*, 1989) or in the Lévis (Samson *et al.*, 2002; Lavoie and Kirkwood, 2006) formations (Figure 8).

4.3. A regional sea-level scenario for the Lower Paleozoic end-rift and passive margin

The proposed Newfoundland-Quebec correlation allows the recognition of four distinctive major sea-level lowstands (Figure 11):

1) A late Early Cambrian event (“Hawke Bay event”) expressed by massive sandstones and conglomerates. This event marks the upper limit of the Sauk I subsequence.
2) An early-mid Upper Cambrian event (Steptoan-Sunwaptan) expressed in limestone conglomerates on the slope. Coeval tectonic instability is indirectly documented near the Saguenay Graben in the Québec Reentrant. This event marks the end of the Sauk II subsequence.
3) A latest Cambrian event (early Skullrockian) represented by local limestone conglomerates and coarse-grained clastics. This event occurs within the Sauk III subsequence but marks the end of the Cambrian Grand Cycle C.
4) a) In western Newfoundland, a sea-level lowstand at the Tremadocian – Arenigian boundary represented by more limestone conglomerates, and b) in southern Québec – eastern Ontario, a slightly younger sea-level lowstand in mid-Arenigian expressed in the major limestone conglomerate of the Lévis Formation. Diachronism is related to tectonic instability of the Ottawa – Bonnechère Graben (Dix and Salad Hersi, 2004).

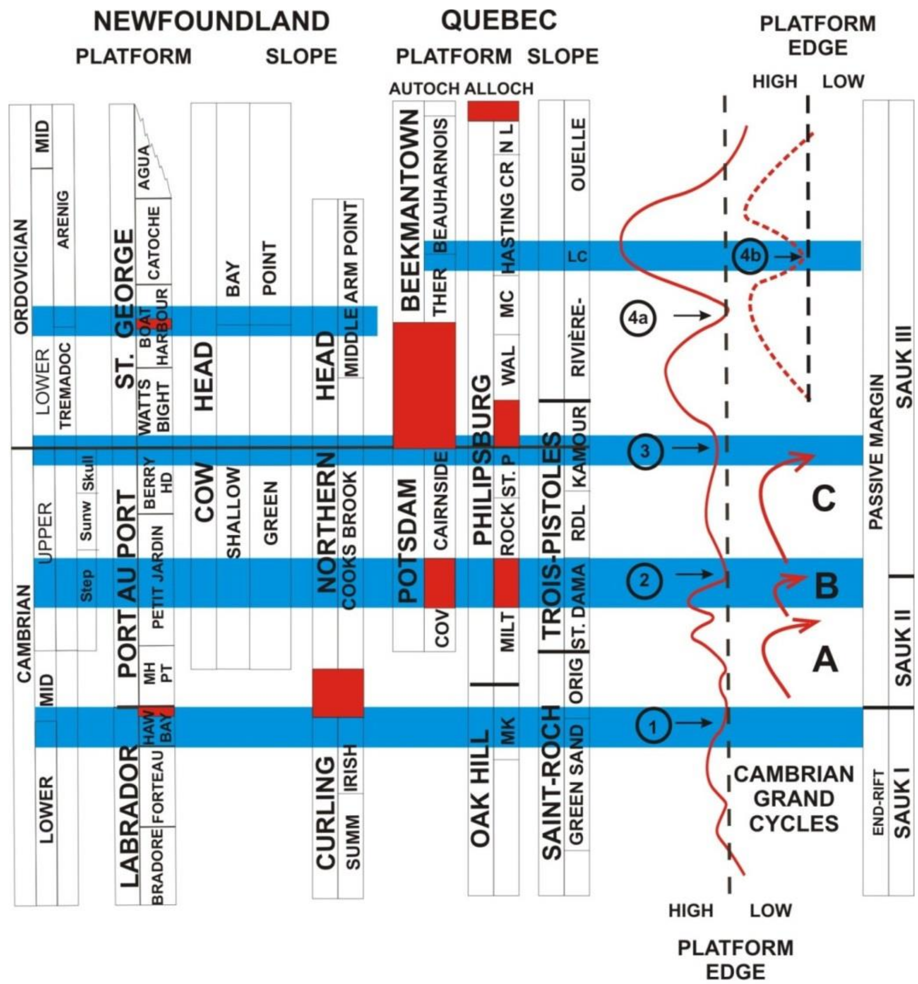


Figure 11. Chronostratigraphic correlation for selected units of the end-rift – passive-margin successions along the entire Canadian segment of Laurentia. The four major sea-level lowstands discussed in text (blue-coloured intervals) are identified (1 to 3 and the slightly diachronous 4a and 4b). Depositional hiatus are in red. The sea-level curve is from James *et al.* (1989); the curve applies well to the Québec succession prior to the Early Ordovician. The dashed line displays the Quebec Reentrant departure from the James *et al.* (1989) curve. Correlation with Cambrian Grand Cycles is shown. MH PT : March Point Fm.; Berry HD: Berry Head Fm.; Agua: Aguathuna Fm.; Summ: Summerside Fm.; Irish: Irishtown Fm.; Covey H: Covey Hill Fm; Strites P: Strites Pond Fm.; Wal Cr: Wallace Creek Fm.; MC: Morgan's Corner Fm.; Hast Cr: Hasting Creek Fm.; NL: Naylor Ledge Fm.; St.Dama: Saint-Damase Fm.; RDL: Rivière-du-Loup Fm.; Kamour: Kamouraska Fm.; L.C.: Lévis Formation. Modified from Lavoie *et al.* (2003b).

The stratigraphic record indicates that tectonism was sporadically active in the Quebec Reentrant from Late Cambrian to Early Ordovician (Lavoie *et al.*, 2001a; Lavoie *et al.*, 2003b; Dix and Salad Hersi, 2004; Dix and Al Rodhan, 2006). Evidence for such instability is associated with the two failed aulacogens in the Quebec Reentrant, the Ottawa – Bonnechère and the Saguenay grabens.

4.4. The Taconian foreland basin

The building of passive-margin successions along the eastern seaboard of Laurentia was stopped by emergence and sub-aerial exposure of the platform in earliest Middle Ordovician. The resulting break is known variously as the St. George (Newfoundland; Knight *et al.*, 1991), the Romaine (Anticosti; Desrochers, 1988), the Beekmantown (southern Québec; Dykstra and Longman, 1995; Salad Hersi *et al.*, 2003), the intra-Philipsburg (southern Québec – Vermont; Knight *et al.*, 1991; Salad Hersi *et al*., 2007), or the Knox (east U.S.A.; Read, 1989; Ettensohn, 2008) unconformity. This unconformity coincides with the boundary between Sloss' (1963) Sauk and Tippecanoe Sequences and marks the inception of the foreland basin at Laurentian continental margin (Figure 1 and Figure 3). The evolution of the foreland basin became strongly diachronous along strike of the continental margin, which suggests that the reentrant-promontory morphology played a key role in the evolution of Laurentia (Lavoie, 1994; Ettensohn, 2008).

4.4.1. The St. Lawrence Promontory (Western Newfoundland)

At the St. Lawrence Promontory (Figure 3), the migration of a tectonic peripheral bulge led to compression, block faulting, uplift and erosion of the St. George carbonate platform. The following subsidence contributed to Mid-Darriwilian carbonate sedimentation (Table Point Formation; Stenzel *et al.*, 1990) (Figure 12). Continued subsidence led to deep-marine carbonate-shale and eventually to deep-marine shales. Early tectonic exhumation along the Round Head Precursor Fault (Waldron *et al.*, 1993; Stockmal *et al.*, 1998) resulted in local submarine erosion of tectonic escarpments and sedimentation of fault-scarp conglomerates (Cap Cormorant Formation). In late Darriwilian, the Taconian-derived foreland flysch (Mainland Sandstone of the Goose Tickle Group; Quinn, 1995) was deposited on the foundered platform (Figure 12).

The transition from the passive margin to a foreland basin is well expressed in the slope and rise environment (Figure 12). Greenish flyschoid sandstone with subordinate shale of the middle to upper Darriwilian Lower Head Formation (James and Stevens, 1986) conformably overlies the proximal carbonate-rich succession of the Cow Head Group. Flyschoid sandstone with shale of the Arenigian to Darriwilian Eagle Island Formation (Waldron *et al.*, 1998; Waldron and Palmer, 2000) overlies the Middle Arm Point Formation of the Northern Head Group. Taconian flysch are demonstrably slightly older in the more distal successions (Figure 12).

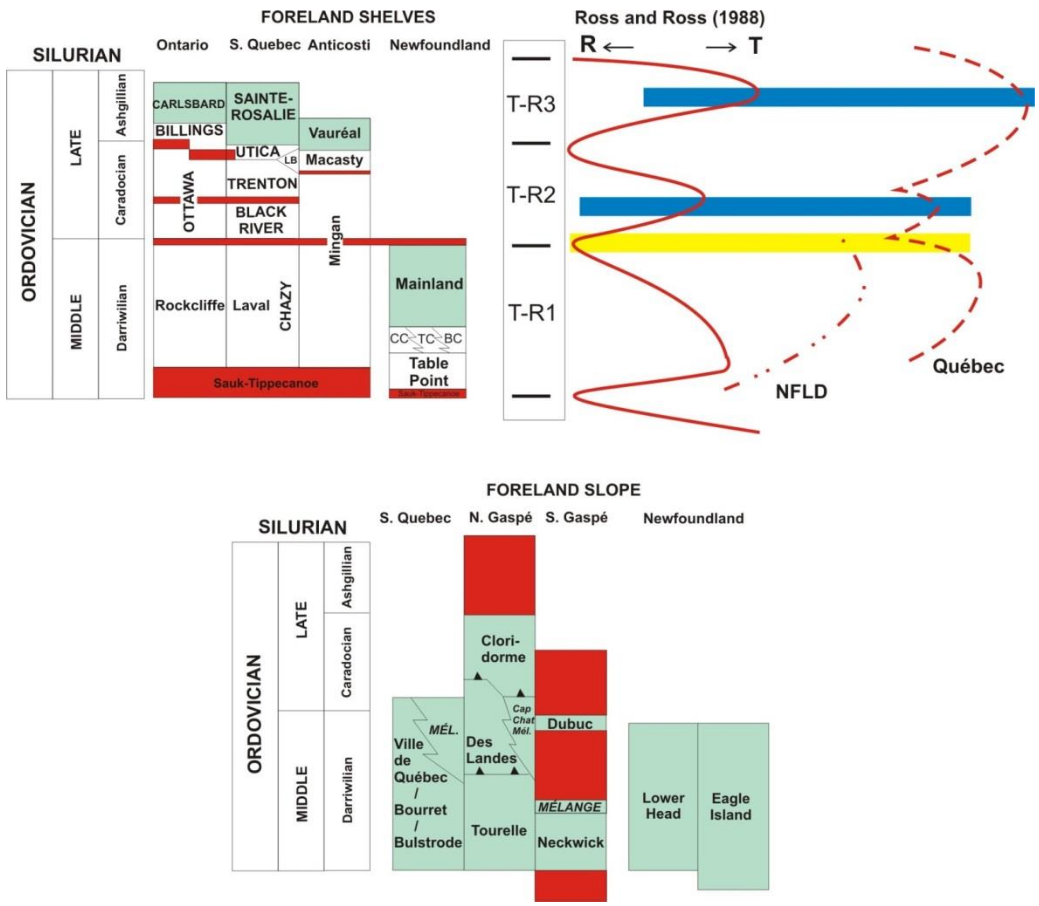


Figure 12. Middle to Late Ordovician foreland-shelf to slope stratigraphic framework at the St. Lawrence Promontory and in the Quebec Reentrant. In Newfoundland, the shallow-marine units are restricted to the Darriwilian and the shelf was buried by westerly migrating Taconian flysch (green-coloured) by late Darriwilian. CC: Cap Cormorant Formation; TC: Table Cove Formation; BC: Black Cove Formation. In the Quebec Reentrant, a progressive westward foundering (green-coloured flysch units) of shallow-marine settings occurred in Late Ordovician (Caradocian – Ashgillian). Taconian flysch sedimentation on the slope was initiated in late Arenigian (Newfoundland) to early Darriwilian time. Red-coloured intervals are for depositional hiatus. The sea-level curve of Ross and Ross (1988) indicates that the evolution of the Newfoundland succession was controlled primarily by tectonism. The Québec Reentrant successions locally record eustatic events (lowstand in yellow, highstands in blue). F: relative sea-level fall; R: relative sea-level rise.

4.4.2. The Québec Reentrant (Eastern Québec)

The inception of the foreland basin and increased tectonic subsidence in the Québec Reentrant (Figure 3) was marked by a significant change in the St. Lawrence platform (Sanford, 1993). Siliciclastic units covered the unconformity (Globensky, 1987; Desrochers, 1988; Salad Hersi and Dix, 1997), and were followed by a thick succession of ramp carbonates in a tectonically active environment (Desrochers, 1988; Sanford, 1993; Lavoie, 1994, 1995a; Sharma *et al.*, 2003; Lemieux *et al.*, 2003). The carbonate sedimentation was shut down diachronously in a westerly direction, with the sedimentation of deep-marine shales and overlying Taconian flysch and final molasse (Sanford, 1993; Lavoie, 1994; Sharma *et al.*, 2003) (Figure 12). A similar westward "younging" of flysch sedimentation is also noted for coeval successions in eastern US (Ettensohn, 2008). In the Québec Reentrant, the carbonate sedimentation lasted from Darriwilian to late Caradocian.

The passive-margin slope deposits are overlain by Darriwilian to lowermost Caradocian flyschoid sandstone with subordinate mudstone, calcarenite, conglomerate and chert (Tourelle Formation and equivalent units, Figure 12) (Clark and Globensky, 1973; Biron, 1974; Hiscott, 1978; De Broucker, 1986; Slivitzky and St-Julien, 1987; Slivitzky *et al.*, 1991; Bloechl, 1996; Prave *et al.*, 2000).

Peculiar mélanges are widely distributed and are interpreted to be roughly coeval with these Middle Ordovician units (Figure 12). The best exposed of these mélanges is the Cap Chat Mélange (Cousineau, 1998). This mélange consists of broken units of the adjacent formations, in particular, cm- to km-sized blocks of the Rivière Ouelle, Tourelle and Des Landes formations (Arenigian to Darriwilian) in a muddy to sandy matrix. In southern Québec (Figure 12), chaotic units described as polymictic conglomerate (Citadelle Formation; Osborne, 1956), olistostrome (Drummondville Olistostrome; Slivitzky and St-Julien, 1987) and tectonosome (Pointe-Aubin mélange; Comeau *et al.*, 2004) are exposed. These chaotic units in southern Québec differ from the Cap Chat Mélange; they are composed of small to large-sized blocks of the various lithologies found in the shallow- and deep-marine passive-margin and foreland-basin succession.

Syn-orogenic sedimentation lasted until end-Caradocian in the Gaspé Peninsula and is represented by Upper Ordovician coarse and fine-grained flysch (Cloridorme Formation; Enos, 1969; Prave *et al.*, 2000) (Figure 12). The Cloridorme Formation is coeval with flysch on the St. Lawrence Platform (Globensky, 1987) (Figure 12).

4.4.3. Correlation Newfoundland – Québec

The evolution of the end-rift and passive-margin episodes was primarily controlled by eustacy with tectonism locally recognized in the proximity of failed rift grabens (Ottawa – Bonnechère and Saguenay grabens). Differences are recorded at the onset of closure of the Humber Seaway (Waldron and van Staal, 2001), a sea arm of the Iapetus Ocean that separated the Dashwoods microcontinent from Laurentia. These differences are expressed in the timing of various sedimentary events (Figure 12). This diachronous evolution suggests that the overriding control on development and evolution of depositional successions was tectonic (see also Ettensohn, 2008). The Middle to Late Ordovician eustatic sea-level curve of Ross and Ross (1988) suggests three transgressive – regressive (T-R) events in that period (Darriwilian to end-Ashgillian) corresponding to Sloss's (1963) Tippecanoe I Sub-sequence (Figure 12). These T-R cycles are: 1) Darriwilian, 2) Caradocian and 3) Ashgillian (Figure 12). Glacio-eustatic processes controlled the last one of these cycles (Brenchley *et al.*, 1994; Gibbs *et al.*, 1997; Lavoie and Asselin, 1998).

The foundering of the continental margin at the St. Lawrence Promontory occurred in the middle to late Darriwilian (Stenzel *et al.*, 1990; Quinn, 1995) at a time of eustatic sea-level fall during the first T-R cycle (Figure 12); this suggests an overriding tectonic control on facies architecture and evolution. The coeval record in the Québec Reentrant suggests the presence of an overall transgressive-regressive cycle, which starts at the Sauk-Tippecanoe unconformity and ends in an unconformity that separates the Chazy and Black River groups (Salad Hersi and Lavoie, 2001b; Dix, 2003) (Figure 12). This suggests that the Darriwilian succession in the Québec-Ontario shallow-foreland recorded a eustatic signal. The Caradocian and Ashgillian T-R eustatic cycles are imperfectly recorded; the transition from carbonate ramp (Trenton Group) to deep-marine sediments (Utica) and flysch (Sainte-Rosalie) records tectonically driven deeper marine conditions (Lavoie, 1994; Lavoie and Asselin, 1998) (Figure 12).

Detailed sedimentologic analyses are unavailable for the deeper marine successions preserved in the Taconian allochthons. The lateral variation in time and nature of Middle-Upper Ordovician Mélanges in the Québec Reentrant and St. Lawrence Promontory reflects foreland-propagating compression and local exhumation and erosion of different segments of the foreland and older passive-margin facies. The propagation of compressive deformation and stacking can form depositional basins fed by the exposed succession at the top of the structural stack (Stockmal *et al.*, 2003). The mid-Darriwilian Cape Cormorant in western Newfoundland represents one of these proximal tectonic basins (Stenzel *et al.*, 1990; Waldron *et al.*, 1993). In the Quebec Reentrant, the Darriwilian Cap Chat Mélange formed far away from the shelf break as it only consists of cannibalized coeval to slightly older deep-marine units. The Darriwilian chaotic units in southern Québec formed closer to the shelf break as suggested by the nature of the fragments (Comeau *et al.*, 2004). These basins reached the shelf in Caradocian resulting in the Lacolle Breccia, for which event and facies correlations with the Darriwilian Cape Cormorant Conglomerate has been proposed (Lavoie, 1994).

5. THE POST-TACONIAN TO ACADIAN BASINS

In eastern North America, the timing and physical expression of the Taconian Orogeny varies significantly (Lavoie, 2008; Ettensohn, 2008). Along strike in the Appalachians, significant stratigraphic differences are known in the Upper Ordovician to Middle Devonian successions, which led previous workers to propose distinct sedimentary basins. These basins may overlie more than one of the previous Taconian zones and they are spatially distinguished and defined on lithologic, paleontological and structural elements.

These basins overlie Taconian zones either unconformably or paraconformably. The most pronounced unconformities occur where the middle Paleozoic successions overlie the Humber Zone. In most cases, where middle Paleozoic strata overlie the Dunnage Zone, the contact is a paraconformity with a more or less important time hiatus.

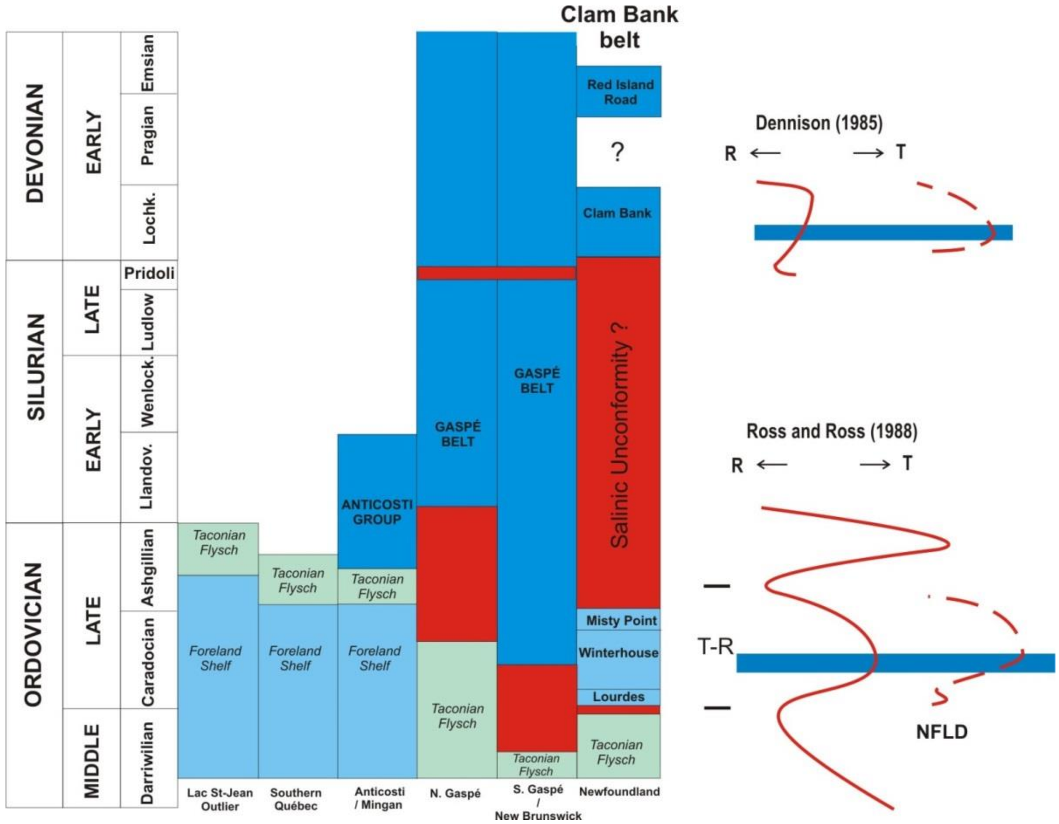


Figure 13. Stratigraphic relationships between the Taconian foreland-shelf and flysch and the overlying post-Taconian basins. Note that the time hiatus (red-coloured intervals) increases from Newfoundland to northern Gaspé. The post-Taconian flysch succession of the Clam Bank Belt in western Newfoundland is detailed. The base of the Long Point Group (Lourdes, Winterhouse and Misty Point formations) is older than the end of Taconian foreland-shelf and flysch in the Québec Reentrant. The Ross and Ross (1988) sea-level curve for the Late Ordovician indicates a Caradocian T-R cycle correlative with the one recorded by the Long Point Group. The Lower Devonian Clam Bank Formation unconformably overlies the Long Point Group with no preserved record Silurian strata. The Dennison (1985) eustatic sea-level curve for the Early Devonian suggests initial transgressive conditions followed by relative sea-level fall; the Clam Bank Formation records this eustatic signal.

The inception of post-Taconian successions follows the westward diachronous sedimentation of flysch. The oldest post-flysch strata (end-Darriwilian to Caradocian) are found at the St. Lawrence Promontory or close to it (in southern Gaspé and Témiscouata) (Figure 13). In the most inner segments of the Québec Reentrant (Connecticut Valley – Gaspé synclinorium), the successor basin formed in Early Silurian (Llandoverian) or Late Silurian (Pridolian) in northern Gaspé Peninsula and southern Québec, respectively.

The post-Taconian basins are limited by two major orogenic events, the Middle-Late Ordovician Taconian and the Middle Devonian Acadian (Figure 3). A significant Silurian deformation event is recognized along segments of the Appalachians and has been called the Salinian or Salinic Orogeny. However, Boucot (1962) introduced the term “Salinic” to designate a Late Silurian unconformity in northeastern USA. Over the years, confusion has arisen about the meaning of Salinic. The Salinian or Salinic Orogeny (Dunning *et al.*, 1990; Cawood *et al.*, 1994; van Staal and de Roo, 1995; Waldron *et al.*, 1998; Tremblay and Castonguay, 2002; van Staal, 2005; Lavoie, 2008; Ettensohn, 2008) is a Silurian event that resulted from the accretion of Ganderia along the outboard segment of the composite Laurentia margin (van Staal, 2005). In the distal part of the Quebec reentrant, its expression is locally subtle (Malo, 2001; Castonguay and Tremblay, 2003; Lavoie and Asselin, 2004; Tremblay and Pinet, 2005).

5.1. Newfoundland

The post-Middle Ordovician successions in western Newfoundland form various depositional belts (Williams, 1995). The focus will be on the Clam Bank belt, because it is one of the few well-dated middle Paleozoic successions of western Newfoundland, and its evolution can be tied into that of the adjacent Gaspé Belt (Figure 1).

5.1.1. The Clam Bank Belt

This post-Middle Ordovician succession occurs in the Port au Port Peninsula and consists of limestone and siliciclastic of Late Ordovician (latest Darriwilian-Caradocian) to end Early Devonian (Emsian) age. Three distinct rock units are preserved: the Upper Ordovician Long Point Group, the Lower Devonian Clam Bank Formation and the upper Lower Devonian Red Island Road Formation (Figure 13).

The Long Point Group (Riley, 1962; Bergström *et al.*, 1974) represents the youngest Ordovician deposits in western Newfoundland. Until recently, the basal contact of the Long Point Group was not exposed in field section and the Long Point was traditionally interpreted to unconformably overlie the Humber Arm Allochthon (Rodgers and Neale, 1963; Stevens, 1970; James and Cuffey, 1989; Stait and Barnes, 1991). Stockmal and Waldron (1990) and Waldron and Stockmal (1991), however, have argued, based on seismic information, that the Long Point Group is structurally at the top of a triangle zone and was thrusted easterly (Tea Cove Thrust) over its actual position (Waldron *et al.*, 1993; Stockmal *et al.*, 1995, 1998) (Figure 5). Recently, the contact between the two units was excavated and documented to be an erosional unconformity, later modified by folding (Batten and Dix, 2004). Waldron *et al.* (1998) interpreted the Long Point Group as belonging to a Late Taconian foreland basin on the basis of ongoing significant subsidence that followed the Middle Ordovician flysch sedimentation.

The Long Point Group consists of three formations, the Lourdes, Winterhouse and Misty Point (Bergström *et al.*, 1974; Quinn *et al.*, 1999; Batten and Dix, 2004) (Figure 13). The upper Darriwilian-Caradocian Lourdes Formation consists of a lower thin assemblage of peritidal sandstone and limestone; the bulk of the unit however, is predominantly an open marine, nodular limestone with shale, thick calcarenite and calcirudite and small coral boundstones (James and Cuffey, 1989). The Caradocian Winterhouse Formation consists of limy sandstone, limestone conglomerate, siltstone and shale. Sedimentary facies and ichnofacies indicate a storm-dominated shelf (Quinn *et al.*, 1999). The Caradocian Misty Point Formation (Quinn *et al.*, 1999) consists of marginal-marine to terrestrial cross-bedded sandstones.

Ross and Ross (1988) recognized a global eustatic sea-level lowstand at the Darriwilian-Caradocian boundary; this was followed by a complete eustatic T-R cycle in Caradocian time (see earlier section and Figure 13). The outer shelf Caradocian Winterhouse Formation overlies the peritidal to shallow subtidal upper Darriwilian Lourdes Formation. The Long Point Group ends in the Caradocian Misty Point Formation which is dominated by marginal-marine to sub-aerial deposits, thus defining a complete T-R cycle (Figure 13). Even if the Upper Ordovician Long Point Group is a late Taconian foreland-basin fill (Stockmal *et al.*, 1995; Waldron *et al.*, 1998; Quinn *et al.*, 1999), sedimentation was likely primarily controlled by eustatic sea-level fluctuations.

The Clam Bank Formation (Rodgers, 1965; Bergström *et al.*, 1974) unconformably overlies the Long Point Group (Quinn *et al.*, 1999) (Figure 13). The lowermost Devonian Clam Bank Formation consists of cross-bedded red sandstone and siltstone, with variegated shale and minor fossiliferous limy siltstone. The stratigraphic succession of the Clam Bank Formation indicates marginal-marine flooding over the unconformity followed by rapid shallowing upward to terrestrial sedimentation (Morin, 1986; Burden *et al.*, 2002). This T-R cycle matches that of the Lochkovian eustatic record of Dennison (1985) (Figure 13).

The Red Island Road Formation was introduced by Williams *et al.* (1996) and elevated to formal status by Quinn *et al.* (2004). It consists of volcanic-rich (rhyolite) coarse conglomerate and sandstone for which an Emsian (late Early Devonian) age is proposed (Williams *et al.*, 1996; Stockmal *et al.*, 1998; Quinn *et al.*, 2004) (Figure 13). The Emsian Red Island Road Formation is structurally deformed. It represents the last known sedimentary unit deposited in the Anticosti foreland basin.

5.1.2. The Salinic Unconformity and Orogeny in western Newfoundland

A major unconformity is present between the Long Point Group and the Clam Bank Formation (Waldron *et al.*, 1998) (Figure 13) with all Silurian strata missing. The unconformity is documented in offshore seismic imaging and the Clam Bank Formation unconformably overlies the Llandoverian succession of the Anticosti Group (Sanford and Grant, 1990). The strata missing render it difficult to unequivocally correlate the unconformity with either the Late Silurian Salinic unconformity (Boucot, 1962), which resulted from a global sea-level lowstand in Ludlovian-earliest Pridolian (Ross and Ross, 1996) or with the Silurian tectonic accretion of Ganderia (Salinic Orogeny, van Staal, 2005). The onset of sedimentation in earliest Devonian time (Clam Bank Formation) correlates with the post-unconformity eustatic-tectonic transgressive event recognized in the nearby Gaspé Peninsula (T2 event of Bourque *et al.*, 1995, 2000, 2001; see further).

Tectonic model in western Newfoundland suggests that Late Ordovician to earliest Silurian subsidence, deformation, burial and metamorphism followed early Taconian thrusting (Dunning *et al.*, 1990; Cawood, 1993; Cawood *et al.*, 1994, 1995; Waldron *et al.*, 1998; Stockmal *et al.*, 1998; van Staal *et al.*, 1998, van Staal, 2005). Tectonic subsidence was halted at the end of the Early Silurian followed by thermal and/or tectonic uplift, erosion and starved sedimentation (Waldron *et al.*, 1998).

5.2. Continental eastern Canada

The end of Taconian flysch sedimentation and/or emplacement of Ordovician oceanic units over continental slope allochthons in eastern North America mainland occurred diachronically from Middle Ordovician at or near promontories (St. Lawrence and New York) to Late Ordovician for the inner segment of the Québec Reentrant (Figure 3). The onset of sedimentation for various successor basins is also diachronous in a northwesterly trend. However, a significant stratigraphic gap is reported along strike in the orogen and the sedimentary record in south-western Québec is less complete compared to other post-Taconian basins.

The post-Taconian successions for the continental segment of the Appalachian Orogen are collectively known as the Gaspé Belt (Bourque *et al.*, 1995, 2000). The middle Paleozoic (Late Ordovician to early Middle Devonian) Gaspé Belt is preserved in a number of tectonostratigraphic elements, including from north to south: the Connecticut Valley-Gaspé synclinorium, the Aroostook-Percé anticlinorium and the Chaleurs Bay synclinorium. The Gaspé Belt was folded and faulted with transpressive, dextral, strike-slip faults as the final event (Malo and Béland, 1989; Malo and Bourque, 1993; Kirkwood and Malo, 1993; Malo *et al.*, 1995; Malo, 2001). Palinspastic reconstruction of the belt in eastern Québec has allowed reconstructing the regional paleogeography based on the restored geometry of the basin (Kirkwood, 1999; Bourque *et al.*, 1995, 2000). From these reconstructions, the segment of the Gaspé Belt that forms southern Gaspé Peninsula was located above the current position of Cape Breton Island, therefore adjacent to the St. Lawrence Promontory (Figure 14). The summary of Bourque *et al.* (1995, 2000, 2001) presents paleogeographic and paleotectonic reconstructions of the Gaspé Belt and is still the reference work for correlation with adjacent middle Paleozoic basins.

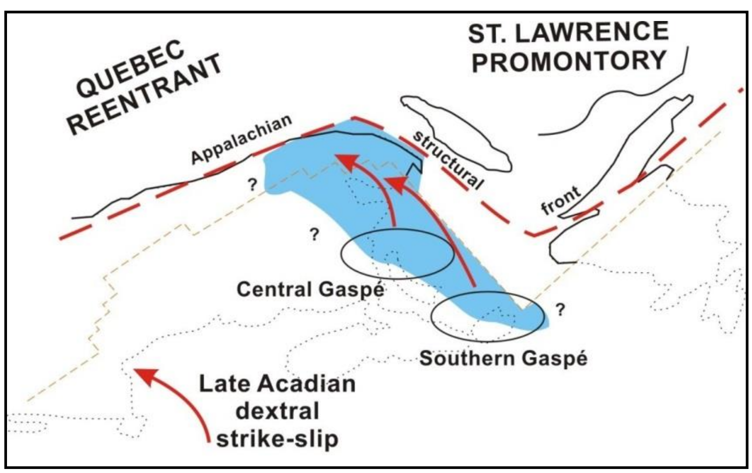


Figure 14. Palinspastic restoration of the Gaspé depositional basin (blue-coloured area) in eastern Québec based on the work of Bourque *et al.* (1995, 2000, 2001) and Kirkwood (1999). The restoration eliminates significant dextral displacement along major Acadian transpressional faults as well as up to 50% of shortening accommodated by folds. Arrows indicate the general displacement along Acadian transpressional dextral faults.

On the northern side of the Gaspé Peninsula and in southern Québec (Figure 15 and Figure 16) the middle Paleozoic Gaspé Belt unconformably overlies Taconian Humber and Dunnage zones. In central and southern Gaspé Peninsula and in northern New Brunswick, the oldest sediments of the Gaspé Belt paraconformably overlie the Dunnage Zone rocks (Figure 15). However, locally, the Silurian section locally unconformably overlies outliers of the Humber and Dunnage zones (Maquereau and Mictaw groups in southern Gaspé and the Fournier and California Lake groups, northeastern New Brunswick). The post-Acadian Maritimes Basin (Lynch, 2001; Gibling and Culshaw, 2008) has its depocenter in the Gulf of St. Lawrence and regionally, uppermost Devonian to Carboniferous sediments unconformably overlies the Gaspé Belt (Jutras *et al.*, 1999, 2001).

Within the three major tectonostratigraphic elements, three rock packages are proposed (Malo and Bourque, 1993; Bourque *et al.*, 1995; Wilson *et al.*, 2004; Lavoie and Asselin, 2004; Malo, 2004) (Figure 17). These assemblages are the results of three distinct regressive phases (R1 to R3) separated by two transgressive events (T1 and T2) (Bourque *et al.*, 1995, 2000; Figure 17).

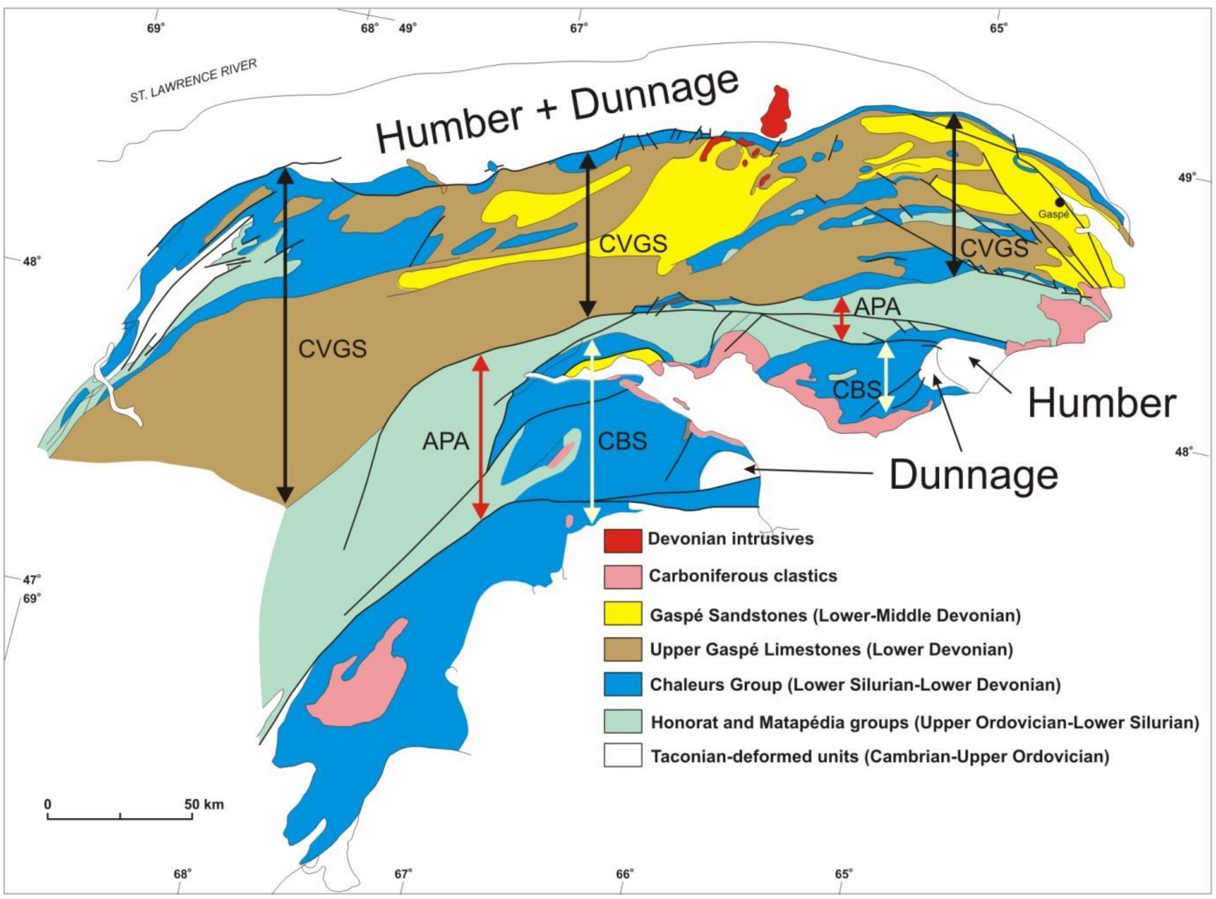


Figure 15. Simplified geological map of eastern Quebec and northern New Brunswick showing the distribution of the major group units of the Late Ordovician to Middle Devonian Gaspé Belt. The major tectonostratigraphic domains are illustrated; the Connecticut Valley-Gaspé synclinorium (CVGS), the Aroostook-Percé

anticlinorium (APA) and the Chaleurs Bay synclinorium (CBS). Map modified from Bourque *et al.* (1995).

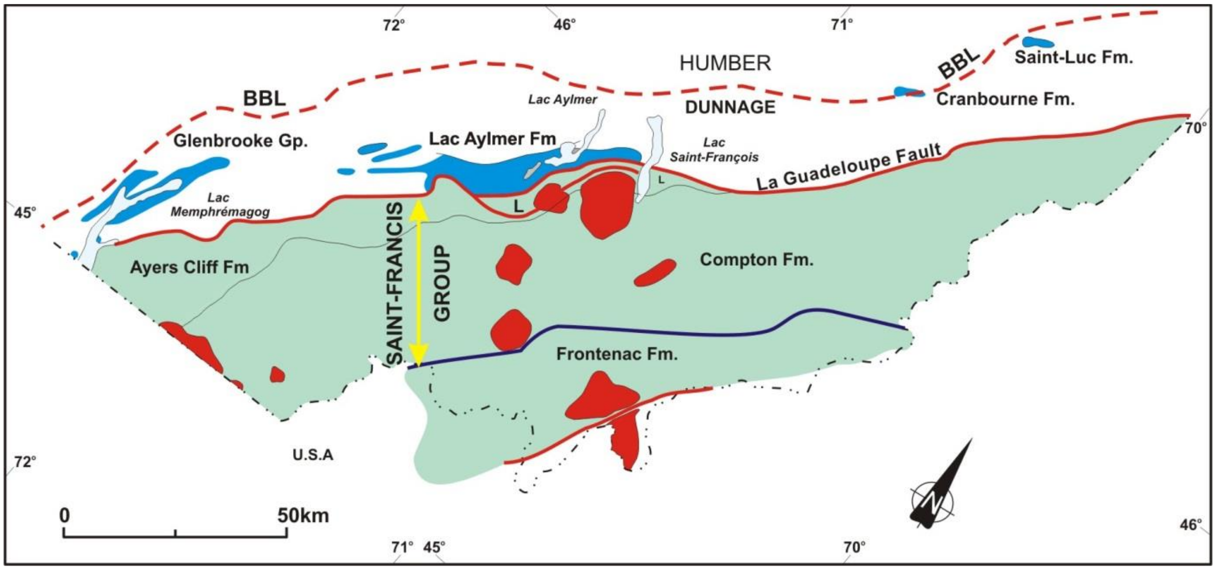


Figure 16. Simplified geological map of southern Québec with the distribution of post-Taconian units in the Connecticut Valley – Gaspé synclinorium. The units in the green-shaded area (Lac Lambton (L), Ayers Cliff and Compton formations of the Saint-Francis Group and the Frontenac Formation) were displaced northwesterly over an unknown distance, along a major Acadian reverse fault (La Guadeloupe Fault). Middle Devonian intrusives are in red. Modified from Williams (1995).

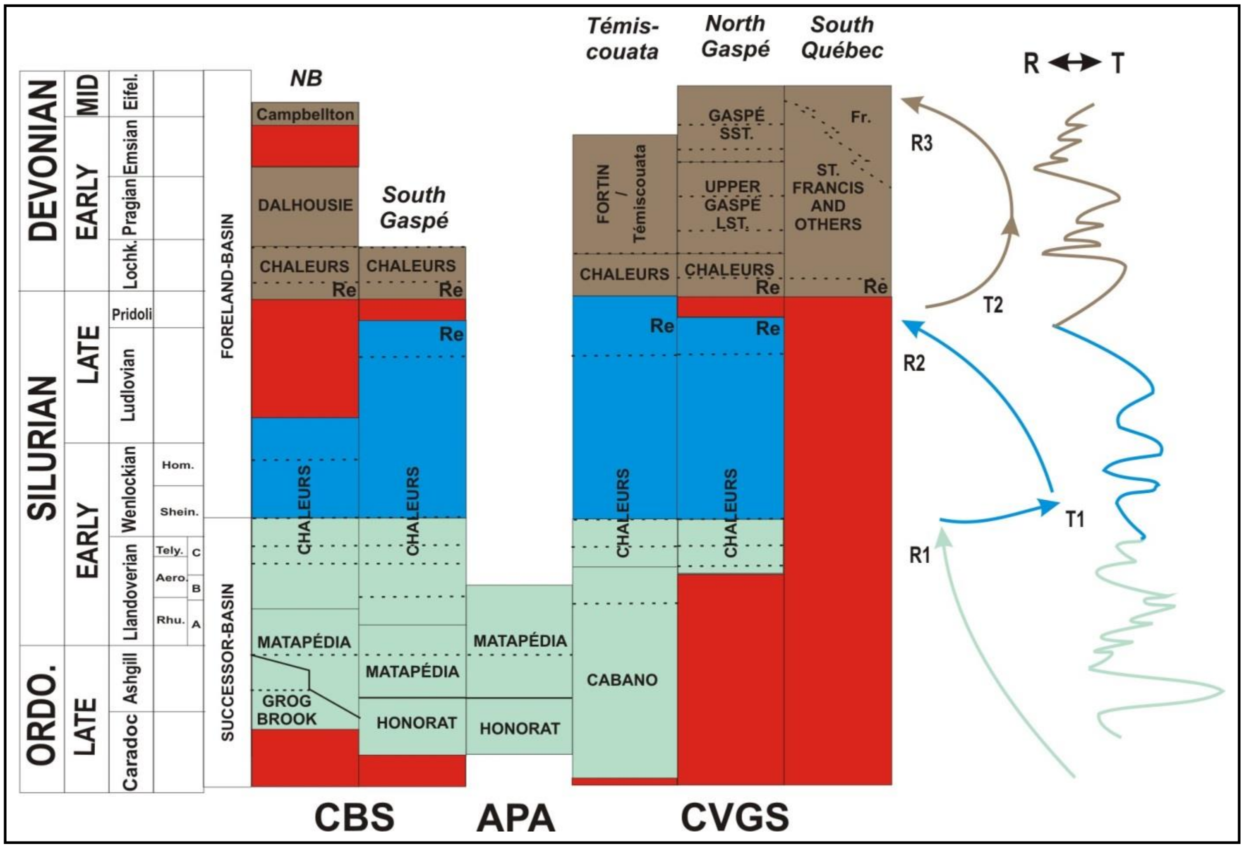


Figure 17. General stratigraphic framework (at group level) for the post-Taconian units in the Québec Reentrant. The detailed formation nomenclature (limits shown in thin dashed lines) can be found in Bourque (1975), Bourque and Lachambre (1980) and Bourque *et al.* (1993, 1995, 2000, 2001) for Gaspé and Témiscouata, in Lavoie and Bourque (1992) and Lavoie and Asselin (2004) for southern Québec and in Wilson *et al.* (2004) and Lavoie and Asselin (2004) for New Brunswick. The major T-R events discussed in the text are shown; the Late Ordovician-Early Silurian R1 event; the Early Silurian-Late Silurian T1-R2 events and the latest Silurian-Middle Devonian T2-R3 events. The Silurian (R1-T1-R2 events) sea-level curve of Ross and Ross (1988, 1996) and the Devonian (T2-R3 events) one of Dennison (1985) are shown for comparative purposes. The red-coloured areas indicate a time hiatus. Rhu.: Rhuddanian; Aero.: Aeronian; Tely.: Telychian; Shein.: Sheinwoodian; Hom.: Homerian; Lochk.: Lochkovian; CBS: Chaleurs Bay synclinorium; APA: Aroostook-Percé anticlinorium; CVGS: Connecticut Valley – Gaspé synclinorium; NB: New Brunswick; LST: Limestones; SST: Sandstones; R: reefal units discussed in text.

5.2.1. Late Ordovician – Early Silurian (the R1 event)

The Upper Ordovician (Caradocian/Ashgillian) – lower Silurian (Wenlockian) package (Figure 17) occurs in all tectonostratigraphic elements. The stratigraphic record from northern New Brunswick to northern Gaspé Peninsula documents a northerly-directed diachronous Late Ordovician to Early Silurian resumption of post-Taconian sedimentation (Malo, 2004) (Figure 13 and Figure 17). Upper Ordovician-Lower Silurian strata are unknown in southern Québec.

For all localities other than northern Gaspé Peninsula (Figure 17), deep marine clastics (Caradocian to Ashgillian Honorat Group and equivalent units) are overlain by below wave base limestones (Ashgillian to Aeronian Matapédia Group and equivalent units). The end of the first regressive event is expressed by deep- to mid-shelf to nearshore clastics (Aeronian to Telychian Chaleurs Group) and the shallowing event ended in peritidal-dominated carbonate platform (Wenlockian Chaleurs Group). Stratigraphic sections on the northern edge of the Gaspé Belt overlie the post-Taconian unconformity; marine sedimentation only resumed in mid-Llandoverian (Figure 17). In northern Gaspé Peninsula, the base of the succession consists of outer shelf clastic-limestone facies (Aeronian-Telychian Chaleurs Group) that passes upward to nearshore clastic and peritidal limestone (Telychian-Sheinwoodian Chaleurs Group).

Tectonism played a key role in controlling the sea-level evolution after the end of Taconian foreland basin sedimentation. Ross and Ross (1988, 1996) proposed an overall regression for most of Ashgillian time followed by punctuated transgressive episodes in Llandoverian to slightly regressive conditions in early Wenlockian (Sheinwoodian) (Figure 17). The curve of Johnson *et al.* (1998) generally follows the one of Ross and Ross (1996), although the Johnson *et al.* (1998) curve suggests transgressive conditions in Sheinwoodian. In Gaspé, Bourque (2001) documented overall regressive conditions (the R1 event) for the first stratigraphic package (Figure 17). The base-level rise documented by Bourque *et al.* (1995, 2000) and Bourque (2001) is coeval with the Early Silurian tectonic and/or thermal doming and uplift in western Newfoundland.

5.2.2. Early Silurian – Late Silurian (the T1 - R2 events)

The Lower (end-Wenlockian) – Upper (Pridolian) Silurian package forms part of the Chaleurs Group (Figure 17). The Salinic unconformity is present at the top of that stratigraphic interval (Bourque *et al.*, 1995, 2000; Wilson, 2000, 2001, 2003a; Wilson *et al.*, 2004; Lavoie and Asselin, 2004).

A second-order sea-level rise is recorded in the deeper marine facies that overlies the Wenlockian carbonate platform (Figure 17) and culminates in the Ludlovian deeper marine clastics on the Gaspé Peninsula (Lavoie *et al.*, 1992; Bourque, 2001). The rapid relative sea-level rise (T1 of Bourque *et al.*, 1995; Bourque, 2001) is late Wenlockian (Homerian) and is interpreted to have been partly controlled by extensional faulting (Lavoie *et al.*, 1992; Lavoie and Morin, 2004; Lavoie and Chi, 2006).

The following regressive succession is correlated with a second-order sea-level fall that started in Ludlovian and ended in a major Pridolian sea-level lowstand (R2 of Bourque *et al.*, 1995; Bourque, 2001) (Figure 17). Third-order T-R cycles are preserved in carbonate facies developed in the late stages of the second-order shallowing event (West Point Formation reefal facies, Bourque *et al.*, 2000; Bourque, 2001). The end of the regressive phase resulted in local sub-aerial exposure of the pre-Upper Silurian succession and deep erosion (Bourque *et al.*, 2000); this generated the Salinic unconformity at specific localities in the Gaspé Peninsula (Lachambre, 1987; Lavoie *et al.*, 1992; Bourque *et al.*, 2000; Bourque, 2001; Malo, 2001; Lavoie and Morin, 2004).

As a whole, the T1-R2 succession matches relatively well the published second-order, eustatic, sea-level curves (Ross and Ross, 1996; Johnson *et al.*, 1998) (Figure 17). However, the

T1 event in the Gaspé Belt was amplified by active synsedimentary collapse of the depositional basin during a eustatic sea-level rise. The following R2 event was significantly controlled by a major eustatic sea-level fall, the magnitude of which largely exceeded the still on-going tectonic foundering of the depositional setting.

5.2.3. Latest Silurian – Middle Devonian (the T2-R3 events)

In Gaspé Peninsula and New Brunswick, the Salinic unconformity commonly marks the base of the uppermost Silurian (Pridolian) to Middle Devonian (Eifelian) stratigraphic interval (Bourque *et al.*, 1995, 2000; Wilson, 2000, 2001, 2003a; Wilson *et al.*, 2004; Lavoie and Asselin, 2004). This rock assemblage is composed of the uppermost Silurian to lowermost Devonian section of the Chaleurs Group, followed by the Lower Devonian Upper Gaspé Limestones / Fortin / Dalhousie groups, and capped by the Lower Devonian to lowermost Middle Devonian Gaspé Sandstones Group (Figure 17). The preserved sedimentary record in the Gaspé Belt of southern Québec is no older than Late Silurian (Figure 17). A Late Silurian (Saint-Francis and correlative units; Figure 17) to Middle Devonian (Frontenac Formation; Figure 17) T-R assemblage is also recognized.

The T2 event started in latest Silurian, with the development of major reef platforms above the Salinic unconformity (West Point, Laplante, Lac Aylmer, Sargent Bay formations; Lavoie, 1985; Bourque *et al.*, 1986; Hughson and Stearn, 1989; Lavoie and Bourque, 1992; Bourque, 2001; Wilson *et al.*, 2004; Figure 17). Locally, in southern Québec, a thick braided fluvial conglomeratic succession overlies the basal unconformity (Lavoie, 1985; Lavoie and Bourque, 1992; Lavoie and Asselin, 2004). The West Point Formation in southern Gaspé built a thick (up to 600 meters) reef margin in a short period of time (Pridolian) indicating combined significant tectonic subsidence and eustatic sea level rise (Bourque, 2001). In northern Gaspé, the rapid sea-level rise resulted in the development of earliest Devonian isolated pinnacle reefs over the rapidly collapsing bioconstructed platform margin (Bourque, 2001). The platforms are overlain by earliest Devonian pro-deltaic to outer shelf facies (uppermost Chaleurs and lower St. Francis Group; Bourque *et al.*, 2000, 2001; Wilson, 2003b; Wilson *et al.*, 2004; Lavoie and Asselin, 2004). These units record the increase in sea-level rise in the basin, which started in latest Pridolian (southern Gaspé-northeastern New Brunswick) to earliest Lochkovian (northern Gaspé) (T2 of Bourque *et al.*, 1995) (Figure 17). The deepest marine conditions in the T2 event are recorded in the Lower Devonian (upper Lochkovian-Emsian) package consists of the mixed deep marine limestone, clastic and volcanic facies (Upper Gaspé Limestones and equivalent units; Figure 17). The geographic distribution of these units indicates that a deep (below wave base) marine carbonate ramp (Upper Gaspé Limestones) developed at the northeastern end of the Gaspé belt (Lavoie, 1992a, 1992b). This carbonate ramp passes basinward (towards the south – southwest) into a deep, siliciclastic, marine environment with significant intra-plate volcanic flows and volcaniclastics (Fortin, Dalhousie and Saint-Francis groups) (Lavoie *et al.*, 1991; Lavoie, 1992a, 1992b, 1995b; Bourque *et al.*, 2000; Wilson, 2003b; Lavoie and Asselin, 2004).

The overlying Lower (Emsian) to lower Middle (Eifelian) Devonian succession records a rapid tectonically-controlled shoaling event. The Gaspé Sandstones Group (and equivalent units in northern New Brunswick; Cant and Walker, 1976; Rust, 1981; Desbiens, 1992; Bourque *et al.*, 2000; Wilson *et al.*, 2004; Figure 17) and the Frontenac Formation in southern Québec (Lavoie, 2004; Lavoie and Asselin, 2004) offer facies indicative of initial marginal-marine to ultimately delta plain and proximal braided-plain deposits. However, a wide area between Gaspé Peninsula and southern Quebec remained under deep marine conditions.

The T2-R3 events poorly match the eustatic curve, this indicate an overriding tectonic control on relative sea-level evolution. Dennison (1985) curve suggests relative third-order sea-level standstill to slightly regressive conditions at a time of the T2 event (Figure 17). Extensional tectonism occurred in Early Devonian time in eastern Gaspé (Lavoie, 1992a; Malo, 2001) and the rapid sea-level rise recorded at the base of the sequences could reflect such collapse. The sea-level rise was abruptly stopped in late Early Devonian; a rapid shoaling of facies is observed and resulted in the R3 event in the basin. This abrupt shallowing succession was deposited at a time of eustatic sea level rise (Johnson *et al.*, 1985; Dennison, 1985) (Figure 17); therefore, the observed regressive succession resulted from the building of the Acadian orogenic wedge (Malo, 2001).

5.2.4. The Salinic Unconformity and Disturbance in the Gaspé Belt

In the Gaspé Belt, the presence of a Late Silurian erosional event has long been known in northern and southern Gaspé (Bourque *et al.*, 1986; Lachambre 1987; Lavoie, 1988; Bourque, 1990; Lavoie and Morin, 2004) and more recently in Northern New Brunswick (Wilson, 2001, 2002, 2003a; Wilson *et al.*, 2004). The tectonostratigraphic work of Bourque *et al.* (1995, 2000, 2001) documented that this erosion resulted from sea-level lowstand (Figure 18).

The oldest evidence of extensional collapse in the post-Taconian basin is found in the upper Llandoverian facies, which marks the inception of the Acadian foreland basin (Kirkwood *et al.*, 2002, 2005). From late Early Silurian to Early Devonian, transtensive fault movements and early NW-folding occurred in the northern segment of the Gaspé Belt (Malo, 2001) and in northwestern New Brunswick (Carroll, 2003). These tectonic events were used to define the Salinic Disturbance (Bourque, 1990; Bourque *et al.*, 2000, 2001; Malo, 2001). Evidence from western Newfoundland (Waldron *et al.*, 1998), central New Brunswick (van Staal and de Roo, 1995) and southern Gaspé (Kirkwood *et al.*, 2002, 2004) indicate building of a tectonic wedge at or near the St. Lawrence Promontory in Early Silurian and the accretion of Ganderia on the Laurentia margin (van Staal, 2005). This event created a major Silurian foreland-basin in the inner segment of the Québec Reentrant (Kirkwood *et al.*, 2002, 2004). The tectono-sedimentary model is similar to what has been proposed by Bradley *et al.* (1998) for the adjacent and coeval Maine Appalachians. On Gaspé Peninsula, the extensional features ascribed to the Salinic Disturbance are interpreted as the northern distal foreland of the tectonic wedge to the south (Figure 18).

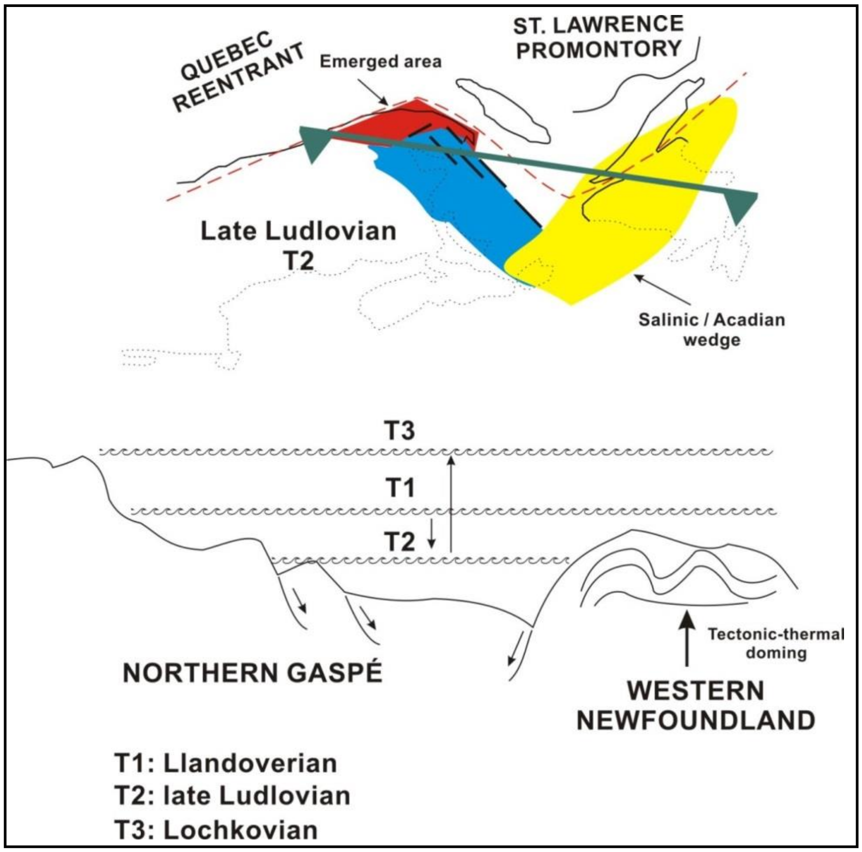
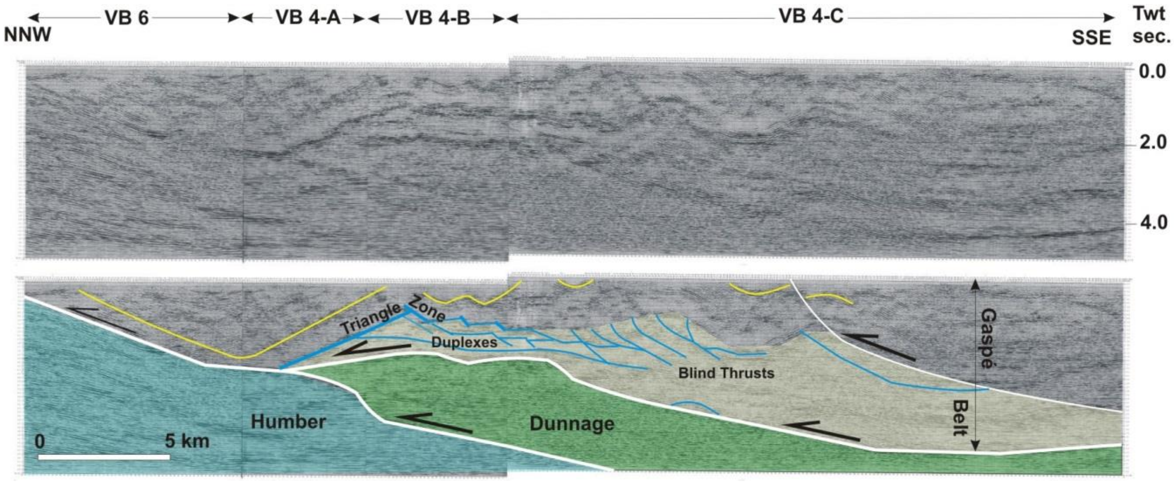


Figure 18. Paleogeographic scenario in late Ludlovian time in eastern Canada. Emerged areas and erosion of pre-Late Silurian units are recorded for western Newfoundland, for the palinspastically restored southern Gaspé (and northern New Brunswick) Belt, and at the northern edge of the Gaspé Belt. The cross-section (located on the paleogeographic map) shows that the Early Silurian (T1: Llandoverian) tectonic exhumation (through tectonic-thermal doming) in western Newfoundland resulted in a significant base-level rise in the southern Gaspé belt. The development of the tectonic wedge in Early Silurian resulted in the formation of a foreland-basin within the Québec Reentrant. In late Ludlovian – Pridolian time (T2), the global eustatic sea level lowstand resulted in erosion (hatched areas) of topographic highs and generated the Salinic unconformity. The following Early Devonian eustatic rise (T3) was enhanced by the continuation of extensional faulting.

From recent seismic lines in the Gaspé Belt of eastern Quebec, the subsurface geometry was previously interpreted to differ significantly from the surface geology of large synclines and tight anticlines. A complex compressive structural style of reverse faults, blind thrusts, duplexes and triangle zone was proposed to affect pre-Upper Silurian units (Morin and Laliberté, 2002a, 2002b; Kirkwood *et al.*, 2002, 2004;



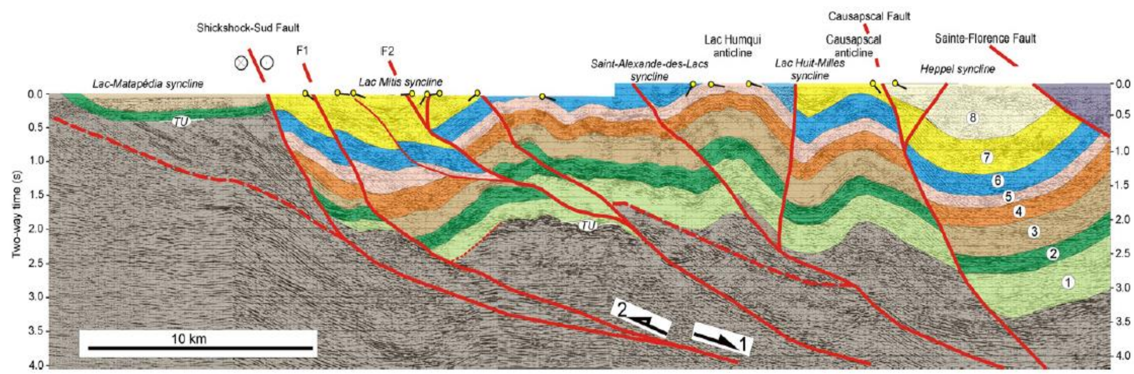


Figure 19). The geometry suggests a compression-formed foreland-propagating basin (Stockmal *et al.*, 2003). A reevaluation of the seismic data coupled with potential field data led to a new, less complex interpretation of the subsurface (Pinet, 2013)

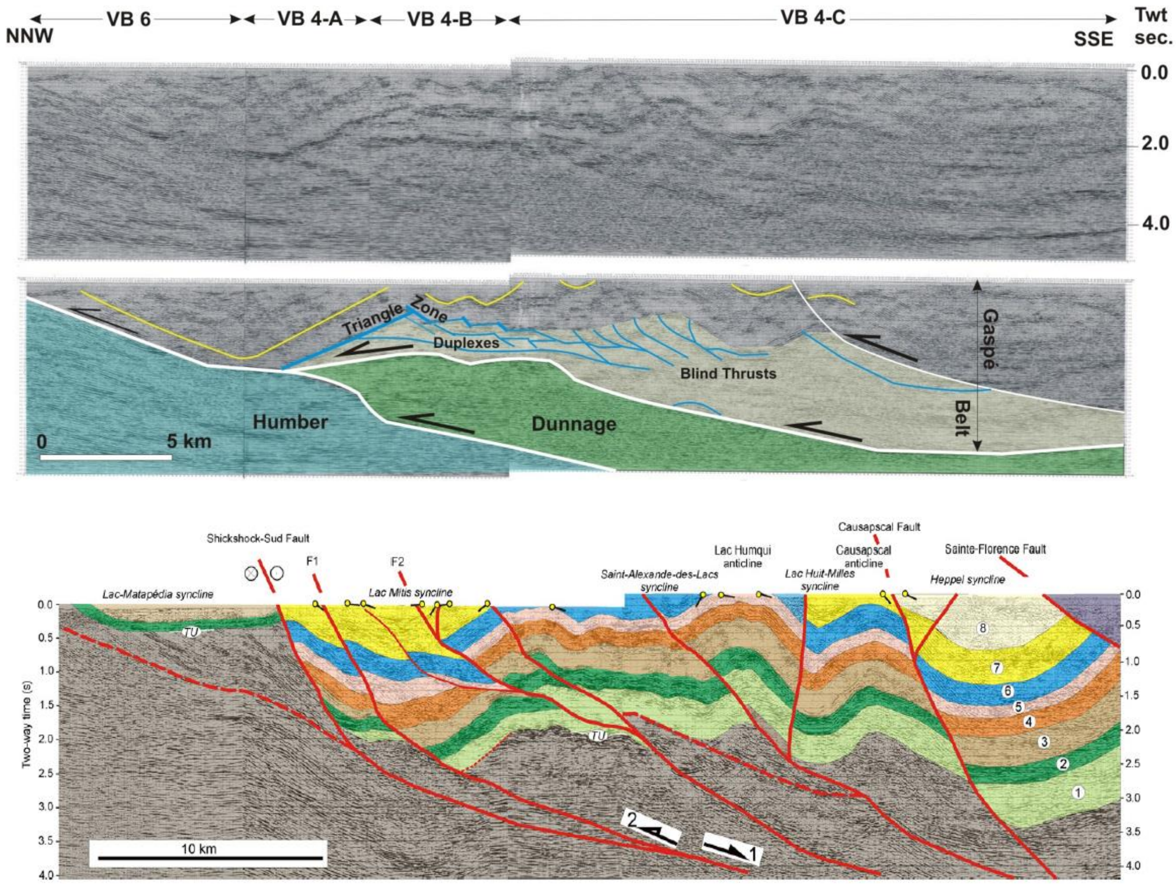


Figure 19. Top: Seismic section based on composite seismic lines VB-4 (a, b and c) and 6 in western Gaspé Peninsula. The location of the seismic lines is shown by the green line on Figure 1. Middle: The Gaspé Belt succession can be seismically divided into two major structural packages, a lower one that comprises Upper Ordovician to Upper Silurian units that is characterized by major compressive structures (blind faults, reverse thrust and triangle zone) and an upper one that comprises Devonian units that are characterized by fault-bounded tight anticlines and open synclines. Modified from Morin and Laliberté (2002a, 2002b) and Kirkwood *et al.* (2004). Bottom: Alternative interpretation of Pinet (2013) where the triangle zone and duplexes are rather interpretated as the geometric results of multiphase movements (extension followed by inversion).

In southern Québec, Castonguay *et al.* (1997, 2001), Tremblay and Castonguay (2002) and Tremblay and Pinet (2005) proposed based on metamorphic, geochronology, seismic and structural evidence, that some faults within and east of the Humber Zone recorded Late Silurian – Early Devonian extension prior to the compressive Middle Devonian event (Acadian Orogeny). This Late Silurian extensional event is ascribed to the Salinian Orogeny (Tremblay and Castonguay, 2002; Tremblay and Pinet, 2005). The following rapid marine inundation was accelerated by the overall transgressive event recorded along Laurentia at that time (T2 event). However, the exact age of inception for the post-Taconian basin in southern Québec is unknown. The youngest Taconian unit is the Caradocian Saint-Victor Formation (Magog Group, Dunnage Zone) (Cousineau, 1990; Tremblay *et al.*, 1995). However, a late Silurian (Pridolian) age is documented for carbonates locally a few meters above the lower unconformable contact (Figure 17).

5.3. Paleogeographic reconstruction of the post-Taconian basins

The paleogeographic and paleotectonic reconstruction of the post-Taconian Gaspé Belt has been the subject of comprehensive synthesis by Bourque *et al.* (1995, 2000, 2001a), Malo (2001, 2004) and Kirkwood *et al.* (2002, 2004). These palinspastic reconstructions (Kirkwood, 1999) were mostly concerned with the eastern Québec regions. The major conclusion of this restoration is that the post-Taconian Gaspé Belt in eastern Québec and northern New Brunswick matched the shape of the Québec Reentrant and the St. Lawrence Promontory (Figure 14). Such palinspastic restoration of the Gaspé Belt in northern New Brunswick and southern Québec is not available; therefore, reconstructions have to be taken with that limitation. The recent studies of the Silurian-Devonian units in southern Québec (Lavoie, 2004; Lavoie and Asselin, 2004) and northern New Brunswick (Wilson *et al.*, 2004) allow the development of new preliminary regional paleogeographic maps for the Late Silurian (Pridolian) to Early Devonian (Emsian) interval in eastern Canada.

5.3.1. Latest Pridolian / Earliest Lochkovian (Figure 20)

Silurian tectonism significantly controlled sedimentation patterns for the Gaspé Belt in Gaspé Peninsula (Bourque *et al.*, 2001a; Malo, 2001). However, the development of the Salinic unconformity occurred because of the significant magnitude of the sea-level fall recorded in Ludlovian – earliest Pridolian time. The following sea-level rise (T2 of Bourque *et al.*, 2001a) was possibly amplified by the on-going Acadian foreland-basin extensional collapse. Figure 20 is built on the late Pridolian paleogeographic maps of Bourque *et al.* (1995, 2000, 2001). It is shown that a latest Silurian – earliest Devonian red-bed coastal plain stretched from Gaspé Peninsula (Plage Woodmans Member of the West Point Formation; Bourque, 2001) to western Newfoundland (Lower Devonian Clam Bank Formation; Burden *et al.*, 2002). The Pridolian reef tract (upper reef complex of the West Point Formation; Bourque *et al.*, 1995) extended from Gaspé Peninsula to northeastern New Brunswick (Wilson, 2003b; Wilson *et al.*, 2004) to the Témiscouata region (Lajoie *et al.*, 1968; Dansereau and Bourque, 2001), and finally, to southern Québec (Hughson and Stearn, 1989; Lavoie and Bourque, 1992; Lavoie and Asselin, 2004) (Figure 20). Late Silurian reefal facies are recognized as south as northern New York (Ettensohn, 2008). In southern Québec, mid- to outer-platform carbonates and siliciclastics surrounded the reefal units along the northwestern edge of the preserved depositional basin (Lavoie and Asselin, 2004). Southeasterly, it is interpreted that the mid to outer shelf carbonate-siliciclastic regime passed to deep outer shelf / slope sedimentation in earliest Devonian time (Lavoie and Asselin, 2004).

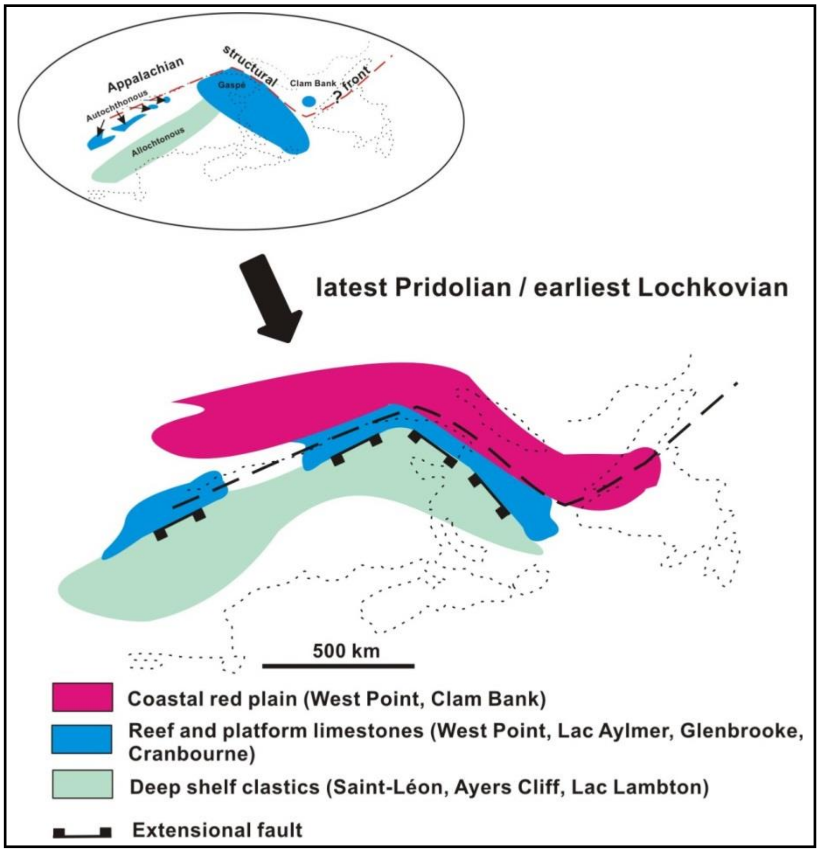


Figure 20. Paleogeographic map for the latest Pridolian-earliest Lochkovian in eastern Canada. An Upper Silurian reef tract (Bourque *et al.*, 1986, 1995, 2000; Hughson and Stearn, 1989; Lavoie and Bourque, 1992) is recognized from southern Gaspé to southern Québec. The inset illustrates the palinspastically restored geometry of the basin upon which the paleogeographic map is based. The exact position of the Acadian-transported units in southern Québec is largely speculative.

5.3.2. Middle Lochkovian (Figure 21)

The northern segment of the Gaspé Belt in Gaspé Peninsula continued to collapse in the Early Devonian, resulting in the establishment of the pinnacle reefs of the West Point in northern Gaspé (Bourque, 2001). In middle Lochkovian, the carbonate regime changed to a deep shelf siliciclastic environment with prograding (basinward) fine- to coarse-grained pro-delta to delta front facies (Bourque *et al.*, 1995, 2001) (Figure 21).

In southern Québec, the latest Silurian reefs and carbonate platform were overlain by pro-deltaic to outer shelf units of the Compton Formation (Figure 21). The lateral facies variation indicates that a south-easterly progradation of a proximal siliciclastic wedge occurred in the early stage of the Early Lochkovian T2 event. Ultimately, with the transgression, a deeper outer shelf regime was established over the entire area (Figure 21).

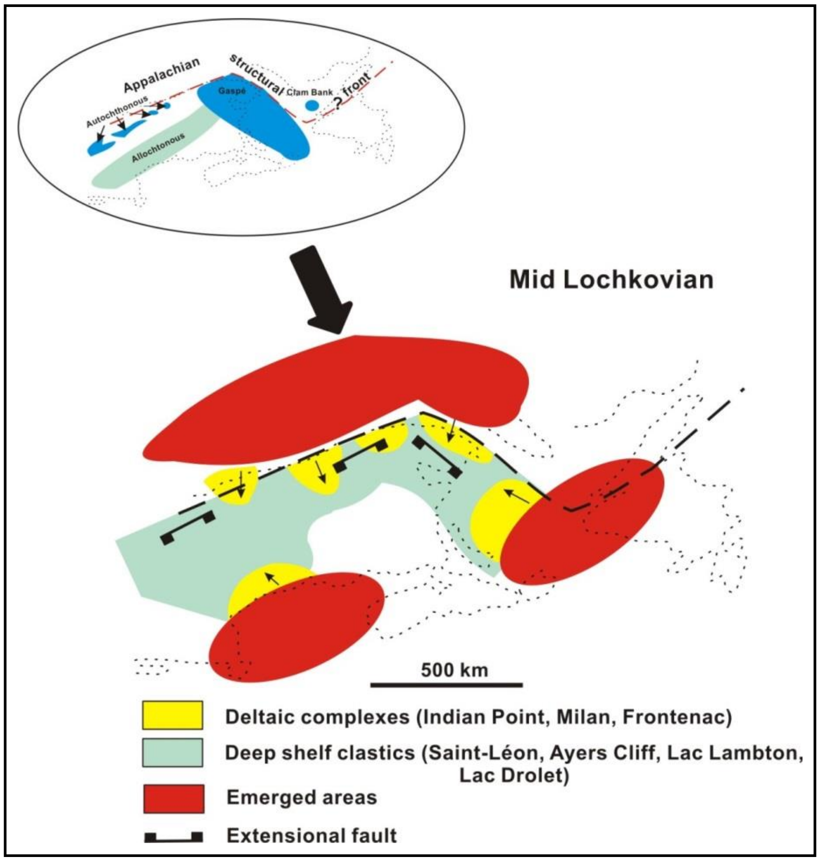


Figure 21. Paleogeographic map for the mid-Lochkovian in eastern Canada. The Gaspé Belt was surrounded by emerged areas feeding prograding (arrows) deltaic units (Bourque *et al.*, 1995, 2000; Lavoie and Asselin, 2004; Lavoie, 2004). The inset illustrates the palinspastically restored geometry of the basin upon which the paleogeographic map is based. The exact position of the allochthonous units in southern Québec is largely speculative.

5.3.3. Pragian – Early Emsian (Figure 22)

On the northeastern Gaspé Peninsula, Silurian-Early Devonian extension reversed into a compressive regime near the end of Upper Gaspé Limestones deposition (Pragian - early Emsian) (Malo, 2001). Significant shortening of the Gaspé Belt in the Gaspé Peninsula was accommodated through folding and transpressive faulting (Malo, 2001) (Figure 22). The sedimentary evolution of the basin was regressive. In response to ongoing Acadian orogenesis, marginal marine to fluvial sediments (Gaspé Sandstones) were deposited along the northeastern margin of the Gaspé Belt in Gaspé Peninsula and in northern New Brunswick (Figure 22). In the south-western portion of this basin, deeper marine sedimentation (Fortin Group) prevailed (Figure 22).

In southern Québec, Pragian-aged sediments occur in carbonate-clastic deep shelf facies in the north (Ayers Cliff Formation; Figure 22) and in north-westerly prograding proximal deltaic facies (Frontenac Formation; Figure 22). The progradation of the deltaic facies has been ascribed to the building of the Acadian wedge to the south (Figure 22).

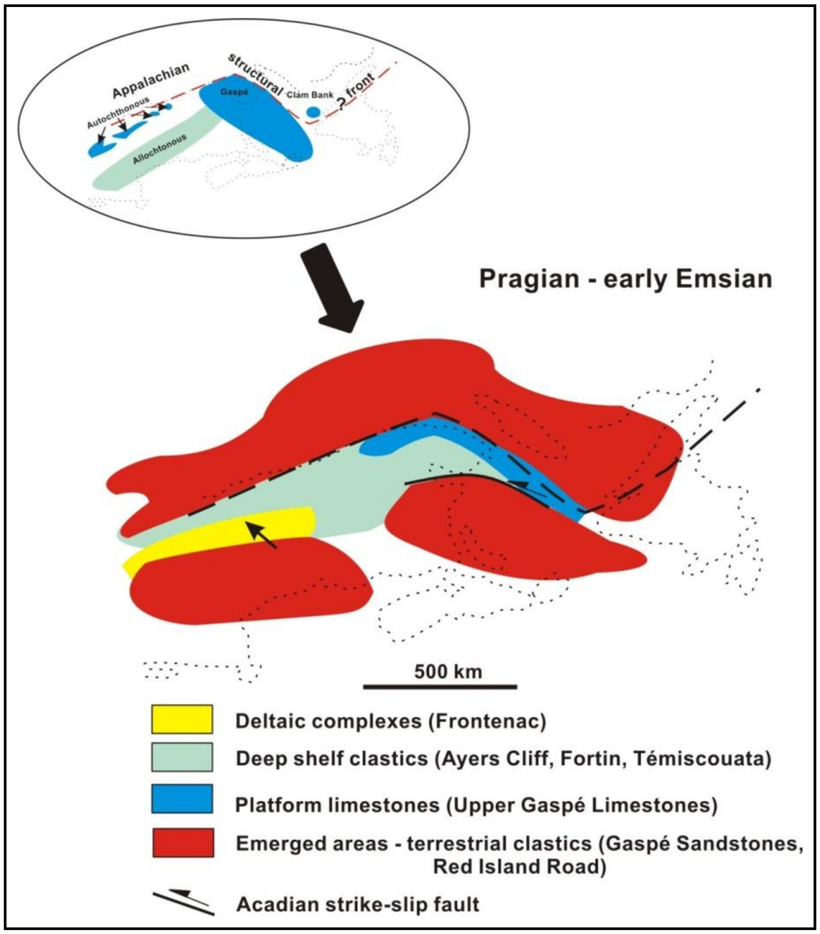


Figure 22. Paleogeographic map for the Pragian-early Emsian in eastern Canada. The Gaspé belt in southern Québec was the site of extensive shallow-marine to marginal-marine deltaic sedimentation (Lavoie, 2004; Lavoie and Asselin, 2004) prograding over outer shelf facies to the north. The northeastern extension in Gaspé Peninsula recorded the end of outer shelf carbonate sedimentation (Lavoie, 1992a, 1992b; Bourque *et al.*, 1995, 2000) with the initiation of progradation of Acadian alluvial fans (Rust, 1981). A seaway (Bourque *et al.*, 1995; 2000) was still opened. The inset illustrates the palinspastically restored geometry of the basin upon which the paleogeographic map is based. The exact position of the allochthonous units in southern Québec is largely speculative.

6. THE SEA LEVEL RECORD IN THE LOWER TO MIDDLE PALEOZOIC APPALACHIANS IN EASTERN CANADA: EUSTASY VERSUS TECTONISM

The evolution of lower to middle Paleozoic Appalachian basins in eastern Canada responded to changing relative sea level. The deep-marine successions preserved in the Cambrian-Ordovician section of the Appalachians imperfectly recorded the fine-scale sea-level fluctuations. However, the nature of the shallow-marine sediments shed into the deeper marine settings indirectly recorded this part of the continental-margin history. The synthesis of our knowledge for both the shallow- and deep-marine settings produces a comprehensive sea-level history. The post-Taconian to syn-Acadian basins preserved in the Appalachians consist of an assemblage of shallow- to deep-marine units, and the middle Paleozoic, relative, sea-level history can be more easily reconstructed. This section summarizes the evolution of the Cambrian to Devonian basins in eastern Canada, the controls on sedimentation patterns, either eustatic, tectonic or both.

6.1. Early Cambrian – Late Ordovician Humber Appalachians

The successions from western Newfoundland to southern Québec recorded the initial tectono-sedimentary events that shaped up the Appalachians (Figure 1 and Figure 3). The rift-to-passive margin development has been demonstrated to be fairly similar for both areas and primarily controlled by eustacy, but minor divergences in the evolution on that continental margin are related to local tectonic activity in the proximity of failed rifts at the Quebec Reentrant (Figure 3 and Figure 11). The preserved slope records allow recognizing major eustatic sea-level events (end Early Cambrian global lowstand, Middle to Late Cambrian Grand Cycles and the slightly diachronic Tremadocian – Arenigian / mid Arenigian lowstands) (Figure 11). These events characterize the Sauk Sequence of Sloss (1963) and are recorded in the Appalachians (see also Ettensohn, 2008).

At the continental margin of Laurentia, the end of the Sauk Sequence coincides with the inception of significant oceanic sea-floor subduction and the migration of a tectonic forebulge (Jacobi, 1981; Knight *et al.*, 1991; Ettensohn, 2008). The Tippecanoe Sequence (Sloss, 1963) in eastern Canada was deposited in a tectonically active environment.

The Taconian Appalachian Humber foreland basin followed a strongly diachronic along-strike evolution (Figure 3 and Figure 12). The foreland-shelf at the St. Lawrence Promontory was short-lived, being restricted to the Darriwilian with rapid flysch encroachment (Figure 12). The foundering of the shelf at the St. Lawrence Promontory occurred at a time of global sea-level fall, and both shallow- and deep-marine facies patterns responded to a dominant tectonic signal (Figure 12). In the Québec Reentrant, foreland marine shelves were built while the Taconian foredeep flysch migrated towards the shallower settings of the reentrant (Figure 12). Even with documented active tectonism (Lavoie, 1994; Lavoie *et al.*, 2003b; Lemieux *et al.*, 2003; Sharma *et al.*, 2003), the eustatic signal is detected in the evolution of the shallow-marine shelves (Dix, 2003) until tectonic collapse and burial under flysch in late Caradocian to Ashgillian (Figure 12).

The Taconian accretion of volcanic arcs occurred diachronically along the continental margin of Laurentia (see also Ettensohn, 2008). The final emplacement of oceanic units on the continental margin of Laurentia in western Newfoundland only occurred in Middle Devonian. There, the youngest flysch deposited above the Laurentia shallow-foreland shelf is Darriwilian. This flysch is unconformably overlain by end-Darriwilian shallow-marine carbonates. The youngest flysch in the Quebec Reentrant is upper Middle Ordovician to middle Upper Ordovician in southern Québec and the Gaspé Peninsula, respectively. The Taconian foreland-basin ended prior to the latest Ordovician glacio-eustatic lowstand that marks the limit of the Tippecanoe I / II sub-sequences.

6.2. Latest Ordovician to Middle Devonian Acadian basins

Sedimentation in post-Taconian basins took place throughout most of the Taconian tectonostratigraphic zones. The post-Taconian sedimentation lasted until the Middle Devonian. The succession covers the Tippecanoe II sub-sequence and ended near the base of Sloss' (1963) Kaskaskia Sequence (mid-Lower Devonian to end Mississippian).

Diachronic Taconian flysch sedimentation and local obduction of oceanic rocks, is followed by an along-strike diachronic resumption of sedimentation (Figure 13). At the St. Lawrence Promontory, the Darriwilian-Caradocian Long Point Group overlies Taconian flysch. The Long Point Group belongs to a late Taconian foreland basin and records a T-R cycle that correlates with the Caradocian eustatic signal (Figure 13). In Caradocian however, active tectonism has been demonstrated to control relative sea-level and foreland-platform foundering in the adjacent Québec Reentrant (Figure 12).

The evolution of the post-Taconian Gaspé Belt is best constrained in the northeastern segment of the Québec Reentrant (Bourque *et al.*, 1995, 2000, 2001). The succession results from three second-order regressive phases (R1 to R3) separated by two transgressive events (T1 and T2) (Figure 17).

The R1 event (Caradocian – early Silurian) resulted from base-level uplift in the successor basin (Figure 17); the rise is related to tectonic-thermal doming and Salinic Orogeny at the St. Lawrence Promontory in early Silurian (Waldron *et al.*, 1998, van Staal, 2005). The R1 event ended at a time of global sea-level rise (Figure 17).

The following T1 event has been associated by Bourque *et al.* (2000) to a poorly defined Homerian (upper Wenlockian) sea-level rise (Figure 17). At that time, the northern segment of the Gaspé Belt recorded the first pulses of a new extensional tectonic environment, which was created in response to the initial building of the Acadian orogenic wedge near the St. Lawrence Promontory (Kirkwood *et al.*, 2002, 2004). The magnitude of the T1 event was enhanced by the extensional tectonic regime.

The R2 event ended in Late Silurian with sub-aerial exposure of the Gaspé Belt (Figure 17). The Salinic unconformity (Boucot, 1962) resulted from the global late Ludlovian – early Pridolian eustatic lowstand in the Acadian foreland basin (Figure 18).

The following T2 event led to the initiation of sedimentation in the southern Québec extension of the Gaspé Belt (Figure 17). The inception of the T2 event correlates with a sea-level rise in Early Devonian time (Figure 17). The magnitude of the sea-level rise resulted from combined eustatic and continued collapse of the Gaspé Belt (Lavoie, 1992a; Tremblay and Castonguay 2002).

The R3 event culminated in the final closure of Iapetus oceanic basin along Laurentia. From a dominant extensional regime in Early Devonian, the basin was inverted into a compressional high in Pragian-Emsian (Figure 21). The regressive conditions culminated in fluvial sedimentation during Acadian transpressive faulting and folding.

7. HYDROCARBON POTENTIAL OF THE APPALACHIAN BASINS

Hydrocarbon exploration from offshore Mesozoic units of Atlantic Canada is a well-established priority for the industry. Exploration in the frontier Paleozoic sedimentary basins is less mature and has had minimal success due in part to the limited sub-surface understanding of the architecture of these basins (Lavoie and Bourque, 2001). However, production of oil and gas is recorded in all tectonostratigraphic elements forming the ancient continental margin of Laurentia in Canada (Lavoie *et al.*, 2009; Dietrich *et al.*, 2011).

7.1. Lower Paleozoic Belts – Humber Zone in Québec

The Lower Paleozoic Humber Zone of the Quebec Appalachians did not receive significant attention until a late 1960's exploration seismic survey by Shell Canada, using a foothill-style play concept. This led to the successful drilling of the 7 Bcf Saint-Flavien gas field (

Figure 4; Béland and Morin, 2000; Bertrand *et al.*, 2003a).

The best-known source rock are Upper Ordovician black shales with TOC values reaching 3wt% and HI up to 154 (Héroux and Bertrand, 1991). Good source rocks are also present in Middle Ordovician black shale units with TOC and HI values up to 5.5wt% and 306, respectively (Comeau *et al.*, 2004). Lower Ordovician shales have a fair potential (TOC up to 1.6wt%; Bertrand *et al.*, 2003b).

Surface maturity data indicate a northeasterly decrease from the US border (sterile; Ro > 3%) toward Quebec City (oil window – condensate; Ro = 0.74 to 1.3%) (Héroux and Bertrand, 1991; Comeau *et al.*, 2004). A northeasterly increase is noted from the Quebec City area toward the Gaspé Peninsula (oil window to sterile) (Chi *et al.*, 2000; Comeau *et al.*, 2004). Transported burial maturation is indicated by significant maturity jumps from one tectonic slice to another, and at the transition between the St. Lawrence Platform and the Appalachian basin (Héroux and Bertrand, 1991).

The main reservoir target consists of hydrothermally-altered, fractured, intervals in tectonic slices of shallow-marine platform rocks of the St. Lawrence Platform (Bertrand *et al.*, 2003a; Lavoie *et al.*, 2005). Secondary reservoir targets are the thick Cambrian-Lower Ordovician coarse-grained submarine fan deposits where secondary dissolution porosity is locally abundant.

The hydrocarbon systems, plays, risk analyses and evaluated in-place resources have been published in detail in Lavoie *et al.* (2009) and summarized in Dietrich *et al.* (2011).

7.2. Lower Paleozoic Belts – Humber Zone in Western Newfoundland

The first report of oil in Newfoundland goes back to 1812 with notice of floating oil on Parsons Pond in western Newfoundland. Reinterpretation of some 1970's seismic was published in the early 1990's (Waldron and Stockmal, 1991; Figure 5). The new interpretation documented the presence of an unknown Foothills-type structural style and a triangle zone at the edge of the deformation zone (Stockmal and Waldron, 1991; Stockmal *et al.*, 1998; 2004). Extensive seismic and exploration drilling led to the discovery of the Garden Hill oil field in 1995 (Figure 5; Cooper *et al.,* 2001).

The Cambrian-Ordovician deep marine black shales have high TOC and HI (10.35%, 759) values. Extracts of these shales have good biomarker correlation with the oils (Fowler *et al.*, 1995). The surface samples from western Newfoundland show a south to north increase in maturation (Williams *et al.*, 1998). A depth-related maturation increase is documented in exploration holes. In most wells, deeper units (4000+ m) are still in the oil window. The available burial-history scenarios indicate that the source rocks entered in the oil window during the Acadian Orogeny and a significant migration event occurred after the development of the hydrothermal dolostone reservoir in Early Devonian (Lane, 1990).

The main reservoir target consists of Early Ordovician intertidal to shallow subtidal facies. The best reservoirs occur where hydrothermal dolomites overprint earlier burial dolomites adjacent to, now inverted, extensional faults (Cooper *et al.*, 2001). The lateral and vertical distribution of the reservoir is highly variable and relates to the proximity of the hydrothermal fairway. Secondary target reservoirs are the Lower Cambrian well-washed quartz arenites.

The hydrocarbon systems, plays, risk analyses and evaluated in-place resources have been published in detail in Lavoie et al. (2009) and summarized in Dietrich et al. (2011).

7.3. Lower Paleozoic Belts – Gaspé Belt

Exploration in Gaspé Peninsula started in the mid-19th century based on the presence of seeping oils near faults in Gaspé (Lavoie and Bourque, 2001). Regional seismic coverage in early 80’s led to first geophysical-based drilling. Small reservoirs were recently put into production (Lavoie and Bourque, 2001, Lavoie *et al.*, 2001b).

The Lower Devonian shales have some fair to poor source rock potential with TOC values below 1.5wt% (Bertrand and Malo, 2001; Roy *et al.*, 2003). GC-MS and GC-IRMS studies of oil produced from Devonian reservoirs suggest that the potential source rock could be Ordovician black shales (Bertrand *et al.*, 2003b; Roy *et al.*, 2003).

Maturation is highly variable in eastern Gaspé and northern New Brunswick, it ranges from locally immature to the dry gas zone; it also positively correlates with depth (Bertrand and Malo, 2001, 2004). The western sector of Gaspé Peninsula is characterized by higher thermal maturation values (Roy *et al.*, 2003). Data suggest that both early and late hydrocarbon migrations occurred. Early migration from pre-Lower Silurian source rocks is recognized in Upper Ordovician to Lower Silurian units; migration occurred before the development of the regional Upper Silurian unconformity (Lavoie and Chi, 2002; Lavoie and Morin, 2004; Lavoie and Chi, 2006, 2010). The Upper Ordovician to Upper Silurian units of the Gaspé Belt have been involved in a foothill-style of deformation most likely related to the northward migration of the

Devonian Acadian foreland-basin (

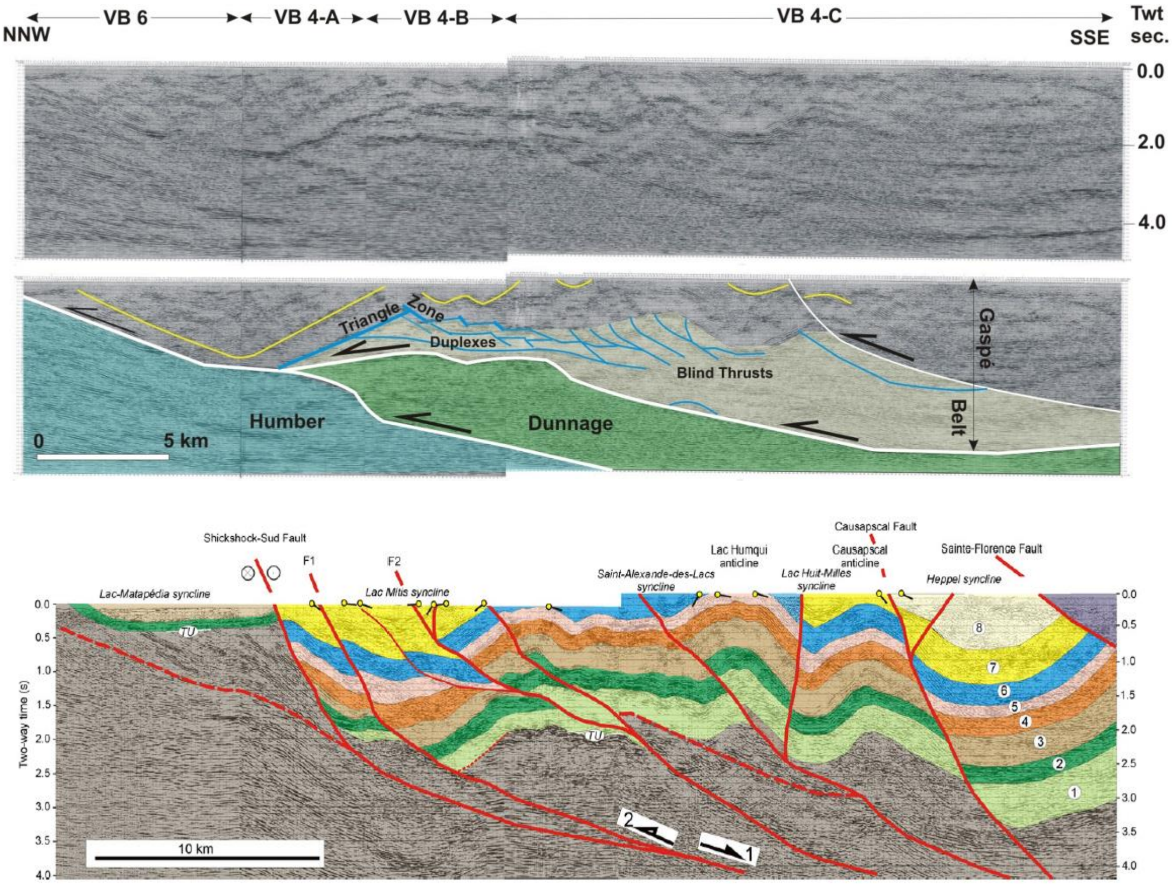


Figure 19).

Gas reservoirs are found in Lower Devonian hydrothermally-altered, fractured, carbonates (Lavoie *et al.*, 2001b). High quality oil is produced from coarse-grained units of the Lower Devonian sandstones (Lavoie *et al.*, 2009). In the last two cases, positive production tests in early 2015 indicate that these fields could be developed in a near future. Good reservoir rocks are also documented in hydrothermal dolomites of the Lower and Upper Silurian carbonates (Lavoie and Chi, 2001; Lavoie and Morin, 2004; Lavoie, 2005; Lavoie and Chi, 2006; Lavoie et al., 2010).

FIELDTRIP

8. OVERVIEW FOR DAY 1 AND DAY 2 (STOPS 1.1 TO 2.2) CAMBRIAN-ORDOVICIAN ROCKS OF THE EXTERNAL HUMBER ZONE

8.1. Introduction

The external Humber Zone in the Lower St. Lawrence Valley and Gaspé Peninsula comprises two major Cambrian-Ordovician rock assemblages, continental slope deposits and foreland basin strata, which are preserved in southeasterly-dipping thrust slices. These slices were emplaced over the Cambrian-Ordovician shelf during the Middle Ordovician Taconian orogeny (St. Julien and Hubert, 1975; St. Julien *et al.*, 1983). Two phases of penetrative deformation are documented in the internal and external Humber Zone in the Gaspé Peninsula. D1 is associated with the obduction of the Mont-Albert ophiolite onto the Paleozoic Laurentian margin, whereas D2 corresponds to later transport of allochthons across the margin (Malo *et al.*, 2008). D1 is best developed in metabasalts of the internal Humber Zone and is characterized by NW-overturned and recumbent folds, and a subhorizontal S1 schistosity with an ENE-trending orogen-parallel lineation. D2 is developed in the internal and external Humber Zone and is characterized by NE-trending F2 folds with a steeply-dipping axial-planar cleavage. The intraoceanic thrusting of ophiolite is dated at 465 Ma (early D1) whereas emplacement of ophiolite onto the margin occurred at 459 – 456 Ma (late D1) (Malo *et al.*, 2008). D2 is dated at 448 Ma throughout the internal Humber Zone (Malo *et al.*, 2008).

Cambrian-Ordovician continental slope deposits crop out from Quebec City to Gaspé Peninsula for some 600 km along the south shore of the St. Lawrence River, whereas foreland basin strata are mainly found in the easternmost part of the Gaspé Peninsula (Figure 1 and Figure 23). The continental slope deposits are the only significant record of a Cambrian passive margin in the Québec Appalachians (Lavoie, 2008). The succession consists of siliciclastic-dominated Cambrian, and mixed siliciclastic / carbonate Ordovician strata (Lavoie *et al.*, 2003b; Lavoie, 2008). The Ordovician foreland basin strata consist of submarine fan, basin plain and slope turbidites, debrites and mudstones (Prave *et al.*, 2000) deposited in front of the Taconian orogenic prism (Malo *et al.*, 2008; Lavoie, 2008).

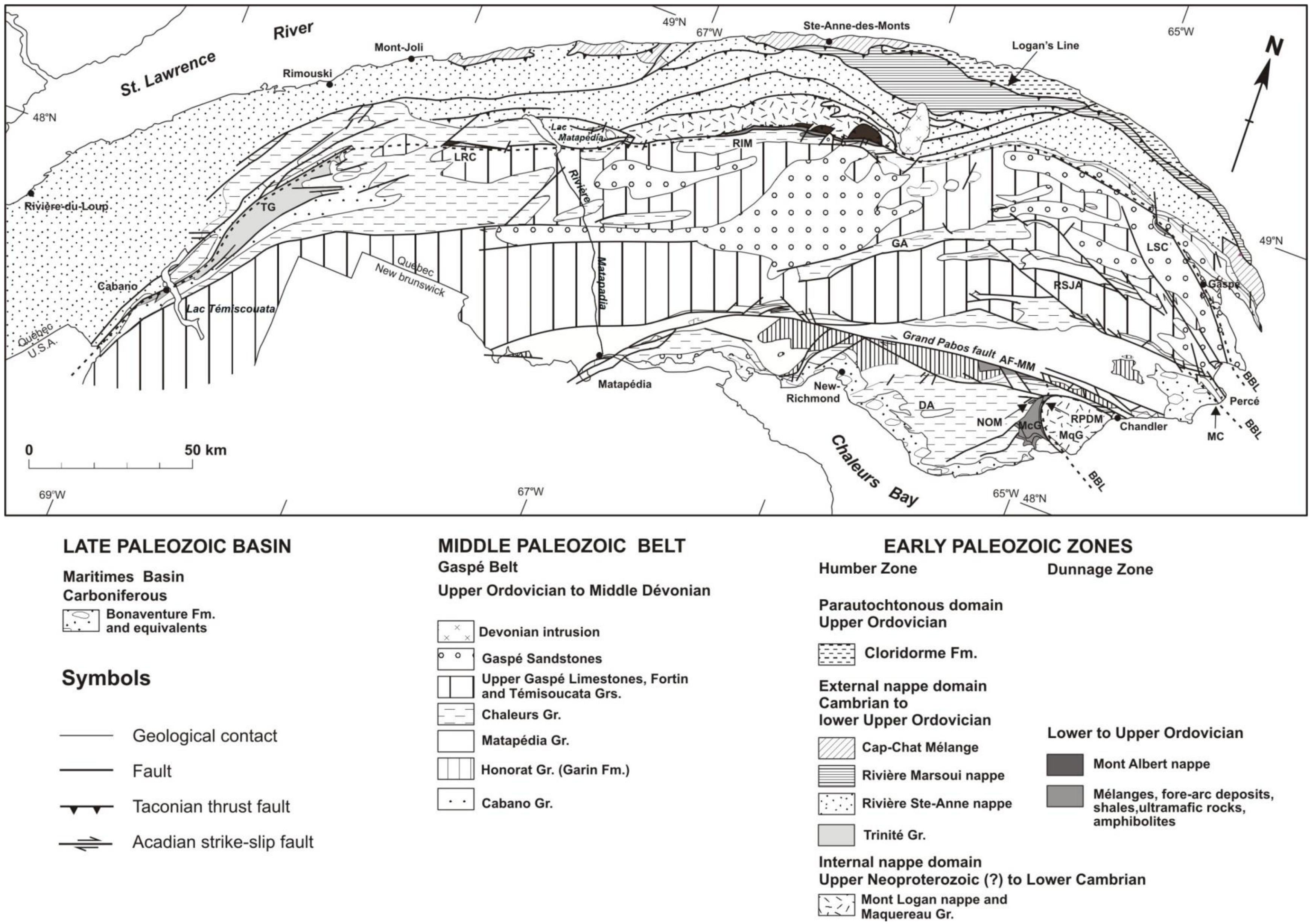

River
St. Lawrence
Mont-Joli
Rimouski
Rivière-du-Loup
Cabano
Lac Témiscouata
Québec
U.S.A.
New brunswick
TG
LRC
Lac Matapédia
Rivière
Matapedia
Matapédia
RIM
Ste-Anne-des-Monts
Logan's Line
GA
LSC
RSJA
Gaspé
Grand Pabos fault
AF-MM
New-Richmond
DA
NOM
McG
MqG
RPDM
Chandler
Percé
MC
BBL
Chaleurs Bay
N
48°N
49°N
67°W
65°W
69°W
0
50 km
LATE PALEOZOIC BASIN
Maritimes Basin
Carboniferous
Bonaventure Fm. and equivalents
Symbols
Geological contact
Fault
Taconian thrust fault
Acadian strike-slip fault
MIDDLE PALEOZOIC BELT
Gaspé Belt
Upper Ordovician to Middle Dévonian
Devonian intrusion
Gaspé Sandstones
Upper Gaspé Limestones, Fortin and Témisoucata Grs.
Chaleurs Gr.
Matapédia Gr.
Honorat Gr. (Garin Fm.)
Cabano Gr.
EARLY PALEOZOIC ZONES
Humber Zone
Dunnage Zone
Parautochtonous domain
Upper Ordovician
Cloridorme Fm.
External nappe domain
Cambrian to lower Upper Ordovician
Cap-Chat Mélange
Rivière Marsoui nappe
Rivière Ste-Anne nappe
Trinité Gr.
Internal nappe domain
Upper Neoproterozoic (?) to Lower Cambrian
Mont Logan nappe and Maquereau Gr.
Lower to Upper Ordovician
Mont Albert nappe
Mélanges, fore-arc deposits, shales,ultramafic rocks, amphibolites

Figure 23. Regional geology of the Gaspé Peninsula.

AF-MM: Arsenault Formation-McCrea mélange assemblage, AI: Anticosti Island, BBL: Baie Verte-Brompton Line, DA: Duval anticline, GA: Gastonguay anticline, LRC: La Rédemption Complex, LSC: Lady Step Complex, MAC: Mont Albert Complex, MC: Murphy Creek Formation in external nappe domain inlier of the Percé area, MM: McCrea Mélange, McG: Mictaw Group, MqG: Maquereau Group, NB: New Brunswick, NE: New England (USA), NF: Newfoundland, NOM: Nadeau ophiolitic Mélange, NS: Nova Scotia, QC: Québec City, RF-RL: Romieu Formation – reference locality, RF-T: area of the Romieu Formation with Late Cambrian trilobites, RIM: Ruisseau Isabelle Mélange, RL: Rivière-du-Loup, Rm: Rimouski, RPDM: Rivière Port-Daniel Mélange, RSJA: Rivière Saint-Jean anaticline, SQA: southern Québec Appalachians, SSG: Shickshock Group, TG: Trinité Group. From Malo (2004).

8.2. Stratigraphy

The stratigraphic framework (Lavoie *et al.*, 2003b; Lavoie, 2008) is based on integration and synthesis of large-scale mapping and some regional thematic studies (e.g., Béland, 1957; Hubert, 1973; Biron, 1971, 1974; Liard, 1973; Lajoie, 1972, 1974; Vallières, 1984; Slivitsky and St. Julien, 1987; Slivitzky *et al.*, 1991; Bernstein *et al.*, 1992; Lebel and Hubert, 1995; Lavoie, 1997, 1998; Prave *et al.*, 2000). The age of continental slope units is loosely-defined, local paleontologic studies have revealed the presence of macrofauna such as graptolites, trilobites and brachiopods as well as microfauna (chitinozoans, conodonts and acritarchs), all of which were used to built the current framework (Lavoie *et al.*, 2003b). Moreover, the age of the slope conglomerates is constrained by the youngest fossils in limestone clasts as well as by the microfauna in the fine-grained interbeds (Lavoie *et al.*, 2003b). In contrast, the age of foreland basin strata is well constrained by graptolites (Riva, 1968; Riva, 1969).

Regionally, the continental slope succession can be divided in broad stratigraphic packages consisting of fine-grained sediments separated by or interbedded with coarse-grained units (Lavoie *et al.*, 2003b; Lavoie, 2008). The lower package consists of Lower Cambrian siliciclastics capped by conglomerate. The overlying package is defined by Middle Cambrian fine-grained siliciclastics capped by lowest Upper Cambrian conglomerates. The third package consists of Upper Cambrian - lowermost Ordovician mixed siliciclastic and limestone conglomerates, sandstones and shales. Finally, the last package is represented by Lower to Middle Ordovician fine-grained successions of siliciclastics and limestones locally punctuated by conglomerates. The foreland basin strata comprise three main lithostratigraphic units. The Middle Ordovician (Llanvirnian) unit is made up of thick siliciclastic turbidites. The lower Upper Ordovician unit (lower Caradocian) consists of fine-grained siliciclastics and chert deposited in a deep water environment, and the overlying unit is made up of an Upper Ordovician (upper Caradocian) flysch succession.

8.2.1. The Lower Cambrian siliciclastics and limestone conglomerate (Stops 1.1 and 1.2)

The Lower Cambrian rocks are found in thrust slices of the external Humber Zone in the Lower St. Lawrence Valley and are known as the "Green Sandstone Unit" (Vallières, 1984; Lebel and Hubert, 1995). They consist mainly of greenish grey sandstone locally red. Sandstones are feldspathic and interbedded with green, red and grey slates. The Green Sandstone unit overlies tholeiitic basalts of the Montagne Saint-Anselme. In the Gaspé Peninsula, Lower

Cambrian (Neoproterozic?) metabasalts and metasedimentary rocks (arkoses and minor conglomerates) of the Shickshock Group are correlative to the Montagne Saint-Anselme/Green Sandstone Unit package, but they crop out in the internal Humber Zone (Slivitzky *et al.*, 1991). These lower clastics are commonly capped by limestone conglomerates of limited lateral and vertical extensions (Lavoie et al., 2003b; Lavoie, 2008).

8.2.2. The Middle Cambrian fine-grained siliciclastics

This stratigraphic package is represented by the Middle Cambrian Orignal Formation which consists mainly of red, green and grey shale. This unit is well-developed in the Lower St. Lawrence Valley region and Gaspé Peninsula

8.2.3. The Upper Cambrian-lowermost Ordovician sediments (Stop 1.3)

These sediments represent an important marker succession owing to their coarse-grained nature and their regionally persistent distribution along the entire external Humber Zone. Readers interested in the regional distribution of the Upper Cambrian to Lowermost Ordovician succession are referred to Lavoie (1997, 1998), Lavoie *et al.*, (2003b) and Lavoie (2008). The most recent formal stratigraphic study of this package was conducted in the Rivière-du-Loup area by Vallières (1984). He introduced the term Trois-Pistoles Group for the Upper Cambrian - lowermost Ordovician sediments of the area. As defined, the Trois-Pistoles Group consists, in ascending order, of the Saint-Damase, Rivière-du-Loup and Kamouraska formations.

The Saint-Damase Formation is represented by thickly-bedded locally pebbly arkosic sandstones and limestone conglomerates with minor thinly-bedded mudstones although the middle member (La Pocatière) recognized by Hubert (1973) in the Kamouraska area is not developed. The Saint-Damase Formation (previously named the Cap Enragé Formation; Lajoie, 1972) is typified by cyclic alternation of limestone conglomerate-dominated intervals with fine-grained to pebbly sandstone intervals. Each of these "cycles" is generally marked by a lower conglomeratic zone that thins- and fines-upward and passes to the sandstone-rich interval which also fines- and thins-upward. In the Trois-Pistoles area, up to three of these cycles have been recognized (see Hein and Walker, 1982) and details of the conglomerates are found in Lavoie (1997). In the Grosses Roches area, Hendry (1979) introduced the term Grosses-Roches Formation for the stratigraphic succession that overlies the Middle Ordovician Orignal and the Lower Ordovician Rivière-Ouelle (Cap des Rosiers Fm in Hendry, 1979) formations, As defined by Hendry (1979) and discussed in Bernstein *et al.* (1992), Bertrand *et al.* (2003b) and Lavoie *et al.* (2003b), the Grosses-Roches consists of a lower informal member of coarse grained facies (equivalents to the Saint-Damase and Cap Enragé formations) and an upper fine-grained unit that extends into the Ordovician and likely correlative with the Rivière-du-Loup Formation.

The very distinctive Rivière-du-Loup Formation has been introduced by Vallières (1984) to designate a mudstone and siltstone unit developed between the Saint-Damase and Kamouraska formations in the Rivière-du-Loup map area. The distribution of the Rivière-du-Loup Formation is rather erratic. This unit has not been recognized in the sector southwest of the type area whereas it is reported to be present at many places to the northeast (Slivitzky *et al.*, 1991).

However, local detailed studies have shown some inconsistencies in reported occurrences of that unit (Bernstein *et al.*, 1992; Lavoie, 1997; Lynch and Arsenault, 1997).

The typical quartz arenite of the Kamouraska Formation are well exposed at the top of the Trois-Pistoles Group in the Rivière-du-Loup area, however, towards the northeast, this unit is locally stratigraphically pinching out. Recent detailed work on the quartz-rich sandstones has resulted in the documentation of deep-marine mass debrites deposition of reworked aeolian sands (Malhamme, 2007).

8.2.4. The Lower to Middle Ordovician fine-grained successions of siliciclastics and limestones

This rock package is represented by the Rivière-Ouelle Formation which crops out from the Rivière-du-Loup area to the eastern tip of the Gaspé Peninsula at Cap-des-Rosiers (Brisebois and Nadeau, 2003). The Rivière-Ouelle Formation consists of red, green, and black mudstones with subordinate thinly bedded siliceous and feldspathic sandstones, ribbon limestones, calcarenites and limestone conglomerate (Lavoie *et al.*, 2003b; Lavoie, 2008). This lithostratigraphic unit is correlative with the Pointe-de-la-Martinière and the Lévis Formation in the Québec City area.

In the Les Méchins area, Bernstein *et al.* (1992) introduced the Anse-du-Crapaud Formation for the Lower – Middle Ordovician stratigraphic interval based on the high limestone content of the succession. These limestones were not described by Hubert (1973) as part of its new Rivière-Ouelle Formation, however, visit by D. Lavoie to the type section has revealed that meter to decameter thick intervals with ribbon limestone, calcarenite and limestone conglomerate are present within the Rivière-Ouelle Formation. Lavoie *et al.* (2003b) reassigned the Anse-du-Crapaud to an informal member status to be locally used for areas with higher than usual (10%) limestone content for the Rivière-Ouelle Formation.

8.2.5. The Ordovician foreland basin strata (Stops 2.1 and 2.2)

The lower lithostratigraphic unit of the foreland basin is the uppermost Arenig to Llanvirnian (Middle Ordovician) succession of turbidites of the Tourelle Formation which overlies conformably the Rivière-Ouelle Formation in the Rivière-du-Loup area (Vallières, 1984). The Tourelle Formation consists of grey greenish lithic wackes and siltstones interbedded with dark grey mudstones and/or mudshales. Lithic conglomerates with volcanic rocks fragments, chert and mudshales are locally present. Lithic wackes and conglomerates exhibits several sedimentary structures typical of turbidtes deposited in a mid-fan lobe environments (Hiscott, 1978). The presence of chromite grains in greywacke implies that ophiolites were eroded in the beginning of the Middle Ordovician (Llanvirnian to Darriwilian).

The second lithostratigaphic unit is the lower Upper Ordovician Des Landes Formation which consists of chert, shale, and muddy flysch. Rocks of the Des Landes Formation crop out in the Gaspé Peninsula mainly in the Marsoui nappe. The contacts with the older Tourelle Formation and the younger Cloridorme Formation are not known (Slivitzky *et al.*, 1991). Rocks of the Des Landes were deposited in a fore-deep basin (Prave *et al.*, 2000) and contain the typical *Nemagraptus gracilis* fauna of early Caradocian (Riva, 1968).

The middle Upper Ordovician flysch succession of the Cloridorme Formation is the youngest rock unit of the foreland basin. The formation crops out in the eastern Gaspé Peninsula. The Cloridorme Formation was studied in detail by Enos (1969) and divided into several rocks units. Slivitzky *et al.* (1991) also divided the Cloridorme into six members. In this guidebook, we prefer using the practice of Prave *et al.* (2000) who recognized the lower and the upper Cloridorme. The lower part of the formation consists of megaturbidites, thinner greywacke, black mudstone and minor amount of dark-grey micritic carbonate beds (Prave *et al.*, 2000). The upper part consists of monotonous dark-grey to black mudstone with subordinate thinly graded sandstone and siltstone beds. The Cloridorme Formation spans the *Climacograptus bicornis* to *Climacograptus spiniferus* Zones of the Caradocian.

9. OVERVIEW FOR DAY 2 (STOPS 2.3 AND 2.4) AND DAYS 3 TO 5 SILURIAN-DEVONIAN ROCKS OF THE GASPÉ BELT IN THE GASPÉ PENINSULA

9.1. Introduction

The Gaspé Belt is the largest depositional belt of the middle Paleozoic rock assemblage of the Canadian Appalachian. It comprises the most complete stratigraphic record consisting of four broad temporal and lithological assemblages (Bourque *et al.*, 2000, 2001a). From the base to the top (Figure 23 and Figure 24), these are : 1) the uppermost Ordovician-lowermost Silurian deep water, fine-grained carbonate-siliciclastic facies of the Honorat and Matapédia groups (HO-MA), 2) the Silurian-lowermost Devonian shallow to deep shelf facies of the Chaleurs Group (CH), 3) the Lower Devonian mixed siliciclastic and carbonate fine-grained deep shelf to basin facies of the Upper Gaspé Limestones and Fortin groups (UGL-FO), and 4) the Lower to Middle Devonian nearshore to terrestrial coarse-grained facies of the Gaspé Sandstones Group (GS). Upper Silurian and lower Devonian continental tholeiitic basalts and andesites are present in the upper Chaleurs, Upper Gaspé Limestones and lower Gaspé Sandstones groups. The Gaspé Belt is located in the Québec reentrant (Figure 1) where the metamorphic grade and the intensity of the deformation of the Middle Paleozoic rocks are lower than in Newfoundland, to the northeast, and in southern Québec, to the southeast.

In the Gaspé Peninsula (Figure 23), rocks of the Gaspé Belt are deposited unconformably on, or are in fault contact with rocks of the Humber and Dunnage zones (Malo and Bourque, 1993). In southern Gaspé Peninsula, rocks of the Gaspé Belt, as well as those of the Humber and Dunnage zones, are unconformably overlain by flat-lying Carboniferous strata (Figure 2). The two angular unconformities which bound the Gaspé Belt sequence, the sub-Caradoc and the sub-Carboniferous, are used to constrain the timing of deformation within the Upper Ordovician to Middle Devonian rocks of the peninsula. Folding and faulting are clearly dated as Middle to Late Devonian (Malo and Bourque, 1993; Malo and Kirkwood, 1995) and the main deformation within the belt is ascribed to the Acadian orogeny. The Gaspé Belt rocks were affected by regional anchimetamorphism to low-grade metamorphism usually associated with burial metamorphism (Nowlan and Barnes, 1987; Chagnon, 1988; Hesse and Dalton, 1991). Older rocks are generally more thermally mature and found in anticlines (Chagnon, 1988; Hesse and Dalton, 1991; Bertrand and Malo, 2001; Roy, 2008). Illite crystallinity and organic-matter reflectance studies indicate anchimetamorphism grade for rocks of the Honorat Group (Chagnon, 1988), and the intensity of metamorphism decreases to the top where some rock of the Upper Gaspé Limestones and Gaspé Sandstones group are still in the oil window (Bertrand and Malo, 2001). The intensity of metamorphism also decreases regionally eastward. Local zones of high-grade metamorphic rocks are spatially associated with Devonian intrusions (e.g. Murdochville area, Bertrand and Malo, 2001) and dyke swarms along major Acadian faults (Malo *et al.*, 2000). Intrusions are restricted to the northern part of the peninsula (e.g. Mont McGerrigle plutonic complex, Dôme Lemieux area, Copper and Porphyry mountains in the Murdochville area; Figure 23). Several stocks and dyke swarms intrude the Gaspé Belt rocks further south (Doyon and Berger, 1997).

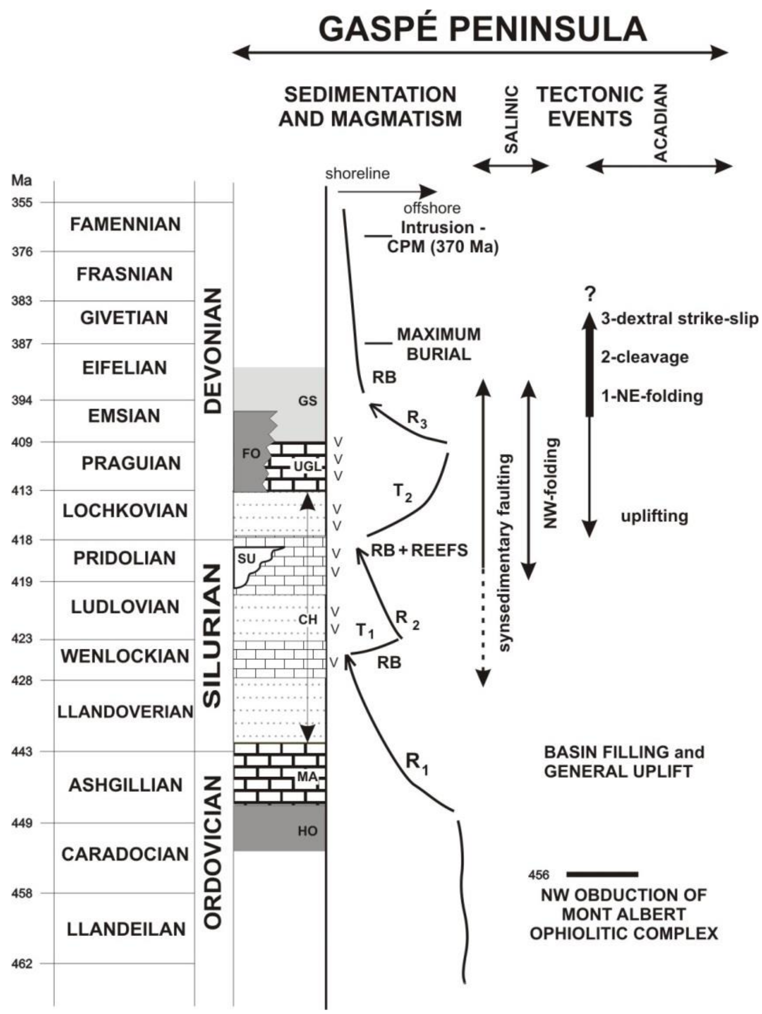


Figure 24. Summary of the main sedimentological, magmatic and tectonic features in the Gaspé Belt. CH: Chaleurs Group, CPM: Copper and Porphyry mountains stocks; FO: Fortin Group, GS: Gaspé

Sandstones Group, HO: Honorat Group, MA: Matapédia Group, R: regression, RB: red beds, SU: Salinic unconformity, T: transgression, UGL: Upper Gaspé Limestones Group, V: volcanic rocks. Modified from/ Modified from Bourque, Malo and Kirkwood (2001). Absolute ages from Tucker and McKerrow (1995), and Tucker *et al.* (1998). Absolute age of the CPM from Wares and Brisebois (1998).

The major Acadian structural trend of the Gaspé Belt rocks is oriented NE. The Gaspé Belt is divided into three major structural zones following this regional trend, from northwest to southeast: (1) the Connecticut Valley-Gaspé synclinorium, (2) the Aroostook-Percé anticlinorium, and (3) the Chaleurs Bay synclinorium (Figure 2). The major deformation features are large, open and upright NE-trending folds, NW-directed high-angle reverse faults and dextral ENE- to E-trending strike-slip faults such as the Shickshock Sud and the Grand Pabos faults (Figure 23). Deformation features related to these two major strike-slip faults are compatible with a classical strike-slip tectonics model (Malo and Béland, 1989; Sacks *et al.*, 2004). New seismic data in the Gaspé Belt suggest that transpressional Middle Devonian Acadian folding and faulting were preceded by an initial stage of shortening that produced tectonic structures typical of fold and thrust belt (Beausoleil *et al.*, 2002; Kirkwood *et al.*, 2004). During the Late Silurian, a minor tectonic event related to the Salinic orogeny is marked by angular and/or erosional unconformities, synsedimentary faulting and extensional-related folding mainly recorded in northeastern Gaspé Peninsula (Bourque, 2001; Malo, 2001). The Middle Devonian Acadian orogeny resulted from oblique continental collision between peri-Gondwanan terranes and Laurentia with its Taconian accreted terranes (Malo *et al.*, 1995).

9.2. Stratigraphy

The two lower lithological assemblages of the Gaspé Belt, the uppermost Ordovician-lowermost Silurian Honorat and Matapédia groups and the Silurian-lowermost Devonian Chaleurs Group, crop out mainly in the Aroostook-Percé anticlinorium and the Chaleurs Bay synclinorium in southern Gaspé Belt, whereas the two upper lithological assemblages, the Lower Devonian Upper Gaspé Limestones and Fortin groups and the Lower to Middle Devonian Gaspé Sandstones Group crop out in the Connecticut Valley-Gaspé synclinorium in northern Gaspé Belt (Figure 23).

9.2.1. Southern Gaspé Belt - Aroostook-Percé anticlinorium and Chaleurs Bay synclinorium

The southern Gaspé Belt is the type area for the Honorat, Matapédia and Chaleurs groups. The surface geology has been presented in number of geological maps and reports (Bourque and Lachambre, 1980; De Broucker, 1987; Malo, 1988a; Malo, 1988b; Kirkwood, 1989; Brisebois and Nadeau, 2003). Seismic acquisition programs by the Quebec Department of Natural Resources have helped to improve our knowledge of the subsurface (Pinet, 2013).

9.2.1.a. Basement of the southern Gaspé Belt

The Gaspé Belt sequence overlies Cambrian-Ordovician rocks of the Humber and Dunnage zones (Pinet *et al*., 2010) in several inliers in southern Gaspé (Figure 23): the Murpy Creek inlier in the Percé area, and the Maquereau-Mictaw, the Nadeau and the McCrea inliers in the Chandler-Port Daniel area (Malo *et al.*, 1992). Cambrian rocks occur within the Murphy Creek inlier. The southwest contact of the inlier is a sub-Caradoc unconformity where Middle to Upper Cambrian rocks of the Corner-of-the-Beach and Murphy Creek formations are overlain by the Upper Ordovician to Lower Silurian Matapédia Group (Figure 23). The Corner-of-the-Beach Formation consists of limestones with oolitic facies and shales whereas the Murphy Creek Formation is made up of clayshales, argilaceous limestones, dolomitic siltstones, lithic and quarzitic sandstones, and limestone conglomerate (Kirkwood, 1989: Lavoie, 2001). The two Cambrian formations are included in the external nappe domain of the Humber Zone of northeastern Gaspé, and the unconformity is attributed to the Taconian Orogeny (Kirkwood, 1989).

The larger inlier of Cambrian-Ordovician rocks in southern Gaspé is the Maquereau-Mictaw inlier a tectonic collage of Humber and Dunnage zones rocks against the Baie Verte-Brompton Line (BBL) represented by the Port-Daniel fault (Williams and St-Julien, 1982). The Maquereau Group, northeast of the BBL, is composed of metasedimentary and metavolcanic rocks correlated with rock units of the internal Humber Zone, the Shickshock Group in northern Gaspé (St-Julien and Hubert, 1975). The Rivière Port-Daniel Mélange, southwest of the BBL (Figure 23), is a Lower Ordovician olistostromal mélange made up of blocks of serpentinite, volcanic rocks, chert, greywacke, silty limestone and red siltstone; it is unconformably overlain by the Middle Ordovician Mictaw Group. The Nadeau ophiolitic Mélange, northwest of the Maquereau-Mictaw inlier (Figure 23), contains blocks of serpentinized peridotite, quartzite and granite in a serpentinite matrix as well as immense (up to 1km) blocks of metagreywacke and amphibolite which correlate with the Chain Lake Massif (De Broucker, 1987). North of the Maquereau-Mictaw inlier, the McCrea mélange crops out along the Grand Pabos fault and consists of a black pebbly mudstone with blocks of sedimentary rocks and serpentinite. This melange is unconformably overlain by the turbidite sequence of the Middle Ordovician Arsenault Formation (Figure 23) which correlates with the base of the Mictaw Group (Malo and Bourque, 1993). The Mictaw Group and the Arsenault Formation are interpreted as synorogenic turbidites deposited in a fore-arc basin overlying an accretionary prism represented by the mélange units (Nadeau ophiolitic Mélange, Rivière Port-Daniel and McCrea mélanges).

9.2.1.b. The Mictaw Group

The Mictaw Group overlies the Rivière Port-Daniel Mélange. It has been divided into three formations (De Broucker, 1987), from base to top, 1) the Llanvirnian (Darriwilian) Neckwick Formation that is dominated by of thick flysch sandstones, 2) the undated Mélange de la Rivière du Milieu that consists of various sedimentary blocks within a shale matrix and 3) the Llandelian-Caradocian Dubuc Formation that encompasses a succession of shale, sandstone and conglomerate. The Mictaw Group is unconformably overlain by the lower unit (Clemville Formation) of the Chaleurs Group (Bourque and Lachambre, 1980). The Mictaw Group has been considered as recording tectono-sedimentary events in a deep marine environment of the oceanic domain of the Dunnage zone (De Broucker, 1987). Regional synthesis suggests that the Mictaw Group correlates with the Balmoral Group of Northern New Brunswick (Wilson *et al.,* 2004).

The internal stratigraphy of the Dubuc Formation is variable with areas being richer in coarse grained facies while other sectors are dominated by dark shale (up to 90% of the unit; De Broucker, 1987). At its type section, the thickness of the Dubuc Formation has been evaluated to be at least 700 meters (De Broucker, 1987); the formation has been divided into two members, the lower shale-dominated Rivière du Milieu Member and the upper sandstone-conglomerate-dominated Pont de Clemville Member. The Rivière du Milieu Member is significant for the hydrocarbon potential of southern Gaspé, in old geological report, these shales were commonly described as “bitumineous shales” (Parks, 1930); this shale-dominated succession is characterized by abundant septaria-rich carbonate concretions. The concretion is a diagenetic product that results from early bacterial sulphate reduction followed by bacterial methanogenesis, both processes being documented by carbon isotopic ratios of the carbonates ($\delta^{13}C$ of -5l to -20l for sulphate reduction and -5l to -12l for methanogensis; N. Tassé work in progress and pers. comm. to D. Lavoie); the septaria are deeper burial features. The presence of the carbonate concretions within the dark shale is an indirect indicator of organic matter within the sediment; similar concretions are found in the Rivière Ouelle Formation (Bernstein *et al.*, 1992) and more importantly in the Green Point Formation (Coniglio and James, 1990); the latter being a demonstrated hydrocarbon source rock in western Newfoundland (Fowler *et al.*, 1995).

The hydrocarbon source rock potential of the Dubuc Formation has recently being supported by Rock Eval VI analyses of some of the dark shale intervals (Lavoie, 2007; Lavoie et al., 2009, 2011). TOC values range between 0.1 to 10.7% with seven results over 3%. HI values are up to 254 with half of the results over 150. Reflectance analyses of few samples have suggested that this potential source rock is within the oil window; however, the exact nature of the organic matter is still unknown.

Regionally, the Mictaw Group has been correlated with the Balmoral Group; the latter includes the Popelogan Shale, a Llandeilan unit that is poorly outcropping in northern New Brunswick (Wilson *et al.*, 2004; Bertrand and Malo, 2004). A few Rock Eval analyses of the Popelogan shales have yielded modest TOC values (max of 1.8%) but still quite anomalous given the high thermal rank of these shales (RoVitrequi of 2.9%, dry gas zone). Petrographic examination of the Popelogan Shale has documented the dominance of amorphous organic matter together with minor content of graptolites and bitumen (Bertrand and Malo, 2004).

9.2.1.c. The Honorat Group

The Honorat Group is the oldest unit of the Gaspé Belt in southern Gaspé Peninsula (Malo, 1988b). The Honorat Group consists of the Garin Formation, the latter being composed of non-calcareous, dark grey mudstone and siltstone with subordinate sandstone and conglomerate. The Garin sandstones offer the typical sedimentary structures related to turbidity current sedimentation and lack wave-induced structures. In places, fine-grained sedimentation occurred under slightly anoxic to dysaerobic conditions and few above regional background TOC values are preserved (TOC > 0.5%).

The Upper Ordovician (Caradocian) Garin Formation disconformably overlies the Middle Ordovician (Llavirnian) Arsenault Formation of the Dunnage Zone. The Garin has been interpreted as the initial post-orogenic basin infilling unit with sediments being sourced from the south (Malo, 2004). The assumed source area for the Garin is made up of Dunnage Zone terrains croping out in the Gaspé Peninsula and northern New Brunswick (Dupuis *et al.*, 2009). The study of volcanic rocks in conglomerate of the Garin Formation suggests correlation with volcanic assemblages of the McCrea mélange, along the Grand Pabos fault (Figure 23), and the Popelogan inlier in New Brunswick (Dupuis *et al.*, 2009). The deep marine sedimentation of the Honorat Group occurred during the first 2nd order regressive event (R1) in the Gaspé Belt with the regressive phase culminating in nearshore facies in the lower part of the Chaleurs group (Bourque, 2001; Bourque *et al.* 2001a).

In adjacent northern New Brunswick, the Honorat Group correlates with the Grog Brook Group (Wilson *et al.*, 2004; Bertrand and Malo, 2004) whereas the Garin correlated facies and time-wise, with the clastics of the Cabano Group in westerly adjacent Témiscouata (Malo, 2004).

9.2.1.d. The Matapédia Group (Stops 3.4 and 3.5)

The Matapédia Group conformably overlies the Honorat Group in southern Gaspé Peninsula (Malo 2004) and the Grog Brook Group in northern New Brunswick (Wilson *et al.*, 2004). The Matapédia Group consists of a lower Pabos Formation and an upper White Head Formation. The Matapédia Group is well exposed in the Aroostook-Percé anticlinorium but the unit is also outcropping in the Connecticut Valley-Gaspé and Chaleurs Bay synclinoria. Based on diverse assemblages of macrofauna (graptolites and brachiopods) and microfauna (chitinozoans and conodonts), the age of the Matapédia is well constrained and ranges from the lower Ashgillian to the Llandoverian B (Aeronian); the Ordovician-Silurian boundary occurs in the White Head Formation (Malo, 2004).

The Pabos Formation is a transition unit between the underlying deep marine clastics of the Garin Formation and the overlying below wave base limestones of the White Head Formation. The Pabos Formation has been divided into two informal members (Malo, 1988b) that consist of alternating more or less limy mudstone and siltstone with more or less shaly and silty calcilutite. The succession was deposited in a below wave base marine environment based on sedimentary structures and lack of shallow marine metazoans.

The White Head Formation has been divided into four formal members (Lespérance *et al.*, 1987), from base to top, a lower calcilutite-dominated member (the Burmingham), an overlying fine-grained siliciclastic member (the Côte de la Surprise), a succeeding calcilutite-dominated member (the L'Irlande) and an upper argillaceous limestone member (the Des Jean). Pelagic organisms with calcareous tests were absent in Early Paleozoic seas; all carbonates that accumulated in shallow to deep marine environments are derived from shallow subtidal zone that was christened the "carbonate factory" (James, 1984). In latest Ordovician – earliest Silurian, the only known nearby shallow marine setting prone for carbonate production was the Anticosti platform (Figure 1). The fine-grained clastics of the Côte de la Surprise Member carry a Hirnantian fauna; the carbonate-free sediments are the deep marine expression of the climax of the Late Ordovician glaciation as the cooler marine conditions resulted in the shutting down of the carbonate factory on the nearby Anticosti platform. Shallow marine carbonate production resumed in latest Ordovician on Anticosti and sedimentation of lime mud in the below wave base setting resumed. The increase amount of clays in the upper member of the formation heralds the lowermost unit of the overlying Chaleurs Group.

Overall, the thickness of the White Head Formation increases in a southwesterly direction (Malo, 1988b; 2004; Wilson *et al.*, 2004); this trend is also associated with an overall homogenization of the lithofacies whereas shallower facies (calcarenite beds) are restricted to the Percé area in eastern Gaspé. These elements are supportive of a northeasterly located sediment source (Anticosti platform) for the White Head Formation. As for the underlying Honorat Group, the relatively deep marine (below fair-weather wave base) Matapédia Group belongs to the first second-order regressive event (R1) in the depositional basin (Figure 24).

A detailed study of the fractures and their cement-fill in eastern Gaspé and cross-cutting relationships with other diagenetic elements (Kirkwood *et al.*, 2001) resulted in the recognition of a complex tectonic history of the White Head Formation. Based on petrography, stable isotopes and fluid inclusion microthermometry, the fracture fills indicate that after initial burial, the succession was fractured and uplifted during the Late Silurian Salinic event, followed by deeper burial fracturing and faulting related to the Early Devonian Acadian orogeny. The presence of light liquid hydrocarbons fluid inclusions in Salinic vein cements and of methane inclusions in Acadian veins indicate that hydrocarbons migrated in the fracture network. This also supports the presence of a mature pre-late Silurian source rock (as will be also discussed in the following sections). These indications of hydrocarbon migration are key elements for the prospectivity of overlying (Silurian to Devonian) coarser grained carbonate and clastic potential reservoirs.

9.2.1.e. The Chaleurs Group (Stops 2.3, 3.3, 4.1 to 4.5)

The Chaleurs Group is a Lower Silurian to lowermost Devonian succession that is present in southern (Chaleurs Bay synclinorium), central and northern (Connecticut Valley-Gaspé synclinorium) Gaspé. Significant facies variations are recognized over such a large area and since the pioneer years of stratigraphy in the area, local stratigraphic nomenclatures have been introduced (see Bourque, 1975 for an overview). The Chaleurs Group succession is better understood when described according to three broad superposed assemblages (Bourque *et al.*, 2000): a lower siliciclastic assemblage, a middle carbonate assemblage, and an upper siliciclastic assemblage with local reef and volcanic bodies. These three assemblages are well expressed in southern Gaspé Peninsula.

Lower siliciclastic assemblage

In southern Gaspé, the lower siliciclastic assemblage of the Chaleurs Group conformably overlies the L'Irlande member of the White Head Formation, sedimentation of the Clemville Formation began in Llandoverian A (Rhuddanian) time (Bourque *et al.*, 2001a). However, the base of the Chaleurs Group is younger (Llandoverian C; mid-Aeronian) in central (Burnt Jam Brook Formation) and northern (Sources and Awantjish formations) Gaspé.

In the Port-Daniel to New Richmond area, the lower assemblage records a large scale, 2nd order shallowing event that was initiated in the underlying Honorat and Matapedia groups. The lower assemblage begins with below fair-weather wave base but above storm wave base fine-grained clastics of the Clemville Formation (Bourque, 2001). This unit is abruptly overlain by the peritidal and mineralogically impure, coarse grained sandstone and conglomerate with subordinate mudstone of the Weir Formation, the abrupt facies change could indicate some tectonic uplift of the Maquereau-Mictaw Inlier, the source of the clasts in the Weir (Bourque and Lachambre, 1980; Bourque, 2001). Finally, the shallowing upward cycle culminate in the nearshore and relatively well-washed quartz and feldspar-rich sandstone of the Anse Cascon Formation.

The lower assemblage in the eastern part of the Chaleurs Bay synclinorium is Llandoverian A to C6 in age; at the western end of the synclinorium, the tripartite succession is coeval with the Mann Formation that consists of shaly fine-grained sandstone and mudstone. In northern Gaspé, the lower siliciclastic assemblage consists of the coeval fine-grained facies of the Sources and Awantjish formations and the shallowing event culminate in the nearshore quartz arenite of the Val Brillant Formation of Llandoverian C6 age.

The coarse-grained sandstones of the lower siliciclastic interval (Weir / Anse Cascon and Val Brillant formations) have hydrocarbon reservoir potential. Lachambre (1987) reported the presence of pore-filling bitumen in some outcrops of the Val Brillant Formation in northern Gaspé and some sandstones of the Anse Cascon Formation are pervasively bitumen-impregnated (D. Brisebois pers. obs.). In a preliminary diagenetic study of sandstones of the Val Brillant Formation, Lavoie and Chi (2002) documented the presence of bitumen in secondary pore space. The secondary porosity resulted from the dissolution of feldspars and other alumino-silicates in the burial environment, remnants of these are found in the secondary pore space. The dissolution event took place after early silica cementation of primary pore space, such cementation occurred at relatively shallow burial depths as indicated by the low homogenization temperatures of the aqueous fluid inclusions in the silica (T_h of <50° for monophase inclusions to 80°C for biphase inclusions), the cementation in the primary pore space occurred in the presence of some hydrocarbons as highly fluorescent HC inclusions are associated with the aqueous ones. This last element is an important fact as it supports the presence of pre-Late Silurian source rock in the area, a conclusion also reached through the study of vein-fill cements in the White Head Formation (see earlier in text) and of HTD in the Sayabec Formation (see further in text).

The secondary porosity event has been related to the circulation of organic acids with early up-dip migration from the dark shaly facies of the deep marine Burnt Jam Brook Formation

(Lavoie and Chi, 2002). This working hypothesis relies on a limited database although, if right, the mineralogically less mature sandstones of the Weir / Anse Cascon formations would represent more interesting targets for secondary dissolution.

Middle limestone assemblage

The middle limestone assemblage in southern Gaspé is represented by the offshore facies of the Anse-à-Pierre-Loiselle and the peritidal ramp carbonate of the La Vieille formations (Bourque *et al.*, 2001a), this assemblage is Llandoverian C6 to early Wenlockian in age (Bourque, 2001); these units form a distinctive limestone assemblage in the Gaspé Belt with the Sayabec and Laforce formations in northern and central Gaspé, respectively. The La Vieille and Sayabec formations consist of peritidal, reefal and various subtidal facies (Lavoie *et al.*, 1992), whereas the Laforce Formation is composed of deeper water sandy lithoclastic calcarenites and calcirudites with abundant fine-grained siliciclastic facies (Lavoie, 1988). In northern New Brunswick, the La Vieille Formation passes westerly to the coeval deeper marine facies of the Limestone Point Formation (Wilson *et al.*, 2004; Lavoie and Chi, 2006).

The type-area of the La Vieille Formation is in the Port Daniel - Gascons area in southern Gaspé Peninsula (Schuchert and Dart, 1926). In Gaspé and northern New Brunswick, the La Vieille Formation typically consists of three units defined as informal members by Desrochers (1981) and Lavoie *et al.* (1992). These consists of 1) a lower nodular, locally highly fossiliferous limestone member of outer shelf origin, 2) a middle well-bedded wackestone to packstone calcarenite of subtidal origin with local algal-metazoan bioherms / biostromes belt that rims a wide spectrum of algal and cryptobacterial facies (laminites, stromatolites, thrombolites and oncolites) of peritidal origin, and 3) an upper nodular, poorly fossiliferous limestone member that records a abrupt and rapid return to outer shelf conditions. A forth member has been recognized at the base of the Sayabec Formation in northern Gaspé, a shallow subtidal to peritidal lower member which stratigraphically corresponds to the Anse-à-Pierre-Loiselle Formation. The coeval La Vieille and Sayabec formations have been interpreted to record the end of the first major regressive event (R1) in the Gaspé belt (Bourque, 2001; Bourque *et al.*, 2001), the upper nodular limestone member marks the base of the first 2nd order transgressive event in the Gaspé depositional basin (Bourque, 2001).

The Sayabec and La Vieille ramps consisted of four parallel depositional belts (Lavoie *et al.*, 1992). These are, from nearshore to offshore: (1) a wide peritidal mud flat dominated by microbial communities (laminites, stromatolites, thrombolites); (2) a narrow knob reef rim built by a consortium of skeletal metazoans (corals, bryozoans, stromatoporoids), skeletal calcareous algae and microbial communities; (3) a well-sorted lime sand belt and; (4) a deeper water nodular mud belt with the latter forming the lower and upper nodular limestone members.

At number of localities both in northern and southern Gaspé and northern New Brunswick (Lachambre, 1987; Lavoie and Bourque, 1993; Bourque *et al.*, 2001a; Lavoie and Morin, 2004; Lavoie and Chi, 2006), the lower Silurian carbonate ramps have been sub-aerially exhumed and eroded. This event affected the successions on paleotopographic highs and is related to the combined effects of the Late Silurian Salinic global sea level lowstand and tectonic activity.

Evidence for the meteoric event are multiple and range from map relationships to red clastic infills of solution pipes and fractures (Figure 25) to petrographic and stable isotope evidence (Lavoie and Bourque, 1993; Lavoie and Morin, 2004; Lavoie and Chi, 2006). The significance of that subaerial event in constraining the timing of hydrothermal dolomitization and initial hydrocarbon charge will be discussed further.

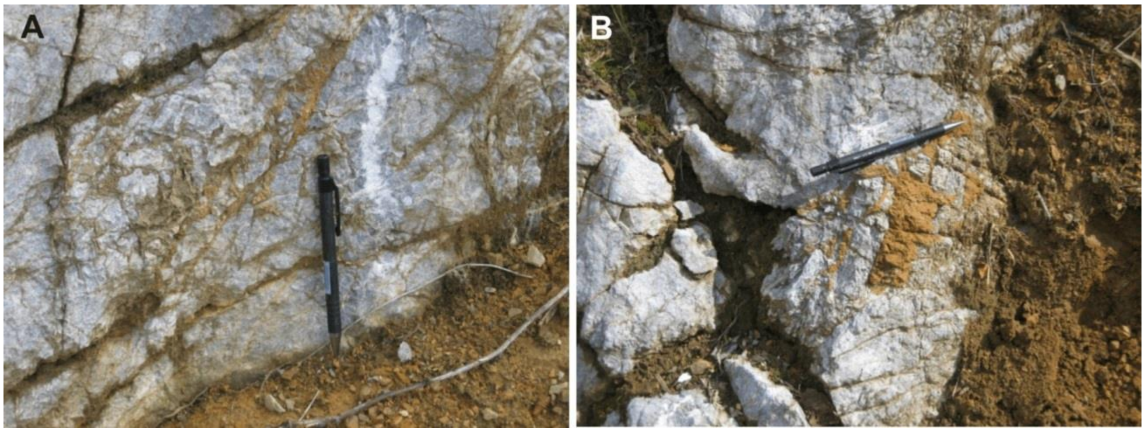


Figure 25. A and B) Solution pipes and cavities filled by orange silt. Dissolution in limestones of the La Vieille Formation in a quarry at l'Alverne in southern Gaspé.

Diagenetic evolution of the Lower Silurian carbonates and reservoir potential

The general diagenetic evolution of the Sayabec and La Vieille formations is characterized by little marine cementation followed by burial (Lavoie, 1988; Lavoie and Bourque, 1993; Lavoie and Chi, 2001). Initially recognized by Lachambre (1987), Lavoie and Chi (2001; 2006; 2010) and Lavoie and Morin (2004) documented an important hydrothermal dolomitization event that consists of pervasive dolomitization of the shallow marine (peritidal to shallow subtidal) facies. The dolomitization also occurs in fractured and locally highly brecciated zones and is associated with abundant pore-filling coarse-grained saddle dolomite. Petrographic examination of the dolomites has revealed that dolomitization was a relatively early process and occurred before the Late Silurian subaerial exposure and alteration (partial dissolution and meteoric calcite cementation) of the carbonate ramp (Lavoie and Morin, 2004; Lavoie and Chi, 2006, 2010). The geochemical signatures of the dolomites indicate the presence of high temperature and very saline (21 to 24 wt% $NaCl_{equiv}$) fluids at the time of replacement and/or precipitation. The homogenization temperature (T_h) of the fluid inclusions in the dolomites range from 111°C to 218°C (Lavoie and Chi, 2001 and 2010) and the associated $\delta^{18}O_{PDB}$ ratios of the dolomites range from little to strongly ^{18}O-depleted (−6.3 to −17.3‰). The paired T_h and $\delta^{18}O_{PDB}$ values from individual analysis indicate that the fluids responsible for the dolomitization were enriched in ^{18}O (Lavoie and Chi, 2010). The $\delta^{18}O_{SMOW}$ values for the Silurian fluids were significantly more enriched in ^{18}O compared to the fluids responsible for the dolomitization of the Ordovician carbonates in Anticosti and western New York.

The hydrothermally-altered carbonates in northern Gaspé and northern New Brunswick host abundant bitumen in the stratiform dolomite intercrystalline pore space as well as in the dolomitic breccia. The hydrocarbon migrated in the secondary pore space prior to the late Silurian sub-aerial exposure of the carbonate ramps as bitumen precedes meteoric calcite in pore space (Lavoie and Morin, 2004; Lavoie and Chi, 2006). This relationship is another argument to support the presence of pre-Late Silurian hydrocarbon source rock in the area.

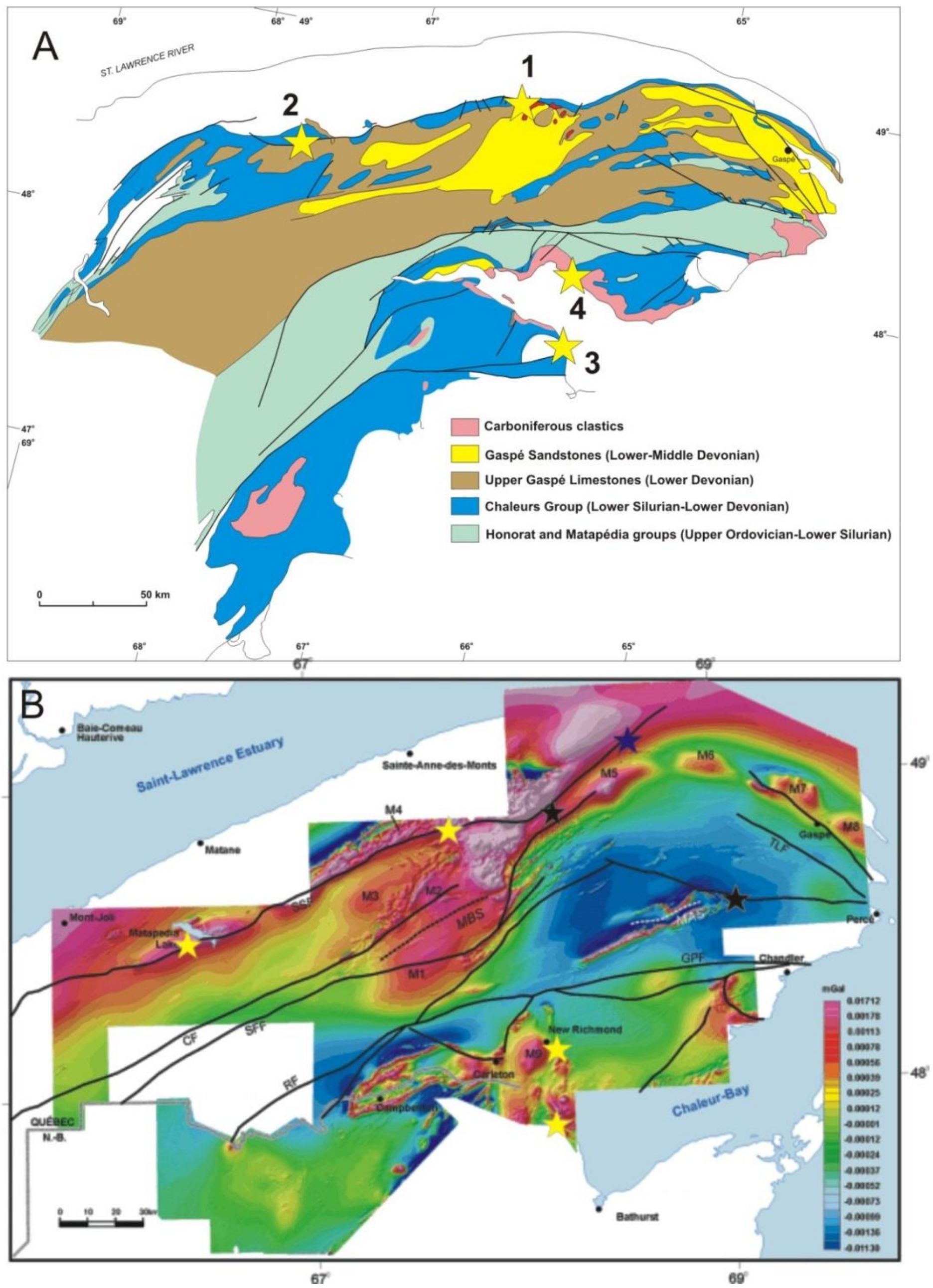


Figure 26. Figure A) Simplified geological map of Gaspé and Northern New Brunswick with the location of four HTD localities (yellow stars) in the Lower Silurian carbonates. Modified from Bourque *et al.* (2001). B) Map of the residual magnetic field for the Gaspé Peninsula and the location of the HTD localities. All are

associated with magnetic and gravity (not shown) highs related to Ordovician ultramafics and mafic volcanics (Lavoie and Pinet, 2008; Lavoie and Chi, 2010). Modified from Pinet *et al.* (2005).

Upper siliciclastic assemblage

The upper siliciclastic assemblage is dominated by the fine-grained siliciclastic facies of the Saint-Léon Formation and its lateral equivalent Gascons and Indian Point formations (Bourque, 1975; Bourque *et al.*, 2001a). Facies of the three formations are very similar and loosely interpreted as pro-delta to deep clastic shelf deposits; their recognition is based on a nomenclature framework that suggests the term Saint-Léon Formation should be used where Upper Silurian-Lower Devonian reef and limestone facies of the West Point Formation are absent whereas the fine-grained clastics should be designated as the Gascons and Indian Point formations where they underlie and overlie West Point reef limestone, respectively (Bourque, 1975). This upper interval ranges from the upper Wenlockian to the lower Lochkovian, and the succession results from the second 2nd order regressive phase (R2) and the early phase of the following 2nd order sea level rise (T2) (Figure 24) (Bourque *et al.*, 2001a).

The Salinic unconformity (Boucot, 1962; Malo and Bourque, 1993) is developed between R2 and T2 (Figure 24). This unconformity is not present over the entire peninsula and has been recognized at some localities in northern (Lachambre, 1987; Lavoie and Bourque, 1993), western (Dansereau and Bourque, 2001; Lavoie and Morin, 2004) and southern Gaspé (Bourque and Lachambre, 1980; Lavoie and Bourque, 1993; Bourque *et al.*, 2001a). Rocks younger than Ludlovian have never been found below the unconformity, and beds above the unconformity are no older than Pridolian, therefore constraining the age of the peak of this event as Ludlovian-Pridolian. Detailed mapping in northeastern Gaspé has shown that the Salinic and Taconian unconformities are locally merged into one surface (Lachambre, 1987; Bourque *et al.*, 2001a). At some places in northern and central Gaspé, the Salinic unconformity is marked by conglomerates in the upper siliciclastic assemblage. A conglomerate assigned to the Griffon Cove River Member (West Point Formation) marks the Salinic unconformity in northeastern Gaspé (Bourque, 2001). The conglomerate is composed of pebbles and cobbles of quartz, chert, mafic and felsic volcanic rocks, various sedimentary rocks and, in places, stromatoporoid clasts.

The West Point reef facies

Ludlovian to lower Lochkovian carbonate platforms and reefs are found in the upper siliciclastic assemblage; these very diverse carbonates belong to the West Point Formation. The type area for the West Point Formation is the Chaleurs Bay synclinorium, where it reaches thicknesses of nearly 800 m (Bourque *et al.*, 1986; Bourque *et al.*, 2001). In southern Gaspé, the West Point Formation is Late Silurian in age and is composed of three superposed complexes (Bourque *et al.*, 1986; Bourque, 2001) (Figure 27) from base to top: 1) a deep marine sponge mound (Gros Morne Member) evolving into a shallow marine microbial reef (Anse-à-la-Barbe Member) with fore reef debrites, 2) a shallow marine crinoidal-stromatoroid bank (Anse McInnes Member) with a conglomeratic fore-bank facies and 3) a laterally well zoned reef platform with i) a narrow stromatoporoid reef margin (Colline Daniel Member) passing to ii) a subtidal lagoon (Sandy Cove Member) with abundant patch reefs to iii) a nearshore continental red bed facies (Plage Woodmans Member) consisting of stromatoporoid rubbles, microbial laminites and mudcracked red beds (an assemblage correlated with the Griffon Cove River Member in northern Gaspé; Bourque, 2001). The upper reef complex shares strong similarities in facies architecture with the famous Middle and Late Devonian reefs of the western Canada sedimentary basin (Bourque and Amyot, 1989).

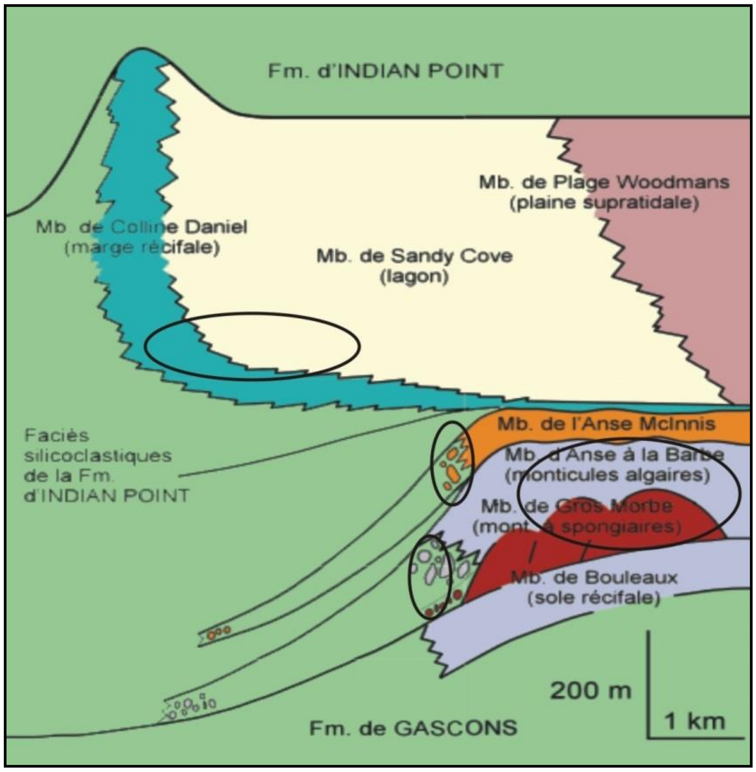


Figure 27. The three reef complex stratigraphic model for the Upper Silurian West Point Formation from the decades of work by Pierre-André Bourque (see Bourque, 2001). In this trip, stops to be visited are circled. See text for details.

The lower and middle reef complexes were formed near the end of the major 2nd order sea level fall that ultimately resulted in the Salinic unconformity. At a finer scale, higher order sea level fluctuations are recorded in these carbonates and controlled the local facies architecture (Bourque *et al.*, 1986; Bourque, 2001). The upper reef complex was developed at the onset of the rapid sea level rise that followed the Salinic subaerial exposure; this 2nd order sea level rise (T2 of Bourque *et al.*, 2001a; Figure 24) resulted from combined eustatic sea level rise and tectonic collapse of fault-bounded blocks in the depositional basin (Bourque *et al.*, 2001a; Bourque, 2001). In the early stages of T2, the stromatoporoids and other metazoan built a 600 meters high reef margin (Colline Daniel Member) in a short interval during the 3 Ma long Pridolian. This construction testifies to the high construction potential of metazoan reefs and to significant tectonic foundering of the margin in order to create such accommodation space in a limited time. Ultimately for facies preserved in the Chaleurs Bay synclinorium, the reef complex was unable to keep pace with rising sea level and the Upper Silurian West Point reef construction ended in Late Pridolian time; carbonates were drowned below deep marine fine grained siliciclastics of the Indian Point Formation (Bourque *et al.*, 2001a; Bourque, 2001).

In northern Gaspé, a reef margin extended into the Lochkovian; these lowermost Devonian reef facies are strikingly different from the Silurian ones. They are made up of two main facies: a shallow water well-bedded crinoidal limestone and massive stromatoporoid pinnacle reef. A number of pinnacle reefs reaching thicknesses of 300 m with km-sized bases are known in northern Gaspé (Bourque, 2001). The Lochkovian pinnacles developed on paleotopographic highs left by the Salinian erosion (Bourque, 2001). The West Point pinnacle reefs are similar in size and overall setting with the Upper Devonian “Leduc” type pinnacles in the western Canada sedimentary basin.

Based on decades of detailed field work by Pierre-André Bourque and his students, a model for reef settlement has emerged (Bourque, 2001). The reef margins of the Upper Silurian and lowermost Devonian carbonate complexes of the West Point Formation were established on paleotopographic highs at the faulted margins of paleotectonic blocks in the depositional basin. This model has major implications for the hydrocarbon prospectivity of the carbonates as the thick reef margin is located near potential conduits fluid circulation (Bourque, 2001).

Diagenetic evolution of West Point carbonates and reservoir potential

The diagenetic history of the Silurian West Point reefs in southern Gaspé allowed proposing an evolution of the pore space within the reefal facies (Savard and Bourque, 1989; Bourque *et al.*, 2001b); the study also led to the identification of a major meteoric diagenesis imprint on the lower and middle reef complexes. The available field sections of the Silurian West Point Formation in southern Gaspé do not show any visible primary or secondary pore space although from the detailed diagenetic study, up to 8% of the primary pore space was still open at the onset of deep burial (after physical compaction) (Bourque *et al.*, 2001b). Even if saddle dolomite is found as a late element in the paragenetic succession (Savard and Bourque, 1989), nowhere in southern Gaspé does dolomite form any significant part of the field section of the Silurian West Point. However, it is noteworthy that in central Gaspé, dolomitized sections of the Silurian West Point are recognized (Bourque, 1977; Lavoie, 2007), the origin of the dolomite is currently under investigations (Lavoie and Chi, work in progress).

Previous studies of the diagenetic evolution on the Devonian pinnacle reefs in northern Gaspé have revealed that late calcite phases precipitated out of a high temperature fluid with elevated $\delta^{18}O_{SMOW}$ values ranging between +4 to +8l (Bourque *et al.*, 2001b). Such isotopically heavy fluids are common in hydrothermal systems and have been recognized in the hydrothermal dolomites of the Lower Silurian succession in the Gaspé Belt. The late calcite phases are locally host to abundant oil and other light hydrocarbon fluid inclusions (Bourque *et al.*, 2001a). Evidence for massive dolomitization affecting a Lower Devonian pinnacle were presented (Lavoie, 2006; Lavoie *et al.*, 2010). The dolomitized pinnacle is located near the junction between two major dextral strike-slips faults in northern Gaspé, the Shickshock Sud and the

Rivière Madeleine Sud faults. Extensive dolomitization occurs over 10 meters wide by 100 meters long zone oriented N85°. Locally, dolomite fills small transtensional structures which suggest that the dolomitization occurred at a time of lateral movement along the fault system. The dolomite consists of fabric-destructive, replacement matrix and saddle dolomites. The $\delta^{18}O_{PDB}$ ratios of the dolomite range between −15.8 to −19.1l whereas $\delta^{13}C_{PDB}$ ratios range between −1.4 to −7.9l; these anomalously depleted ratios are indicative of significant involvement of exotic fluids in the diagenetic system. Fluid inclusions data indicate that two events of saddle dolomites are recognized, an early one with T_h values over 350°C and a late one with T_h lower than 175°C (Lavoie *et al.*, 2010).

9.2.1.f. Units Related to the Gaspé Sandstones Group in the Ristigouche Syncline (Miguasha Museum stop)

The core of the Ristigouche Syncline in western Chaleurs Bay is occupied by a sequence of Emsian to Frasnian terrestrial rocks, overlying the mafic to intermediate volcanic rocks of the Lower Devonian Dalhousie Formation. The sequence is composed of four conglomerate units (Alcock, 1935; Williams and Dinely, 1966; Zaitlin and Rust, 1983): 1) the Lagarde conglomerate, composed of thick-bedded, well-rounded pebble and cobble conglomerate interlayered with grey or greenish grey, coarse to fine-grained, crossbedded sandstone and lesser mudstone; 2) the Pirate Cove conglomerate, consisting predominantly of red and grey sandy siltstone and mudstone with lenses of channelled sandstone, and subsidiary limestone conglomerate with clasts derived predominantly from the Matapédia Group exposed to the north; 3) the Fleurant conglomerate, a grey, well-rounded pebble and cobble sandy conglomerate, whose clasts are dominantly limestone, with lesser amounts of volcanics and sandstone, and minor plutonic rocks; and 4) the Escuminac conglomerate, composed of greenish grey, thin to thick-bedded sandstone, siltstone and varve-like mudstone, with abundant sole marks, parallel lamination, current ripples, and fossil fish and plants (e.g., Miguasha fossil locality).

Several authors have suggested a correlation between the Devonian Gaspé Sandstones of eastern Gaspé and those in the Ristigouche syncline. The Battery Point and the Lagarde formations appear to be of similar age, and of approximately similar lithology. The Lagarde is predominantly an alluvial deposit, hence is broadly similar to the Battery Point. The Malbaie Formation and Pirate Cove conglomerate are also similar in age and superficially similar in lithology, both containing limestone pebble conglomerate. However, mudcracks are essentially absent from the Malbaie Formation, but abundant in the Pirate Cove Formation. The locally variable lithology in the Pirate Cove conglomerate suggests alluvial fan deposition, whereas the internal consistency of the Malbaie Formation indicates deposition on a broad, uniform braidplain (Rust, 1989).

No equivalents of the Giventian-Frasnian Fleurant and Escuminac formations exist in eastern Gaspé. However, the age of the Fleurant Formation is not well established. The unit is homogeneous lithologically, which, together with the abundant horizontally stratified conglomerate, high angle imbrication and the absence of muddy matrix-supported conglomerate, indicates deposition on a proximal gravelly braidplain (Zaitlin, 1981). In terms of facies abundance, it is more like the Malbaie Formation rather than the Pirate Cove Formation (Rust, 1989). The clast composition of the Fleurant is also like that of the Malbaie Formation although limestone lithology is less abundant.

According to Hesse and Sawh (1982, 1989) the sedimentary structures of the Escuminac sandstone suggest deposition by sediment gravity flows. Flute casts, groove casts, brush and prod casts, rill-casts that bifurcate downstream, and squamiform load casts are abundant. Paleocurrent directions indicate west-southwest flow. Most authors have interpreted the Escuminac Formation as a lacustrine deposit (Dineley and Williams, 1986a, b; Carroll *et al.*, 1972; Hesse and Sawh, 1982), based on its close association with other continental deposits and on its fauna. However, the fauna contains elements that have also been described from brackish or marine environments (Schultze, in Carroll *et al.*, 1972). More recently, Chidiac (1996) suggested deposition in a setting that had a salinity transitional between lacustrine and truly marine conditions, based on isotope geochemistry.

9.3. Northern Gaspé Belt - Connecticut Valley-Gaspé synclinorium

The Connecticut Valley - Gaspé Synclinorium lies between the Cambrian-Ordovician Taconian allochthons to the north, and the Middle Ordovician - earliest Silurian Aroostook-Percé anticlinorium to the south (Bourque *et al.*, 1995). The Connecticut Valley - Gaspé synclinorium is an Acadian (Middle Devonian) structure (Malo and Béland, 1989) dissected by a number of faults. In eastern Gaspé Peninsula, the Bassin Nord-Ouest and Troisième Lac faults are strike-slip structures with dextral displacements between 7 and 8 km (Brisebois, 1981; Kirkwood, 1989). These structures are reactivated normal listric faults that were active in Early Devonian time (Roksandic and Granger, 1981; Bourque, 1990; Lavoie, 1992a; Malo and Bourque, 1993; Bourque, 2001; Malo, 2001; Pinet *et al*., 2008; Pinet, 2013).

9.3.1. Basement of the northern Gaspé Belt

Cambrian-Ordovician rocks of the Humber Zone cropping out north of the Gaspé Belt constitutes the most obvious basement of the Gaspé Belt in northern Gaspé, however some inliers along the Shickshock Sud and the Bassin Nord-Ouest faults exhibits more complex relationship with Ordovician rocks, not always correlative with rocks of the Humber Zones to the north. In northwestern Gaspé Peninsula, the La Rédemption Complex is comprised of two rock assemblages: ultramafic rocks in the western part of the complex, and metasedimentary and metavolcanic rocks in the eastern part (Sacks *et al.*, 2004). Ultramafic rocks consist of harzburgite, serpentinite, and minor gabbros. Metasedimentary rocks consist of mudrock, arkosic sandstone, and greywacke. These rocks with the basalt are all metamorphosed at amphibolite grade and are very similar to those at the southern edge of the Shickshock Group. Mylonitic textures are also found in amphibolitic rocks of the La Rédemption Complex close to the Shickshock Sud fault. Geochemical composition (impoverished light rare-earth elements) of metabasalts (M. Malo, unpublished data) suggests a correlation with sub-alkaline to tholeiitic basalts of the Shickshock Group in the Mont Logan nappe (Camiré *et al.*, 1995). Further east along the Shickshock Sud fault (

Figure 4), the Ruisseau Isabelle mélange is composed of Ordovician sedimentary rock assemblages (Lower Ordovician Composite Shale, Upper Ordovician Black Shale, and Middle Ordovician Chromite-Bearing Sandstone assemblages), a Cambrian exotic block, an Ordovician Pebbly Mudstone assemblage and slivers of Ordovician serpentinized peridotite, and Cambrian metamorphic tectonite (Malo *et al.*, 2001). These various units are all in fault contact with each other. The Ruisseau Isabelle Mélange is interpreted as a tectonic mélange which was formed during several episodes of faulting between Late Ordovician and Middle Devonian times (Malo *et al.*, 2001). The Blach Shale unit of the mélange is a good source rock with TOC ranging between 1.59 to 2.73% (Roy, 2004).

The Mont Serpentine inlier, along the Bassin Nord-Ouest fault (Figure 23), comprises an ophiolitic mélange of serpentinites, metamorphic arkoses, metabasalts and amphibolitized gabbros (the Lady Step Complex; Berger and Ramsay, 1993).

9.3.1.a. The Upper Gaspé Limestones Group (UGL) (Stop 2.3).

The UGL conformably overlie the Chaleurs Group of Early Silurian (Llandoverian) - Early Devonian (Lochkovian) age (Bourque *et al.*, 2001a). The UGL are conformably overlain by the late Early Devonian (Emsian) - early Middle Devonian (Eifelian) Gaspé Sandstones (Bourque *et al.*, 2001a). In central Gaspé, the UGL are laterally equivalent to the siliciclastics of the Fortin Group, likely deposited below storm-wave base (Lavoie, 1992a). The UGL constitute one of the rare carbonate units in the otherwise siliciclastic-dominated post-Taconian succession (Bourque *et al.*, 1995). These carbonates accumulated during a sea-level highstand of a 20 Ma-long transgressive-regressive cycle (Lavoie, 1993) comprised of three tectonically-controlled 3rd order cycles in which higher-order cyclic sedimentation is statistically (Achab *et al.*, 1997; Mussard and Lavoie, 1997) documented.

The Forillon Peninsula, at the eastern end of the Gaspé Peninsula (Figure 1), is the type area of the UGL where a three-fold division into Forillon, Shiphead and Indian Cove formations was proposed by Lespérance (1980a, 1980b). These lithostratigraphic units are recognized over much of eastern Gaspé. However, south of the Bassin Nord-Ouest fault, the succession is thicker and represented almost exclusively by a monotonous succession of lime mudstones and wackestones. Farther south, southwest of the Troisième Lac fault, the UGL consist of an even thicker interval of impure limestones with abundant rotational and translational slide structures (Rouillard, 1986; Lavoie, 1990, 1992b; Lavoie *et al.*, 1990, 1991). Based on sedimentological analysis, three paleogeographical domains delineated by the Bassin Nord-Ouest and Troisième Lac faults are recognized, from northeast to southwest: 1) a northeastern proximal outer shelf, 2) a central, gently sloping, distal outer shelf, and 3) a southwestern slope / toe of slope. It has been suggested that active faulting played a key role in controlling Late Silurian - Early Devonian deposition in the eastern part of the Gaspé Belt (Amyot, 1984; Lavoie, 1992a; Malo and Bourque, 1993; Achab *et al.*, 1997; Bourque, 2001; Lavoie, 2008). The proximal outer shelf is the shallowest depositional environment preserved on the Gaspé Peninsula in Pragian time (Lavoie, 1992b). There is also a significant southward increase in thickness of the unit, from an average of 500 meters for the northern proximal outer shelf up to nearly 2 kilometers in the southernmost toe-of-slope depositional belt (Lavoie, 1992a).

In the area north of the Bassin Nord-Ouest fault, the Forillon Formation is divided in two members: the Mont Saint-Alban and the Cap Gaspé members (Lavoie *et al.*, 1990). The Mont Saint-Alban Member consists of siliciclastic mudstone in 3 to 50 cm-thick beds with rare shaly lime mudstone and wackestone. The mudstones are poorly fossiliferous with the exception of a few trilobites and brachiopods indicative of a Lochkovian age (Lespérance, 1980a, 1980b; Bourque *et al.*, 1995). The Cap Gaspé Member consists of wavy-bedded lime mudstone and wackestone in 5 to 50 cm-thick beds. These carbonates are either slightly (diffuse silica) or pervasively silicified. The wackestone displays a well-preserved macrofauna with particularly abundant trilobites and brachiopods of the *Rennselaeria* (Lower Devonian) Zone (Lespérance and Sheehan, 1975; Lespérance, 1980a, 1980b). Scattered packstone beds less than 50 cm-thick also occur. South of the Bassin Nord-Ouest fault, the formation consists of a thick succession of argillaceous lime mudstone (5 to 15 cm-thick beds) with thin shale partings.

North of the Bassin Nord-Ouest fault, the Shiphead Formation is a heterogeneous unit of interbedded impure carbonates (85%), fine- to coarse-grained siliciclastics (10%), and bentonitic clays (5%). Carbonates occur in beds up to 50 cm-thick. They are comprised of silty lime mudstone and wackestone. The macrofauna is similar to that of the Cap Gaspé Member. Sandy packstone / grainstone interfinger with the lime mudstone / wackestone in the upper meters of the unit. South of the Bassin Nord-Ouest fault, the formation consists of a succession similar to that of the Forillon Formation, although significantly more argillaceous and silty.

In the northern domain, the Indian Cove Formation is comprised of siliceous to cherty lime mudstone and wackestone in wavy beds of 10 to 35 cm-thick. The silicified carbonates are interbedded with less than 20% of cm-thick layers of shaly mudstone that are commonly silicified. The wackestone contains an abundant fauna dominated by trilobites and brachiopods with species of the *Etymothyris* (Emsian) Zone in the uppermost part of the formation (Lespérance, 1980a, 1980b). Significant volume (20% of the unit) of cement- and allochem-rich, packstone and grainstone beds (15 to 45 cm-thick) are found in the upper half of the unit. South of the Bassin Nord-Ouest fault, the formation consists of a well-bedded succession of locally siliceous lime mudstone and wackestone (5 to 20 cm-thick) with thin shale partings.

Volcanic rocks are present within the Upper Gaspé Limestones in west-central Gaspé (Lavoie *et al.*, 1991; Lavoie, 1995b). Rhyolitic flows and felsic volcaniclastics occur within the Shiphead Formation, whereas mafic tuffs, flow breccia, hyaloclastics, and massive to pillowed basaltic flows are present in the upper part of the Indian Cove Formation.

9.3.1.b. Fortin Group

The Fortin Group form thick, monotonous, largely unfossiliferous, well-bedded sequences of dark siltstone and shale with intercalated sandstone-rich intervals and minor volcanics (Kirkwood and St-Julien, 1987; Hesse and Dalton, 1989, 1995). Although the rocks below the Fortin are unknown, it is more likely that the group lies conformably on the fine-grained siliciclastics of the Chaleurs Group (Bourque *et al.*, 1995). Hesse and Dalton (1989, 1995) recognized seven turbiditic lithofacies in the Fortin along the Matapédia River Valley, which they interpreted as submarine overbank and channel-fill deposits form the base-of-the-slope to deep-basin settings.

Relationships between Fortin and Upper Gaspé Limestones assemblages are known only in the eastern part of the Gaspé Belt. Elsewhere, they are in fault contact (Gastonguay, Sainte-Florence, or Témiscouata faults, Figure 1). Along the north-south transect from the Forillon Peninsula area to the Grande Rivière Fault in the eastern part of the Gaspé Belt, Lavoie (1992a and 1992b) showed that the lateral transition of the threefold Upper Gaspé Limestones to the Fortin represent a transition from a storm-influenced carbonate shelf in the north, to a distal outer shelf with significant thickening of the limestone sequence, homogenization of the lithofacies, and disappearance of the storm layers, and finally to a tectonically active distal slope, or toe of a slope, where the Upper Gaspé Limestones interfinger with the Fortin siliciclastic facies in the south.

9.3.1.c. Gaspé Sandstones Group (Stop 2.4)

The Gaspé Sandstones Group occupies roughly the northern half of the Gaspé Belt (Figure 23). To the south, it is replaced by the Fortin succession. The group is composed of four rock assemblages: 1) a lower transitional unit (York Lake) composed of alternating siliceous calcilutites with minor quartz arenites and wackes, like those of the underlying Upper Gaspé Limestones Group, and greenish grey, medium-grained, feldspathic wackes, similar to those of the overlying sandstones (York River); 2) an overlying sequence (York River) that coarsens upwards from a mudstone-siltstone-sandstone assemblage, to an upper, thick-bedded sandstone with large-scale crossbedding and minor mudstone; 3) a sequence (Battery Point) of conglomeratic sandstone, medium to coarse-grained sandstone, and minor siltstone and mudstone overlain by a redbed unit of sandstone, siltstone and mudstone (Rust, 1981; Walker and Cant, 1979; Cant and Walker, 1976); 4) an upper sequence (Malbaie) of thick-bedded conglomerate composed of pebbles and cobbles of limestone, siliciclastic and volcanic fragments derived from the older Matapedia and Chaleurs groups, and interbedded with medium to coarse-grained red sandstone (Rust, 1976, 1981). The Malbaie is unconformably overlain by Carboniferous rocks.

In the Forillon-Percé area, the transitional York Lake is absent. In the Big Berry Mountains Syncline area (Figure 23), the Gaspé Sandstones Group shows roughly the same stratigraphic succession as in northeastern Gaspé Peninsula area, except for the following: the occurrence of a thick unit of unfossiliferous red to brownish red shale with siltstone and fine-grained sandstone, and sparse mudcrack and ripple marks (Lake Branch) between the York River and the Battery Point formations, and the absence of the Malbaie conglomerate on top of the sequence. The York Lake and York River formations are nearly the same in the norteastern Gaspé Peninsula, except that they contain thick, bimodal volcanic sequences, each consisting of basal basaltic flows and mafin pyroclastics, overlain by rhyolitic flows and felsic pyroclastics, and capped by rhyolitic flows (Doyon and Valiquette, 1991; Doyon, 1988).

The Gaspé Sandstones Group corresponds to an abrupt shoaling event, from shallow marine facies to terrestrial facies. The transition from the deep water facies of the Upper Gaspé Limestones to the shallow water sands of the Gaspé Sandstones is gradational (York Lake), except in the Forillon-Percé area, where it is abrupt (York River). The York Lake and York River formations contain marine fauna, and a deltaic or estuarine environment was postulated for the York River Formation (Mason, 1971; Sikander, 1975; Lawrence, 1986; Desbiens, 1992).

The overlying Battery Point Formation contains a lower, distal, braided stream deposit and interbedded marine deposits (Cant and Walker, 1976), and an overlying meandering river system associated with playa or ephemeral lake deposits (Rust, 1981), The overlying Malbaie is interpreted as a proximal braided plain deposit (Rust, 1981).

DAY 1

CAMBRIAN-ORDOVICIAN ROCK SEQUENCE IN THE BAS-DU-FLEUVE REGION – QUÉBEC TO MATANE

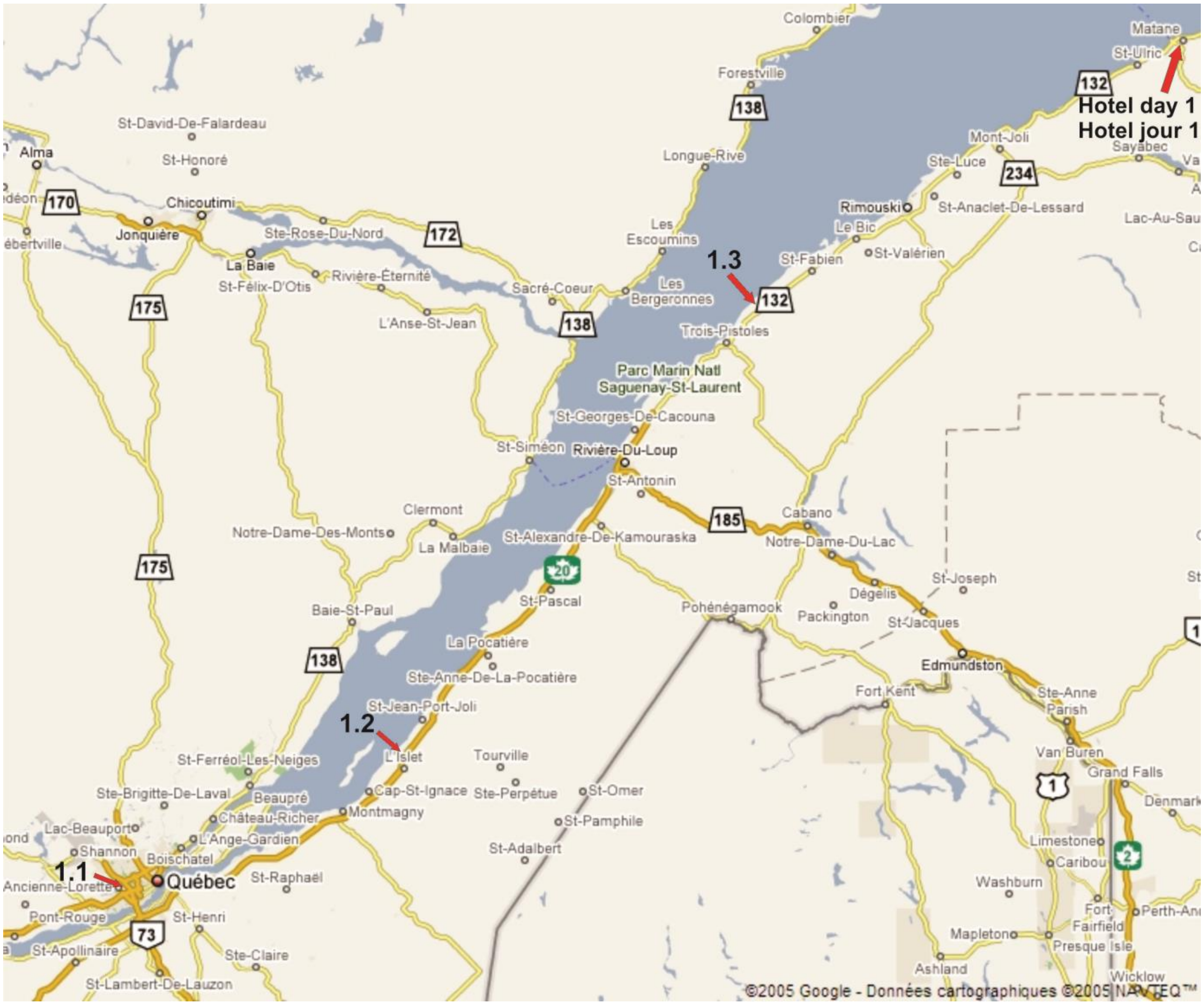


Figure 28. Location of stops for DAY 1 of fieldtrip.

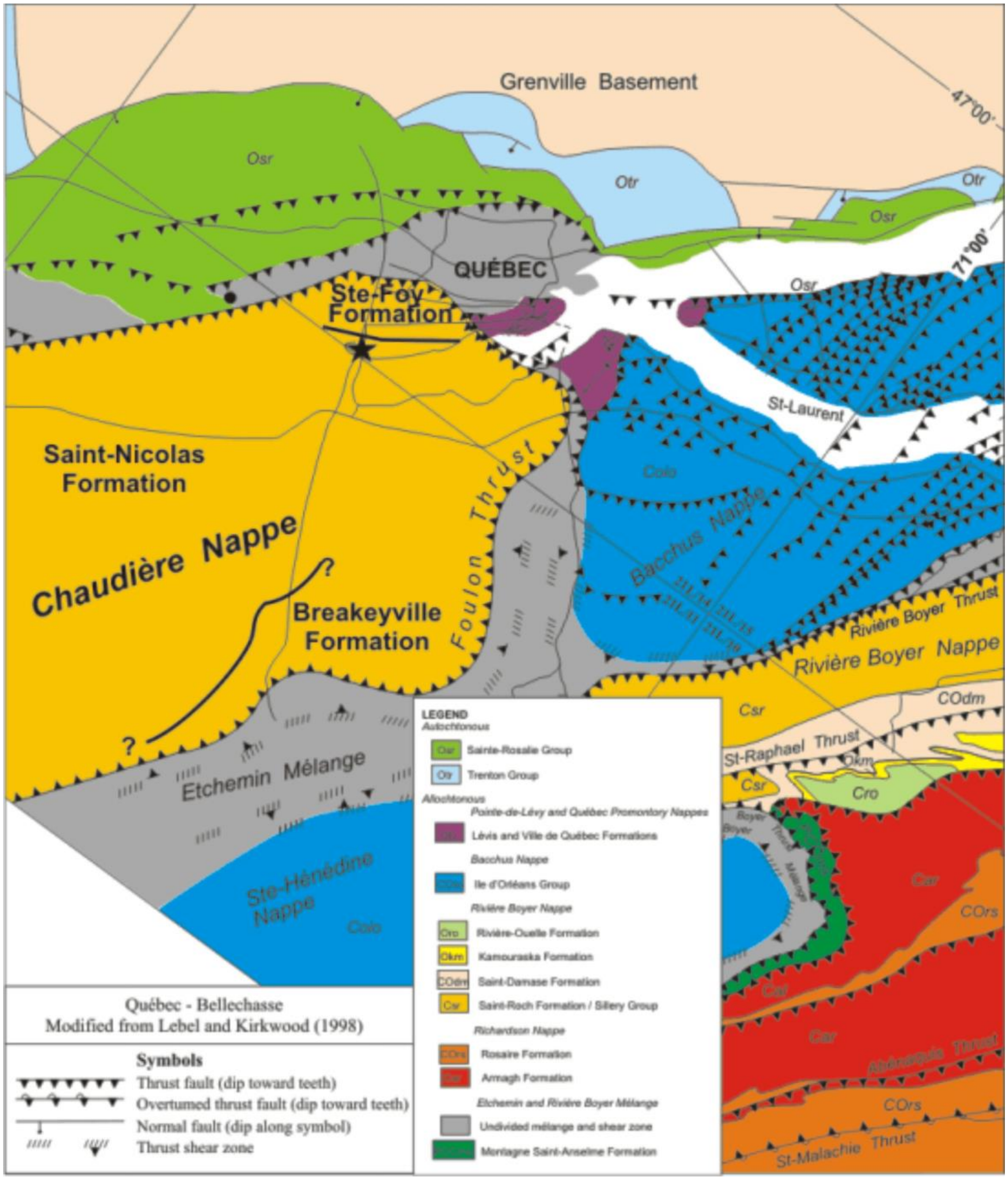
STOP 1.1. - Cambrian sandstone, Saint-Nicolas Formation – Québec City – Pont Laporte

Location: Just before taking the Laporte bridge, take the exit towards Champlain Boulevard. At the trafic light, go straight ahead, you enter CN private land. Follow the road that goes under the passover, the road cut is one kilometer away (Figure).

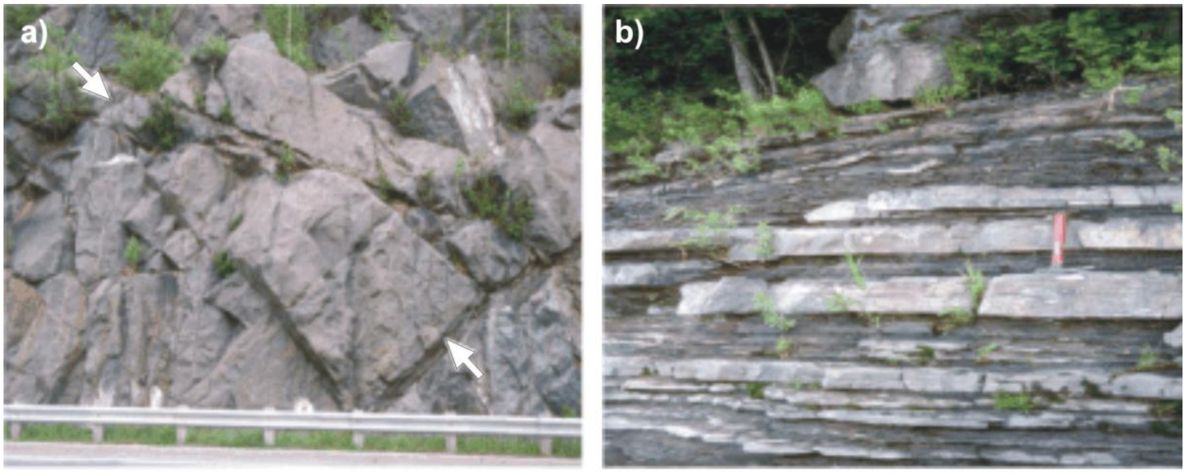
The Chaudière thrust sheet is limited to the north by Logan's Line and associated melange units and to the south, by the Foulon Fault (Stop figure 1.1.1). Sedimentary units of the Chaudière thrust sheet form the Sillery Group which consists of the Sainte-Foy, the Saint-Nicolas and the Breakeyville formations. The biostratigraphic information suggests that the Saint-Nicolas Formation is of Early Cambrian age. The Sainte-Foy Formation tectonically underlies the Saint-Nicolas Formation; the former consists predominantly of variously-coloured mudstone. The Saint-Nicolas Formation is divided into three units: a lower massive and coarse-grained sandstone, a middle cyclic turbidite and an upper red mudstone. The Breakeyville Formation consists of two units, a lower conglomerate-sandstone and an upper mudstone-sandstone. The Saint-Nicolas and Breakeyville formations are both characterized by fining-upward trends which result from initial marine lowstand followed by transgressive events. Correlation with adjacent stratigraphic frameworks is based on the recognition of the massive lower coarse-grained sandstone unit of the Saint-Nicolas Formation in other successions. This unit is temporally well constrained and correlates with a major sea level lowstand (the Hawke Bay event) recognized along the entire continental margin of Laurentia from western Newfoundland to southern Quebec. This event marks the end of the initial rifting episode and the initiation of the passive margin. The framework also relies on correlation of the lower conglomerate of the Breakeyville with Upper Cambrian conglomerates in eastern Québec.

At this stop, we will examine the coarse-grained facies at the base of the Saint-Nicolas Formation. This lower unit is characterized by massive beds of greenish coarse sandstones and conglomerates with subordinate red and green interbeds. The succession is cyclic (fining and thinning-upward trends) (Stop figure 1.1.2). The sandstone/conglomerate are mineralogically and texturally immature, they are rich in pink and flesh-coloured feldspars and blue quartz are locally common. Locally, small micrite clasts testify for the presence of a carbonate platform at that time. The beds are commonly graded with parallel laminations and dewatering pillar structures. Some open fractures and anticline breccia (Stop figure 1.1.3) show bitumen coatings.

In another section of that unit, the red mudstones are typified by abundant examples of the trace fossil *Oldhamia curvata* which is a key Early Cambrian element, moreover, the brachiopod *Botsfordia pretiosa* is also present in sandstone beds and also suggest an Early Cambrian age. This massive sandstone unit at the base of the Saint-Nicolas Formation is correlated with the "Green Sandstones" unit of the Saint-Roch Group and represents the slope sedimentary record of the major sea level lowstand known as the Hawke Bay Event in Western Newfoundland which, there, is recorded in the slope succession by the Irishtown Formation.



Stop figure 1.1.1. Simplified geological map of the Chaudière Nappe with the location of the stop. Modified from Lebel and Kirkwood (1998).



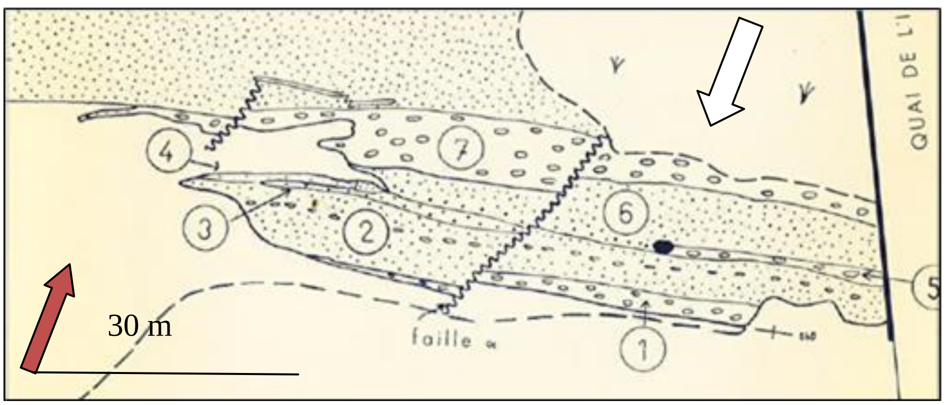
Stop figure 1.1.2. a) Thick beds of immature sandstone/conglomerate at the base of the Saint-Nicolas Formation. These arkosic sandstone beds are also known as the “Green Sandstone” unit and mark the end of the rift episode. b) Well bedded quartoze sandstone and shale of the turbidite unit that overlies the lower massive sandstone interval.

Stop figure 1.1.3. Small anticline in the Green Sandstone unit along the Chaudière River, the nose of the anticline is intensely brecciated with abundant breccia-cemented bitumen.

STOP 1.2. - Cambrian limestone conglomerate, Saint-Roch Group - L’Islet

Location: Trans Canada Highway East. Take exit 400. Take road 285 North to road 132 (~3.9 km). Turn right on road 132 and drive to Chemin du Quai to your left (approx. 1.2 km). Take Chemin du Quai to the parking on the wharf (Figure).

Stop figure 1.2.1. L'Islet Wharf area.The white dashed line shows the outline of the channelized deposits. In yellow, outcrops of limestone conglomerates and conglomeratic feldspathic sandstones; in green, calcareous thin bedded turbidites of the middle unit.

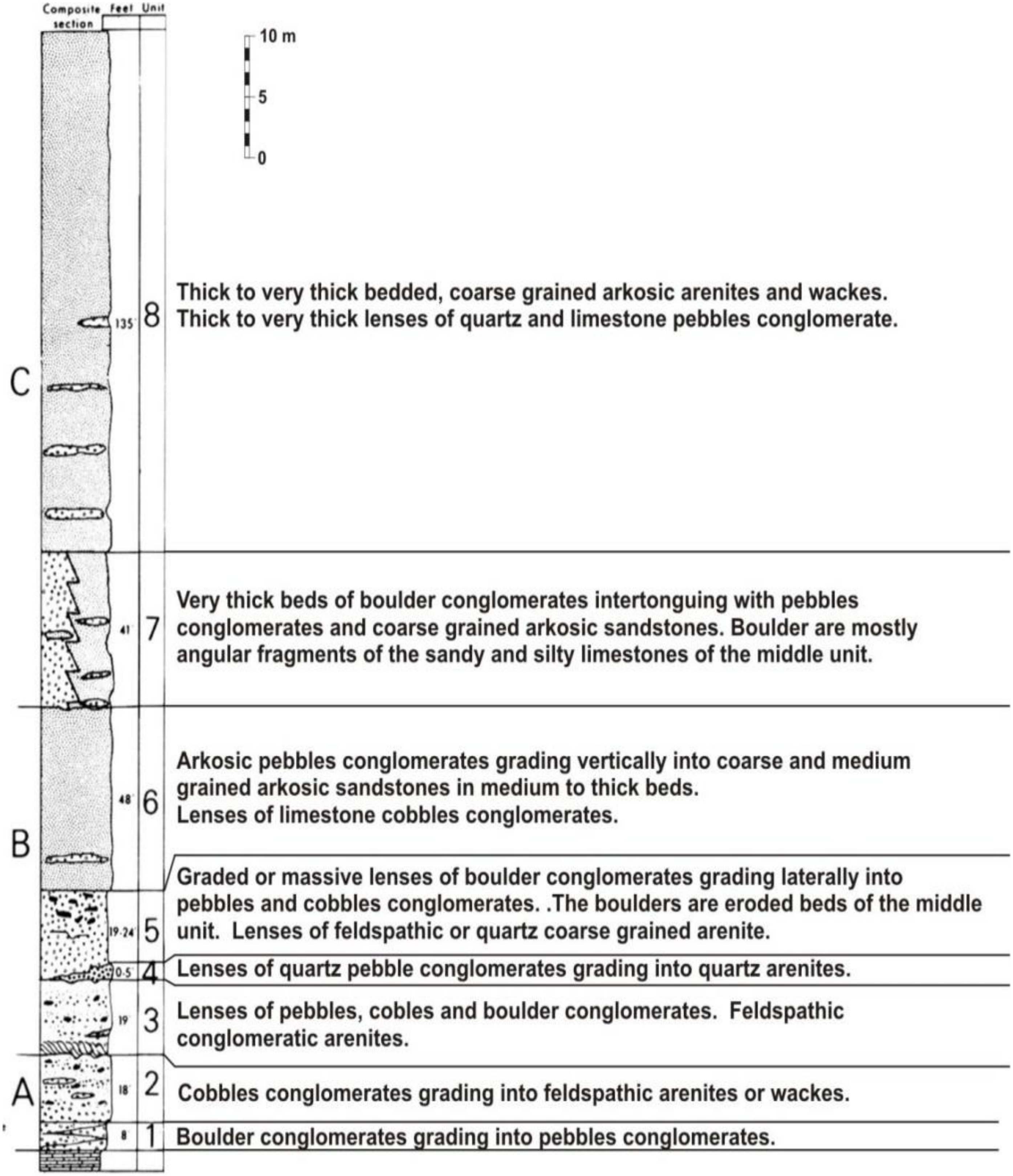


Stop figure 1.2.2. Geological map of the basal part of Quai de l'Islet Member, east of the wharf. Units 1, 5 and 7 are limestone conglomerates; units 2, 4 and 6 are coarse grain, conglomeratic felspathic sandstones; 3 is a cross-bedded sandstone bed. The white arrow indicates the true North and the red arrow indicates the sequence polarity. The black dot is a 1.5m algal limestone boulder. From Brisebois (1972).

The limestone conglomerates and coarse grained feldspathic sandstones exposed at l'Islet wharf are one of numerous channelized deposits or alluvial fans found in the Cambrian deep sea deposits of the Humber zone in the Quebec reentrant. The limestone clasts in the conglomerates are the only witnesses of the limestone platform that covered at least parts of the eastern Quebec Laurentian margin in Cambrian time. The l'Islet Wharf submarine channel deposits, as they are beautifully exposed, show numerous imbricated channels that tend to be broader and thicker up section. The stratigraphy, petrography, and sedimentology of this submarine channel complex have been described among others by Hubert *et al.* (1970), Brisebois (1972), Rocheleau and Lajoie (1974), and Middleton *et al.* (1979).

The exposed section belongs to the lower part of the Lower Cambrian Saint-Roch Group. The age of the coarse deposits is based on Lower Cambrian trilobites and phosphatic brachiopods found in coeval nearby calcarenites. The trilobites are Bolpora canadensis, Calidiscus theokritoffi, and Leptochilodiscus cuspunctulatus (Rasetti, personal communication to Claude Hubert, 1967). East of the wharf, three lithological units were recognized by Hubert *et al.* (1970): a lower, 35 m thick, red mudstones and thin to medium thick-bedded siltstones and fine-grained sandstones showing the b, c and d divisions of the Bouma sequence; a middle, 11 to 99 m thick, unit of sandy and silty calcarenites and calcisiltites in thin to medium thick beds with a to d divisions of the Bouma sequence, interlayered with green and grey shales; an upper unit, and partially lateral equivalent of the middle unit, of conglomerates and coarse grained arkosic sandstones of the channelized complex. The lower unit is lithologically typical of the Saint-Roch Group. The middle unit has a composition similar to the upper one and is considered as the distal submarine-fan equivalent of the channelized conglomerate-sandstone assemblage. The strata are overturned and dip at 60 to 70 degrees to the southwest. The outcrop shows many vertical faults with small displacements. The surface exposure is perpendicular to the axis of the channelized conglomerates.

The third unit, named Quai de l'Islet Member (Brisebois, 1972), is 760 m long and 88 m thick. It is composed of three depositional cycles, each caracterized from bottom to top by a decrease in relative abundance and thickness of the limestone conglomerates, a fining upward of conglomerates and sandstones; a decrease in the abundance of limestone clasts (Stop figure 1.2.). The conglomerates are composed of granules to boulder sized (2 mm to 1.5 m) clasts with a mean of 2 cm. The matrix is the same coarse grained arkosic sandstone as the interbedded sandstones. The first two cycles are better exposed and serve here to illustrate the relations between the channelized deposits and the fine grained equivalent of the middle unit. The most characteristic feature of those coarse sediments is that they represent a stacking of channelized deposits one on top of the other and that after deposition most beds were covered by unit 2 fine grained calcareous turbidites.



Stop figure 1.2.3. Stratigraphic column and description of the basal lithological units of the Quai de l'Islet Member. Unit numbers are the same as on figure 1.2.2. Modified from Hubert *et al.* (1970).

The larger (pebbles to boulder size) clasts consist of sedimentary rocks: limestones of various origins, limy sandstones and siltstones, and limy mudstones slabs. The limestone sandstones and siltstones clasts have their source on the platform wheras the mudstones slabs are intraformationnal and probably derived from the middle unit.

The biggest limestone clast at the Quai de l'Islet is a 1,5 m well rounded boulder in the first cycle that acted as a limit between limestone conglomerate to the west and finer grained conglomerates and sandstones to the east. The size of this fragment is atypical of the conglomerate. It is interpreted as a block that rolled down the channel.

Three types of limestones were seen in thin sections. The most abundant is a silty lime mudstone to fossiliferous (trilobites, brachiopods, archaeocyathans, *Salterella*) wackestone; second in abundance are the sandy and silty micritic limestones; finally oölithic, algal and pellöidal limestones are seen rarely. The largest bloc is an algal boundstone with *Girvanella, Orthonella*, *Renalcis* and *Epiphyton*).

Stop figure 1.2.4. Lower sequence of l'Islet Wharf Member. Cgl: thicker limestone conglomerates units.

STOP 1.3. - Cambrian conglomerate, Saint-Damase Formation - Saint-Simon-sur-Mer

Location: This locality is easily accessible and the section of interest for this field trip, along the shore of St. Lawrence River at Saint-Simon-sur-Mer (Figure).

The Upper Cambrian conglomerates and sandstones are spectacularly exposed at this locality. The shore section of interest makes 500 meters. The succession is dominated by cyclic conglomerate-sandstone packages, and three of these major packages can be recognized at this locality.

The sandstones are thickly bedded with individual beds ranging from 20 cm up to 1.5 meters, the beds are commonly amalgamated. In some cases, the base of the sandstone beds is erosive within the underlying layer with some channel of decimeter size. Some beds show nice examples of rapid dewatering such as vertical pillars. The sandstone is characterized by abundant internal sedimentary structures which include normal to rare inverse grading, large cross-laminations and finer parallel and cross-laminations. The sandstone is arkosic in nature; fragments which range in size from 1 mm up to small cobble, are dominated by quartz and feldspars both of which are sub-rounded to sub-angular. Subordinate fragments include limestone, volcanic and mudstone fragments. The sandstones are immature; a silty to muddy matrix makes up to 35% of the rock.

The conglomerates make 70% of the section at St. Simon sur Mer. The conglomerates are in beds ranging from 50 cm up to 2 meters (Stop figure 1.3.1), the coarser and thicker beds are commonly present at the base of decameter-thick fining and thinning upward packages that include the above described sandstones. The conglomerates are massive and it is only in the finer-grained beds that internal sedimentary structures are visible; these include normal and rare inverse grading and some large-scale pebble trains and laminations. The succession fills meter- to decameter-deep channels with abandonment mud facies and lateral switching; a common fining-upward trend is present within individual channel. Fragment sizes range from 1 mm up to 1.5 meters and almost all fragments, whatever its lithologic composition, are sub-rounded. The composition of the clasts is highly variable from one bed to the other, nonetheless, limestone fragments dominate. The nature of the limestone facies within the Humber Zone conglomerates has been used by Lavoie (1997, 1998) and Lavoie *et al*. (2003b) to identify specific conglomerate intervals as well as correlation at a regional scale. At this locality, the dominant facies in the limestone fragments is lime mudstone. Also abundant are thrombolite, oolitic and bioclastic wackestone, packstone and grainstone, and rare oncolitic and stromatolitic facies. Next to limestone facies, abundant sandstone fragments are recognized, two major types are recognized; the most abundant is an impure, parallel and cross laminated arkosic sandstone whereas the second type consists of massive quartz arenite. Finally, even if less abundant in percentage, huge fragments of mafic volcanic rocks are a distinctive element of this conglomerate. Rare fragments of metamorphic units including gneiss have been observed at this locality.

Stop figure 1.3.1. A large rounded micrite clast of possible microbial origin set in an unsorted limestone conglomerate.

DAY 2

Cambrian-Ordovician Rock Sequences in the Gaspé Peninsula – Matane to Rivière-au-Renard

Figure 19. Location of stops for DAYS 2 to 6 of fieldtrip.

STOP 2.1. - Turbidites of the Ordovician foreland basin, Tourelle Formation – Cap Sainte-Anne, Saint-Joachin-de-Tourelle

Location: This stop is located on the shore of the St. Lawrence River just east of the wharf at Saint-Joachin-de-Tourelle (Figure 19). This locality is known as Cap Sainte-Anne and is the exceptionnaly geological site of the “tourelle”. This is one of several patrimonial sites identified in Québec.

The Tourelle Formation is well exposed along the shore of the St. Lawrence River in and around the village of Tourelle, as well as along the road 132. The Tourelle Formation has been studied in detail by Hiscott (1978) and is considered as the oldest lithostratigraphic unit of the Ordovician foreland basin developed in front of the Taconian thrust sheets. The Tourelle Formation is a succesion of proximal turdibites made up of grey greenish lithic wackes and siltstones interbedded with dark grey mudstones and/or mudshales, and minor conglomeratic beds. At Cap Sainte-Anne coarse grained greywackes are thickly-bedded and exhibit good graded-bedding. Interbeds of grey-greenish shales are thinly-bedded.

Stop figure 2.1.1. The « tourelle » made up of Ordovician sandstone of the Tourelle Formation, a Québec patrimonial site in the Gaspé Peninsula.

STOP 2.2. - Taconian folding, Cloridorme Formation – Mont Saint-Pierre

Locality: Cliffs on the southern side of the road 132 along the St. Lawrence River between Marsoui and Mont Saint-Pierre and a specific stop at Mont Saint-Pierre (Figure 19).

Taconian folds in the foreland basin are well-exposed in cliffs on the southern side of the road 132 from Logan’s Line at Marsoui to Mont Saint-Pierre (Figure 1). The Taconian deformation is characterized by S- to SE-dipping thrust faults, contemporaneous with NE-trending and NW-verging folds with an axial planar cleavage dipping to the SE (Slivitzky *et al.*, 1991). The Des Landes and Cloridorme formations of the Ordovician foreland basin span *Nemagraptus gracilis* to *Climacograptus spiniferus* zones indicating, as a whole, deposition between 460.5 Ma to 452 Ma time interval. This is contemporaneous with the Taconian D1 deformation in the internal Humber Zone (Malo *et al.*, 2008).

The Des Landes and Cloridorme formation represent a true peripheral syn-orogenic foreland basin developed in response to loading of the Laurentian crust to the southeast by the Taconian orogenic prism associated to D1 deformation in the internal Humber Zone dated between 459 – 456 Ma (Malo *et al.,* 2008). The Taconian D2 deformation is dated at ca 448 Ma in the internal Humber Zone (Malo *et al.,* 2008) and the main Taconian folding and faulting in the Ordovician foreland basin is attributed to D2.

At Mont Saint-Pierre, a large-scale NW-verging fold is well exposed in cliffs on both sides of the village, to the northeast and southwest.

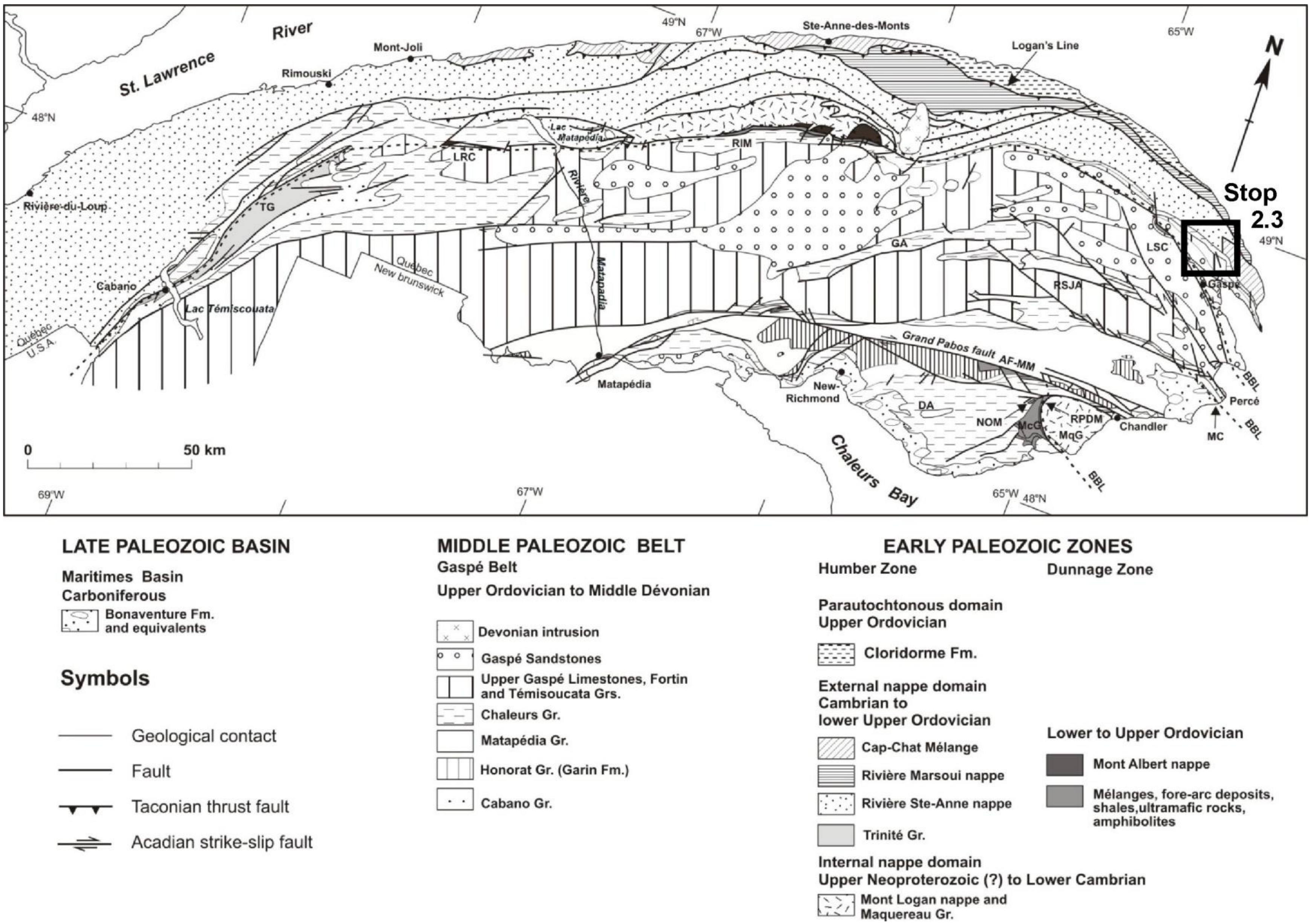
SILURIAN-DEVONIAN ROCK SEQUENCES IN THE GASPÉ PENINSULA – RIVIÈRE-AU-RENARD TO GASPÉ

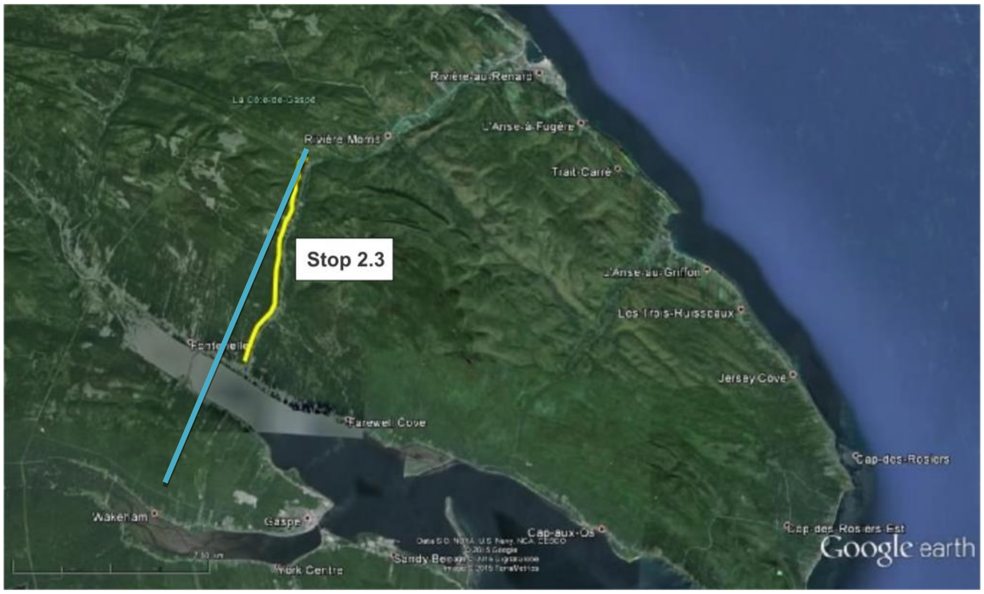
STOP 2.3. - Upper Silurian conglomerate at the Taconian and Salinic unconformities, Griffon Cove Formation, Chaleurs Group – Road 197, Rivière-au-Renard

Location: In Rivière-au-Renard (Gaspé) take road 197 South for approximately 10 km. Park the cars on the road shoulder close to the entry to the old quarry and the road cut west of the road (Figure 19).

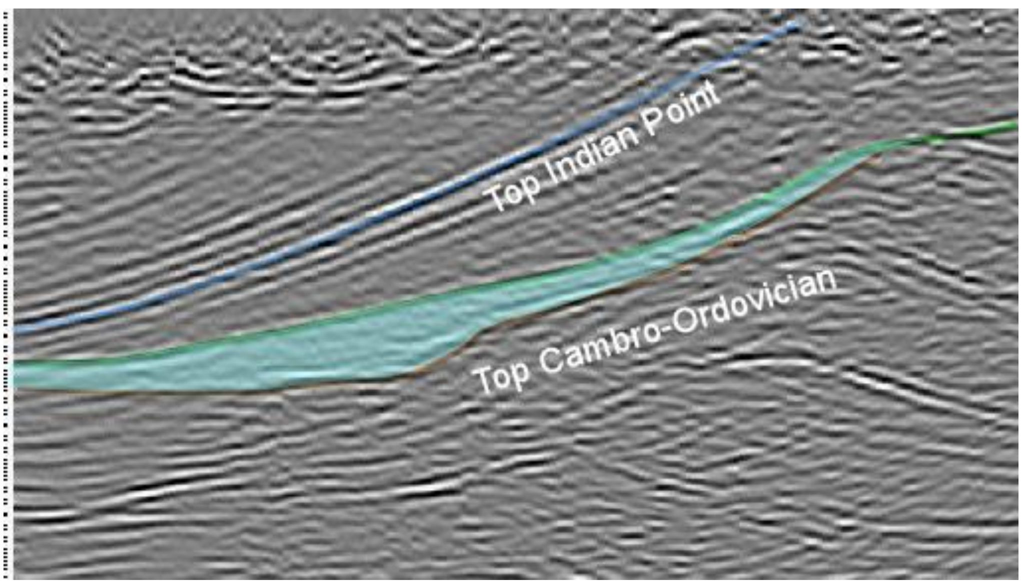
Stop figure 2.3.1. Road cut along road 197. The nearest part belongs to the West Point Formation and the farthest to the lower members (Rosebush Cove and Petit Portage) of the Indian Point Formation.

Stop figure 2.3.2. Geological map of Gaspé Peninsula showing the area of stop 2.3.1. ⟶

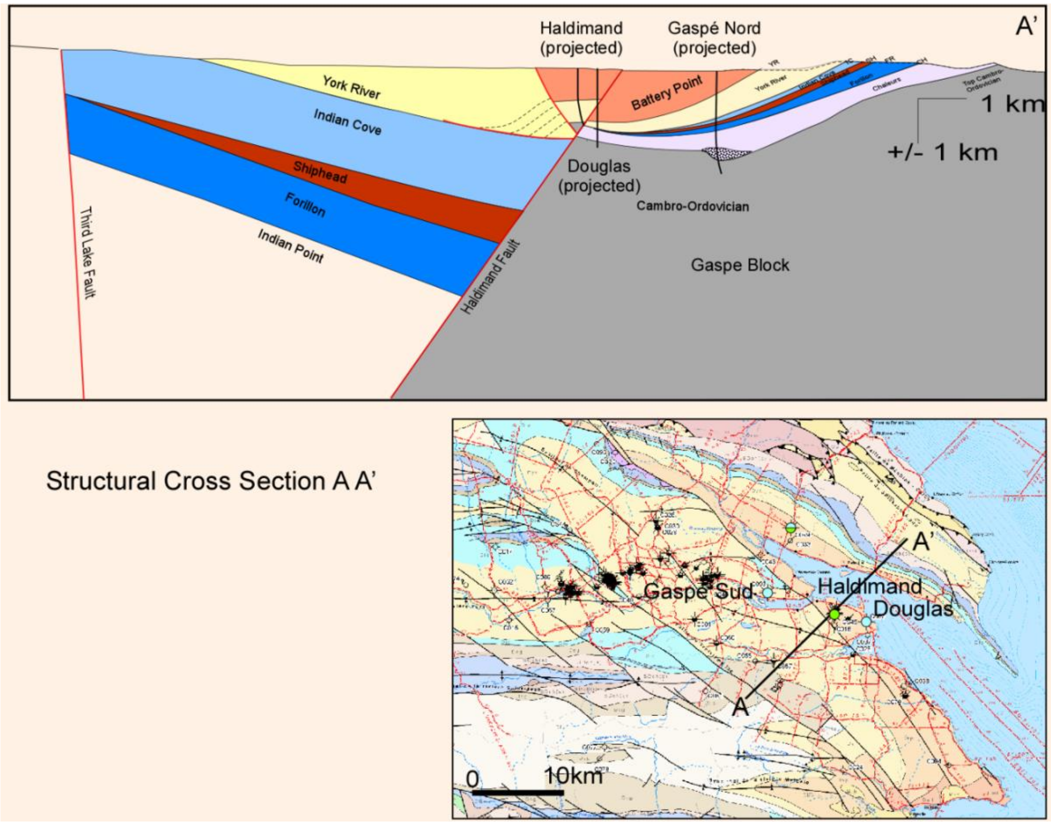

Stop 2.3
N
River
St. Lawrence
Mont-Joli
Rimouski
Rivière-du-Loup
Cabano
Lac Témiscouata
Québec
U.S.A.
Quebec
New brunswick
Lac Matapédia
Rivière Matapadia
Matapédia
Ste-Anne-des-Monts
Logan's Line
LRC
RIM
TG
GA
LSC
RSJA
Gaspé
Grand Pabos fault
AF-MM
New-Richmond
DA
NOM
McG
RPDM
MqG
Chandler
Percé
MC
BBL
Chaleurs Bay
48°N
49°N
69°W
67°W
65°W
0
50 km
LATE PALEOZOIC BASIN
Maritimes Basin
Carboniferous
Bonaventure Fm. and equivalents
Symbols
Geological contact
Fault
Taconian thrust fault
Acadian strike-slip fault
MIDDLE PALEOZOIC BELT
Gaspé Belt
Upper Ordovician to Middle Dévonian
Devonian intrusion
Gaspé Sandstones
Upper Gaspé Limestones, Fortin and Témisoucata Grs.
Chaleurs Gr.
Matapédia Gr.
Honorat Gr. (Garin Fm.)
Cabano Gr.
EARLY PALEOZOIC ZONES
Humber Zone
Dunnage Zone
Parautochtonous domain
Upper Ordovician
Cloridorme Fm.
External nappe domain
Cambrian to
lower Upper Ordovician
Cap-Chat Mélange
Rivière Marsoui nappe
Rivière Ste-Anne nappe
Trinité Gr.
Internal nappe domain
Upper Neoproterozoic (?) to Lower Cambrian
Mont Logan nappe and Maquereau Gr.
Lower to Upper Ordovician
Mont Albert nappe
Mélanges, fore-arc deposits, shales,ultramafic rocks, amphibolites



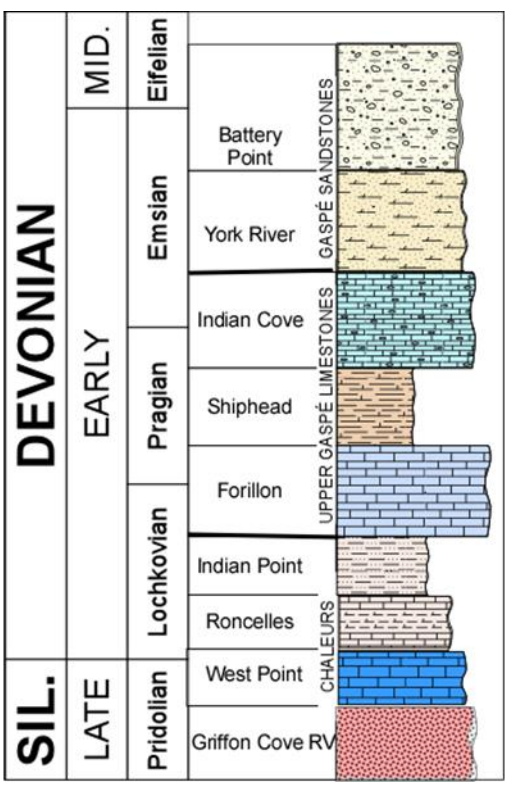
Stop figure 2.3.3. Localisation of road 197 in eastern Gaspé. A serie of road cuts expose parts of every formation of the stratigraphic sequence on the northern edge of the eastern Gaspé Belt basin. The yellow line shows the localisation of the section along the road 197. The blue line shows the localisation of the seismic line of figure 2.3.4.



Stop figure 2.3.4. Seismic line across the northern margin of the Gaspé Belt basin. The blue interval represents the lowest part of the Chaleurs Group exposed at the base of the sequence



Stop figure 2.3.5. Schematic cross section showing the thinning to the south of the Siluro-Devonian formations on the northern limb of the Gaspé Belt basin.



Stop figure 2.3.6 Schematic stratigraphic column of the uppermost Upper Silurian to lowermost Middle Devonian stratigraphic succession of the northern margin of the Gaspé Belt basin in eastern Gaspé Peninsula.

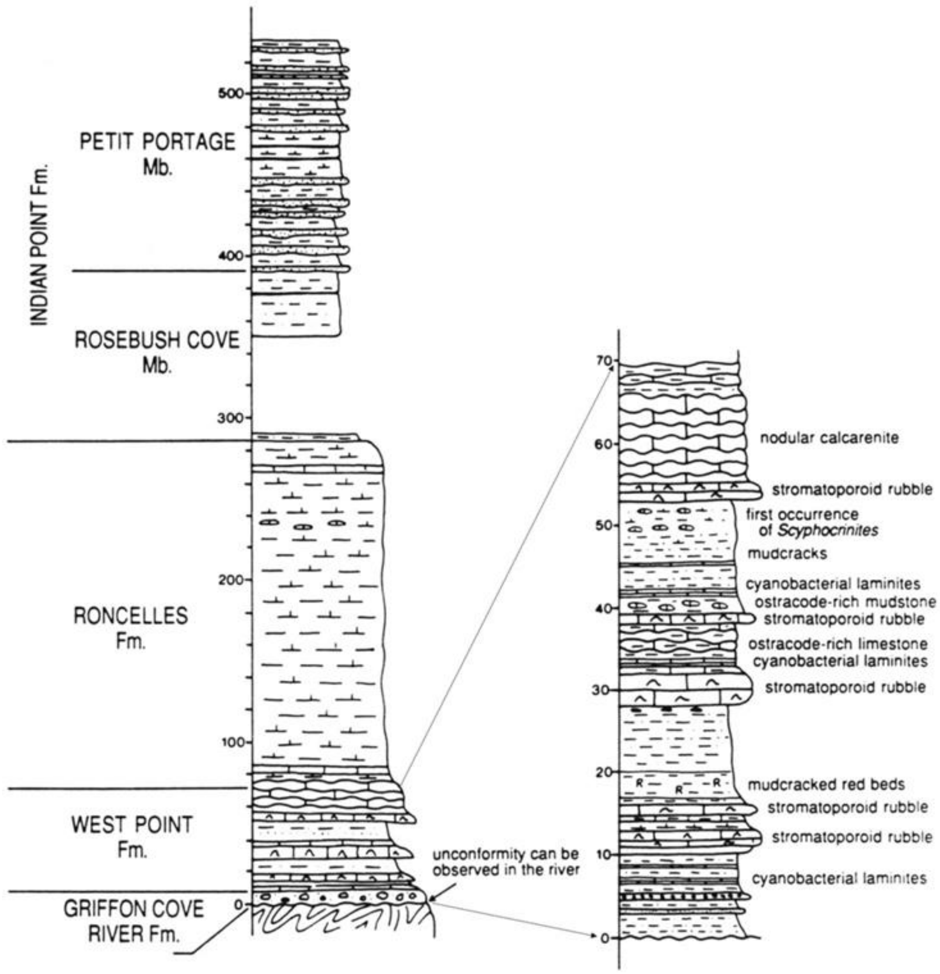
Along a 7,6 km stretch of road 197 is exposed a series of outcrops in road cuts that show all the formations of uppermost Upper Silurian to lowermost Middle Devonian sequence of the northeastern margin of the Gaspé Basin. The Silurian-Devonian sequence of the Gaspé Belt in this locality is homoclinal and dips at 40 to 50 degrees to the south-west.

The main focus of this stop is to look at the basal part of the sequence wich exposes the upper part of the Silurian-Devonian (Pridolian-Lochkovian) Chaleurs Group above the Salinic uncorformity, which in the north-eastern Gaspé area has eroded even below the Taconian unconformity. If time permits, we will also have a look at the other units above.

Although the stratigraphic nomenclature may vary from one locality to the other along the northern outcrop belt, in most places where they are exposed, the rocks above the unconformity are conglomerates and red beds (Griffon Cove River Formation) followed or laterally replaced by coarse grained clastic limestones and mudstones (West Point Formation). This basal sequence is followed by fine grained red and green sandstones and mudstones and some fine grained limestone of the Indian Point Formation (or its equivalents). Along road 197 and for some distance east and west the transition zone between the West Point Formation and the Indian Point Formation is called the Roncelles Formation.

The basal conglomerate (Griffon Cove River Formation) is exposed in and old abandoned quary on the northwest side of the road and the red beds and limestones of the West Point Formation above are exposed along the road cut, the uncorformity is not exposed but only a meter or so is missing between the lower Ordovician Rivière-Ouelle Formation and the Silurian-Devonian Griffon Cove River Formation (sometimes refer as a member of the West Point Formation by some authors). The uncorformity can be seen in a few other localities along river banks or logging road.

The Griffon Cove River Fromation exposed in the quarry is approximately 30 m thick (Stop figure 2.3.7). It is a fining upward sequence of pebbles and cobbles, clast-supported conglomerates, at the base, grading to red and green lithic wacke and red and green mudstones and a few limestones at the top. The clasts are rounded quartz vein fragments, and metasedimentary and metabasalt rock fragments with a few mafic intrusives clasts. Most of those clasts are derived from the Neoproterozoic (?) (Ediacaran ?) Shickshock Group of the internal Humber Zone. Outcrops of those rocks can be seen in the Mont Serpentine, west of the Griffon Cove River outcrops. The Griffon Cove River Formation is interpreted as an intertidal to supratidal deposit (Bourque *et al*., 1993).



Stop figure 2.3.7 Rock succession above Salinic unconformity, road 197 section. Scale in meters. From Bourque *et al.* (1989).

The Griffon Cove River Formation is succeeded by the West Point Formation wich is over 60 m thick in this locality. The West Point Formation is composed of red and green mudstone with mudcracks; of thick beds of stromatoporoid bioclasts calcirudites; of thin cyanobacterial laminites and stromatholites; of ostracods rich mudstones and limestones; of nodular calcarenites. This West Point Formation is considered an infra- to supratidal deposit (Bourque *et al.*, 1993).

The West Point Formation is succeeded by the Roncelles Formation, a 220 m thick sequence of interbedded silty and muddy limestones, mudstones and thin to thick bedded calcarenites and calcirudites deposited in a lagoon environment. The upper part of the Chaleurs Group up to the Upper Gaspé Limestones is a thick (670 m) sequence of calcareous fine grained sandstone and mudstone with minor limestones and bentonites of the Indian Point Formation deposited in deeper waters by turbidity currents as shown by Bouma sequence sedimentary structures.

Stop figure 2.3.8. Basal conglomerate of the Griffon Cove River Formation. Old quarry along road 197.

Stop figure 2.3.9. Stromatoporoid clasts rudstone and crinoïdal grainstone of the West Point Formation. Road cut on 197.

Optional stops.

If time permits, we will look at a few more outcrops along this road. We will stop at the contact between the Shiphead and the Indian Cove formations of the Upper Gaspé Limestones and at the upper part of the York River Formation of the Gaspé Sandstones.

The Upper Gaspé Limestones is a three formations group that is present over all the northern half of the Gaspé Basin in Gaspé Péninsula. The lower (Forillon Formation, 450 m thick app.) and upper (Indian Cove Formation, 180 m thick, app.) units ar more or less cherty, dolomitic, and shaly fine grained (micritic) limestones of uppermost Lochkovian/Pragian to lowermost Emsian age. The middle unit (Shiphead Formation, 100 m thick, app.) is amore or less calcareous and siliceous shale with thick dolomitic bed. It is of Pragian age.

Optional stop 2.3a

Stop figure 2.3.10. Top of the Shiphead and base of the Indian Cove Formations along road 197. The black line is at the contact between the two units. View to the south

This stop shows the contact between the Shiphead and Indian Cove formations. The Shiphead is composed of siliceous and dolomitic/calcareous mudstones and siliceous limestones in beds up to 70 cm. The Indian Cove is a sequence of well bedded thin to medium thick limestone. At the south end of the outcrop, in the road ditch, close to the top of the Indian Cove Formation, fossiliferous beds with corals and brachiops are common. The trace fossil Zoophycos is ubiquitous.

Optional stop 2.3b

This stop shows the upper York River Formation (440 m thick). It is composed of of thin to medium thick beds of fine to medium grained feldspathic sandstone interbedded with argilaceous very fine grained sandstone to mudstone beds. A few very thick coarse grained cross-bedded sandstone beds are also present. Fossils include inarticulate and articulate brachiopods, bivalves, fish fragments, eurypterids and trace fossils.

Stop figure 2.3.11. Lower part of the York River Formation along road 197. View to the north

The following tables present faunal list that have been published in reports for the York River Formation, the upper Gaspé Limestones and the Chaleurs Group in the area around road 197.

Brachiopodes

Lingula sp. 1
Orbiculoidea sp
Globithyris callida (Clarke, 1907)
Globithyris ? sp.
Mutationella sp.

Bivalves

Paleoneilo spp,
Plethomytilus sp.
Mytilarca sp. 1
Montanaria sp.
Modiolopsis ? sp.
Prothyris (Prothyris) sp.
Goniophora (Goniophora) sp. 3
Orthonota ? sp.
Prosocoelus sp.
Genres et espèces indéterminés

Gastéropodes

Genres et espèces indéterminés

Ostracodes

Genres et espèces indéterminés

Arthropodes

Fragments d'Euryptérides

Vertébrés

Aiguillons d'Acanthodiens
Fragments de Placodermes ind.
Phlyctaenaspis spp.
Cartieraspis nigra Pageau, 1969b
Laurentaspis splendida Pageau, 1969b
Batteraspis fulgens Pageau, 1969b

Table 1. Faunal list for nearshore and brackish waters environments of the York River Formation. From Desbiens (1992).

Bryozoaires

Hederella blainvillii Billings 1874
Fénestellidés ind.

Brachiopodes

Lingula sp. 2
Craniops ovata (Hall, 1859)
Orbiculoidea sp.
Salopina hitchcocki Walmsley, Boucot et Harper, 1969
Discomyorthis sp.
«*Leptaena*» sp
«*Schuchertella*» *becraftensis* Clarke, 1900
«*Schuchertella*» *gaspensis* Clarke, 1907
Protoleptostrophia blainvillei (Billings, 1874)
Eodevonaria melonica (Billings, 1874)
Chonostrophiella complanata (Hall, 1857)
Costellirostra peculiaris (Conrad, 1841)
Plicanoplia sp.
Atrypa ? sp.
Leptocoelia flabellites (Conrad, 1841)
Ambocoelia sp.
Cyrtina sp.
Costellispirifer gaspensis Billings, 1874
Havliceckia ? sp.
Brachyspirifer sp.
Etymothyris gaspensis (Clarke, 1907)
Meganterella finksi (Boucot, 1959)
Cloudothyris ? sp.

Gastéropodes

Plectonotus (Plectonotoides) cf. *gaspensis* Clarke, 1907)
Retispira sp.
Tritonophon rotallinea (Hall, 1859)
Sinuitina ? sp.
Platyceras (Platyceras) sp. 1
Platyceras (Platyceras) sp. 2
Bembexia sp. 1
Bembexia sp. 2
Gastéropodes indéterminés

Bivalves

Nuculoidea ? sp.
Nuculites triqueter Conrad, 1841
Nuculites sp.
Paleoneilo spp.
Phestia sp.
Nuculana sp.
Ptychopteria (Ptychopteria) sp. 1
Ptychopteria (Ptychopteria) sp. 2
Cyrtodonta ? sp.
Mytilarca ? sp. 2
Montanaria sp.
Schysodus ? aff. *circularis* Beushausen (1895)
Goniophora (Goniophora ?) aff. *exilis* (Dreverman, 1902)
Goniophora (Goniophora) sp.1
Goniophora (Goniophora) sp.2
Goniophora (Cosmogoniophora) sp.
Goniophorina (Goniophorina) sp.
Modiella modiola Clarke, 1907
Modiella pygmaea (Conrad, 1842)
Paleosolen sp.
Carydium sp.
Grammysia canadensis Billings, 1874
Grammysia sp.

Cricoconarides

Tentaculites cartieri Clarke, 1907

Céphalopodes

Nautiloïdes orthocères ind.

Echinodermes

Stelleroïde ind.
Ossicles de crinoïdes

Trilobites

Phacopina (Phacopina) sp.
Dalmanitidé ind.
Fragments de trilobites ind.

Vertébrés

Fragments de placodermes

Table 2. Faunal list for open marine environments of theYork River Formation. From Desbiens (1992).

		A	B	C	D
	Chaetetes sp.		x		
	Tétracoralliaires indéterminés		x		
	Coraux indéterminés	x	x		
	Bryozoaires Fenestellidés		x		
BRACHIOPODES	*Pholidrops ovata*		x		x
	Acrospirifer murchisoni		x		
	Acrospirifer sp.	a		x	x
	Ambocoelia nitidulus		x		
	Anoplia sp.		x		
	Beachia thunei	x			
	Beachia sp.		x		
	Coelospira cf. *concava*	ta			
	Coelospira sp.		x	ta	x
	Costellirostra peculiaris	tr			ta
	Costispirifer arenosus				x
	Cyrtina rostrata		x		
	Dalejina lucia				x
	Dalejina sp.		x		x
	Dawsonelloides canadensis		a		x
	Dawsonelloides sp.			x	
	Etymothyris gaspensis				x
	Howellella cycloptera				x
	Howellella sp.				x
	Leptaena sp.			x	x
	Leptocoelia flabellites	x		ta	x
	Leptocoelia sp.			x	
	Leptostrophia oriskania		x		
	Leptostrophia sp.		x		x
	Megakozlowskiella sp.				?
	Meristella sp.		x		x
	Nucleospira ventricosa		x		x
	Plicanoplia billingsi				x
	Prionothyris ovalis				x
	Prionothyris sp.	x	x		
	Schuchertella woolworthana		x		
	Schuchertella sp.			x	
	Strophodonta galatea				x
	Strophodonta praecedens		x		
	Strophodonta sp.		x		x
	Strophonella continens				x
	Strophonella sp.		?		x
	Rhynchonelles indéterminés		x		x

		A	B	C	D
MOLLUSQUES	*Cypricardinia distincta*		x		x
	Bivalves indéterminés				x
	Platyceras (Platyceras) sp.		x		
	Platyceras (Platyostoma) spp.		x		
	Platyceras sp.	x			
	Gastéropodes indéterminés		x	x	
TRILOBITES	*Anchiopsis anchiops*			x	
	Centauropyge sp.				x
	Forillonaria russelli			x	
	Leonaspis sp.		x		
	Odontochile pleuroptyx	aff.			
	Odontochile sp.		?		
	Phacops cristata		x		
	Phacops sp.				x
	Prantlia (Prantlia) sp.				?
	Pseudodechenella phocion				x
	Synphoria dolbeli				x
	Synphoria sopita			x	
	Synphoria sp.		x	x	
	Synphoroides dolphi			tr	
	Synphoroides multiannulatus			tr	
	Lichides indéterminés		x		
	Ostracodes indéterminés			x	x
	Echinodermes indéterminés	x			
	cf. *Scalarituba* sp.				x
	Zoophycos sp.				x
	Traces indéterminées	x		x	

Table 3. Faunal list for the Upper Gaspé Limestone on road 132, east of road 197. From Lespérance (1979).

A – Upper Forillon

B – Middle Shiphead

C – Upper Shiphead

D – Upper Indian Cove

Table 4: Faunal list (incomplete) for the Chaleurs Group of the area of road 197 on the northern margin of Gaspé Basin. From Bourque (1977).

Anoplia pygmaea

Atrypa reticularis

Atripa sp.

Camarium sp.

Chonostrophiella ? heldelbergia

Coelospira aff. *concava*

Coelospira virginia

Eatonia sp.

Eccentricosta sp.

Gypidula prognostica

Gypidula coeymanensis

Isorthis sp.

Kozlowskiellina sp.

Leptaena sp.

Leptostrophia sp.

Levenea subcarinata

Mclearnites sp.

Metaplasia sp.

Meristella sp

Monograptus bouceki

Nanithyris sp.

Neristina sp.

Orthostrophia sp.

Platyorthis aff. *verneuilli*

?Plectodonta sp.

Salopina robitaillensis

Scyphocrinites sp.

Strophodonta sp.

Strophonella punctulifera

Strophonella cf. bransoni

Meristellidés

Rhynchonellidés

Spirifiridés

Strophéodontidés

Bivalves.

Ambocoelidés

Halysitidés

STOP 2.4. - Devonian sandstones, Gaspé Sandstones Group – Anse-à-Brillant

Location: After crossing the brige in Gaspé drive south for approximately 24.5 km to the Rue de l'Anse-à-Brillant east of the road 132 (to your left) (Figure 19). Stop at the parking by the wharf. The coastal section is to your left.

Stop figure 2.4.1. Sketch map of the Tar Point Anticline area. The yellow area is underlined by York River Formation sandstone and mudstone. Red lines are strike-slip faults that belong to the Bras-Nord-Ouest fault zone. Grid lines are 1 km apart.

Stop figure 2.4.2. General view of the York River Formation on the south dipping limb of the E-trending anticline, at Anse-à-Brillant. The lighter color beds are fine to medium grained lenticular to parallel bedded sandstones and darker beds are sandy mudstone to very fine grained argilaceous sandstones.

In the first phase of oil exploration in theGaspé area, anticlines in the Gaspé Sandstones Group were the main targets. Many oil seeps were known in those rocks and many drill holes yielded a few barrels of oil but no important discovery was made. The Tar Point Anticline was one of those structures with an oil seep closely associated with a late Devonian diabase dike. At the time this association was used as a proof of the volcanic origin of oil.

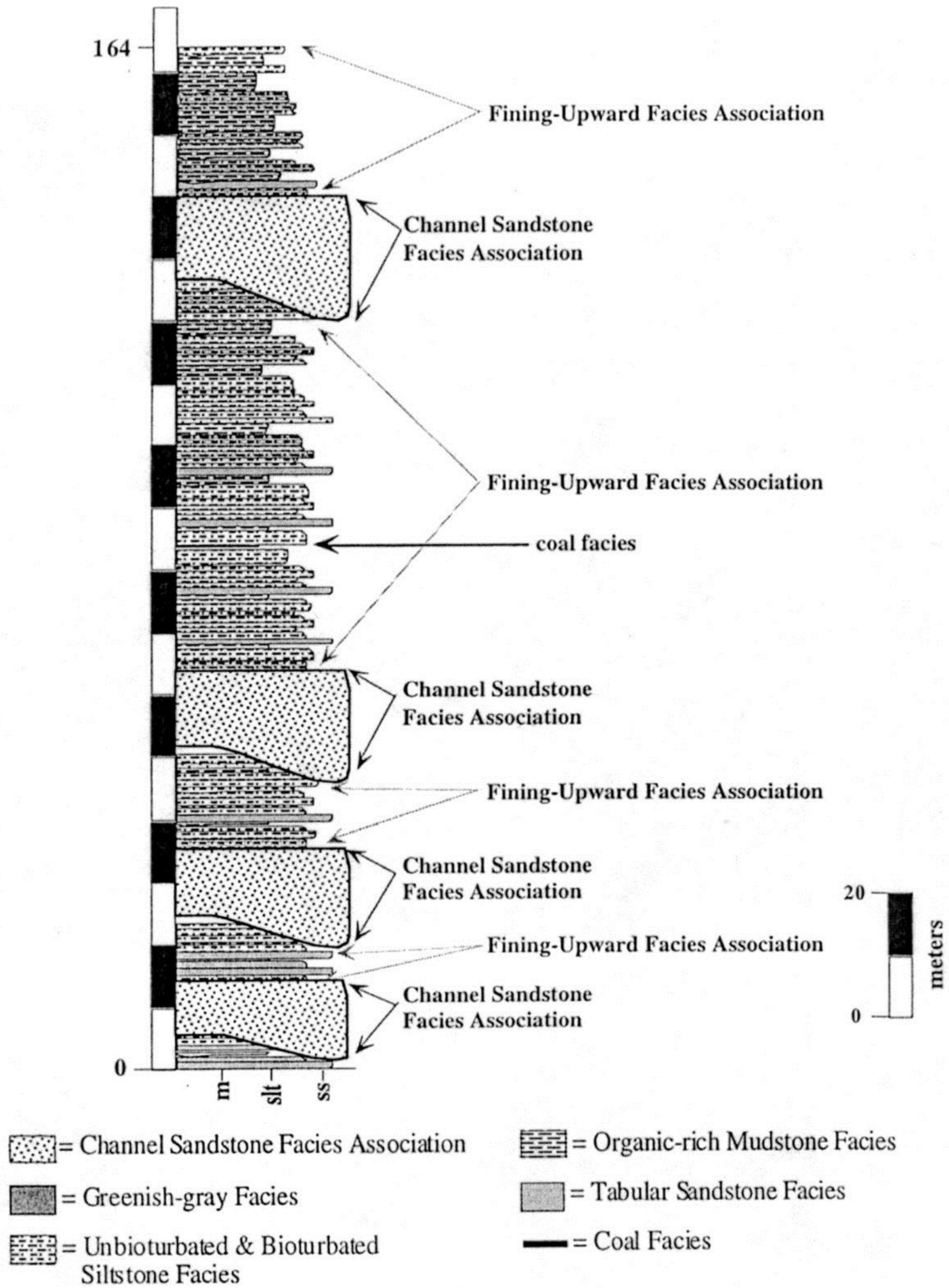
The Gaspé Sandstones Group rocks represent a coarsening-upward siliciclastic sequence of Lower to Middle Devonian (Emsian–Eifelian) age. It succeeds conformably to the deep plateformal limestones of the Upper Gaspé Limestone Group. In the eastern Gaspé Peninsula, their southern most exposures are covered unconformably by the Carboniferous Cannes-de-Roches Formation. They are related to the last regressive sequence of the Gaspé Belt.

The Gaspé Sandstones Group rocks were subdivided into four superposed formations. The lowest unit, the York Lake Formation (wich do not outcrop in the Gaspé area) is transitional between the Upper Gaspé Limestone and the Gaspé Sandstones. It is composed of chertified and dolomitized micritic limestones alternating with mudstone and fine grained sandstone. The next unit, the York River Formation, is a shallow marine/deltaic/estuarine deposit consisting of cycles of channel deposited medium to coarse sandstones and supra channel mudstones/fine grained sandstones. In the Gaspé area, the York River Formation lies directly on the Upper Gaspé Limestones Group. The York River Formation is replaced vertically by the Battery Point Formation, a unit of mixed marine and terrestrial deposits. It consist mainly of coarse grained to conglomeratic, channelized, very thick beds alternating with fine grained sandstone and red to greenish mudstone assemblages. The upper part of the Battery Point Formation is a red mudstone and sandstone continental assemblage. The upper unit of the Gaspé Sandstones Group, the Malbaie Formation, is a conglomerate/sandstone/mudstone assemblage of alluvial plain environment.

In the Anse-à-Brillant section (Stop figure) we will look at parts of a 160 m continuous sequence in the upper York River Formation on the south limb of the anticline. In a nearby well, Tar Point #1, the York River Formation is approximately 1700 m thick. It means that in this area the upper part of the York River Formation is finer grained than in other sections a few km west of Anse-à-Brillant where the upper York River Formation is made of crossbedded coarse grained sandstone (Brisebois, 1981; Desbiens, 1992).

Although this section is not fully representative of the York River Formation that outcrops elsewhere in Gaspé, it shows the main lithologies and many sedimentary structures and textures typical of the unit. It is unsual for the coal bed and the highly bioturbated strata and rhizoliths siltstone and fine grained sandstone beds with rhizoliths of the «mudstone» facies. The Stop figure 2.4.3 and Table 1 show the different facies described by Ansley (1997). Ansley interpreted those deposits as an estuarine/barrier sedimentary environment.

Desbiens (1992) and others, have identified inarticulate and articulate brachiopods, eurypterids, fish fragments and bivalves in the section. Bioturbation and root casts are present.



Stop figure 2.4.3: Generalized stratigraphic column of the York River Formation at Anse-à-Brillant showing the two main facies associations: Channel Sandstone Facies Association and Fining-Upward Facies Association. From Ansley (1997).

LITHOFACIES

Channel Sandstone Facies Association		Fining-Uppward Facies Association	
Facies	**Characteristics**	**Facies**	**Characteristics**
Erosive Scour Facies	- massive sandstone - no bioturbation - erosive scour base - pebble lag - medium to coarse ss	**Tabular Sandstone Facies**	- sheet-like, tabular - medium grained ss - unbioturbated - symmetrical wave ripples
Cross-bed Facies	- large-scale, long, low-angle cross-bed sets - organic hash on foresets - medium to coarse ss	**Bioturbated Siltstone Facies**	- intensely bioturbated siltstone - obliterated bedding - rare root traces
Climbing Ripple Facies	- cross-bedded, medium to coarse ss - numerous climbing ripples present	**Unbioturbated Siltstone Facies**	- no bioturbation
Mudstone Facies	- fine grained - organic rich - bioturbated	**Organic-rich Mudstone Facies**	- massive, fine-grained - hackly weathering - organic rich - some bioturbation - rare
Greenish-gray Facies	- greenish-gray ss or siltstone - caps channel sandstone sequence - often bioturbated	**Greenish-gray Facies**	- greenish-gray color - bioturbated - hackly weathering - glauconite - phosphatic shell fragments - siltstone and sandstone
		Coal Facies	- coal seam composed of plant cuticles and spore algal material

Table 5. Description of the facies in the channel sandstone and fining-upward facies associations From Ansley (1997).

DAY 3

CAMBRIAN TO DEVONIAN ROCK UNITS IN THE PERCÉ AREA

The Percé area is structurally very complex and schematically sketched on figure 30. The geology of Percé area is summarized in Kirkwood (1989). All Paleozoic Systems of the Gaspé Peninsula are locally present in the Percé area, from the Cambrian to the Carboniferous (Figure 30). The two main unconformities of the Gaspé Appalachians are also well exposed: the Taconian unconformity between Cambrian and Ordovician rocks (TU, Figure 30), and the Acadian unconformity between Carboniferous rocks and underlying Cambrian, Ordovician, Silurian and Devonian rocks (AU, Figure 30). The Ordovician-Silurian boundary is also present in the White Head Formation (see below Stop 3.4).

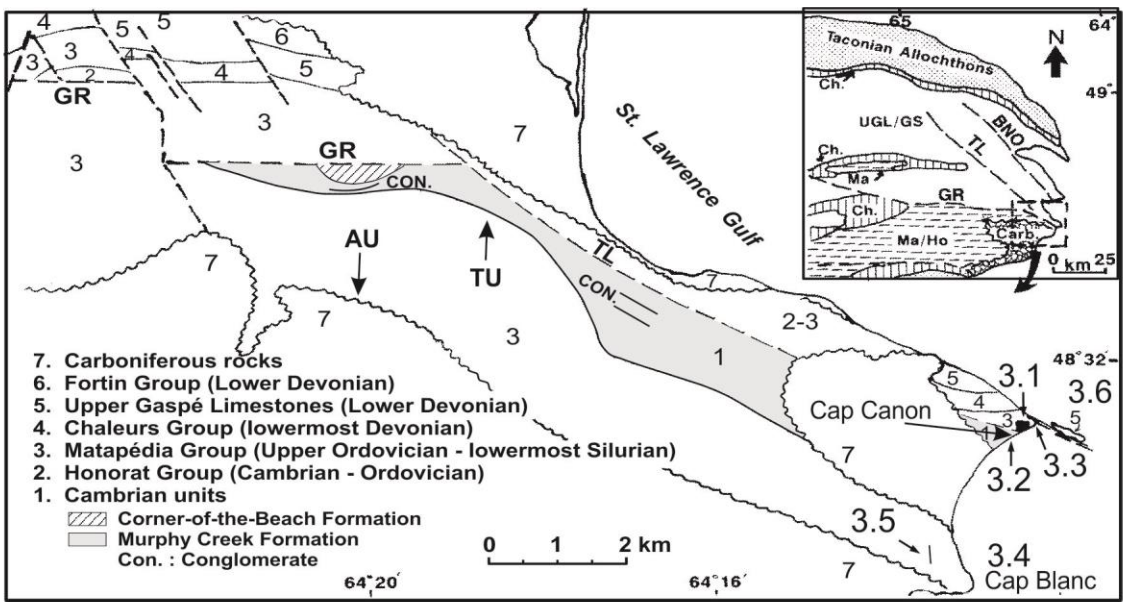
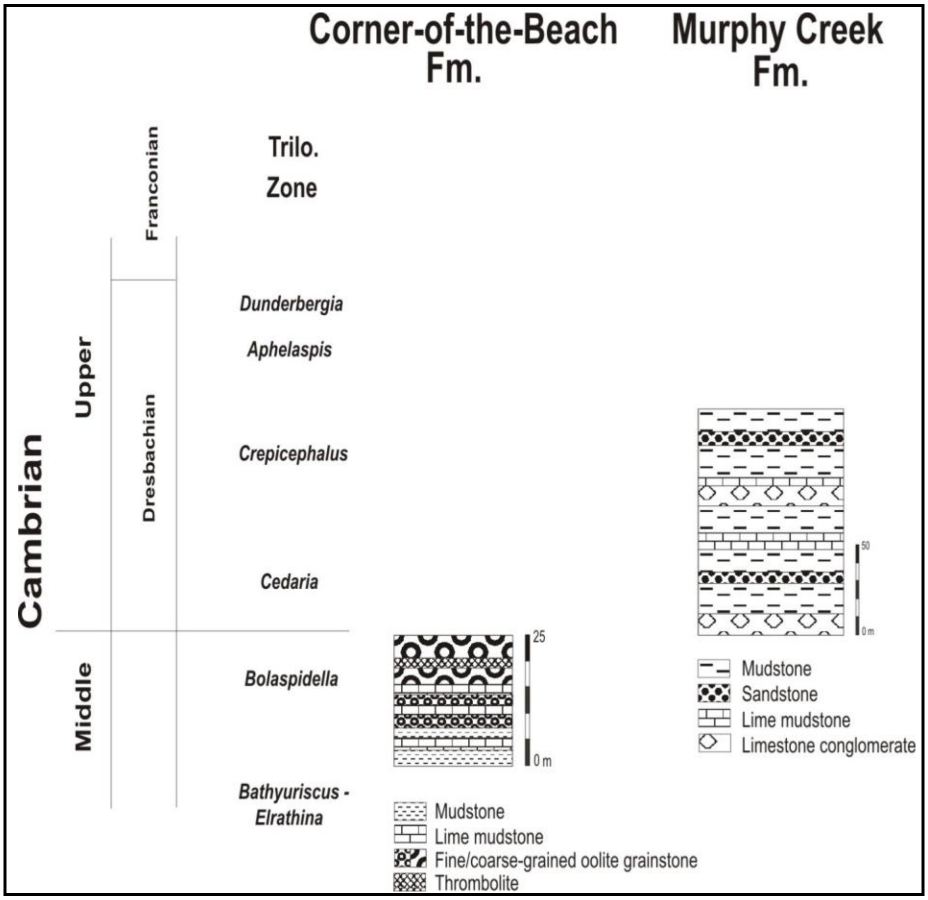


Figure 30. Geology of the Percé area and location of stops for DAY 3. AU: Acadian unconformity, GR: Grande Rivière fault, TL: Troisième Lac fault, TU: Taconian unconformity. Modified from Kirkwood 1989.

STOP 3.1. - Cambrian conglomerate, Murphy Creek Formation– Logan monument, Percé

Location: The monument is in Percé close to the main parking for the wharf (Figure 30).

The Murphy Creek Formation was introduced by Kindle (1942) for a succession of mudstone and sandstone together with fine-grained limestone and dolostone. Two distinct intervals of limestone conglomerate have also been stratigraphically recognized. The Murphy Creek Formation outcrops over a wider area compared to the slightly older Corner-of-the-Beach Formation (Kirkwood, 1989). An early Late Cambrian (Dresbachian) age is suggested by the presence of fauna belonging to the trilobite *Cedaria-Crepicephalus* Zone (Kindle, 1948). The contact with the underlying late Middle Cambrian Corner-of-the-Beach Formation was not observed but was described as likely conformable by Fritz *et al.* (1970); its upper limit is unknown. Our recent work does not clearly support such a contact (Lavoie, 2001) (Stop figure 3.1.1).



Stop figure 3.1.1. Stratigraphic sections for the Corner-of-the-Beach (one locality) and Murphy Creek (composite from three localities) formations. The biostratigraphy is from Kindle (1948) and Fritz *et al.* (1970) and the trilobite zones are reproduced from James and Stevens (1986). From Lavoie (2001).

In the following section, the fine-grained lithofacies of the formation will be described according to their dominant characteristics that are either siliciclastic- or carbonate-dominated. Limestone conglomerates are grouped under one lithofacies.

Siliciclastic facies

Mudstone and sandstone are arranged in rhythmic successions. The mudstone lithofacies dominates, representing roughly 75% of the total volume of the unit. The mudstone is brown, greenish or dark grey and occurs in decimeter-thick intervals, it commonly shows some fine parallel laminae of quartz-rich siltstone. The sandstone lithofacies consists of fine- to medium-grained sublitharenite with a significant percentage of dark matrix. The sublitharenite is in 5 cm to 15 cm beds and consists of sub-rounded to sub-angular quartz and sub-rounded mudstone fragments. A significant amount of these sandstones are calcareous and, at places, the facies is close to a sandy calcarenite. The sandstone is frequently but not invariably characterized by rare granulometric normal-grading followed by parallel laminations similar to a and b division of turbidites. The sandstone forms roughly 10% of the total volume of the formation.

Fine-grained carbonate lithofacies

The fine-grained carbonate lithofacies consist of clayey lime mudstone, lime mudstone and dolomudstone. As a whole, these lithofacies form roughly 10% of the total formation volume and are associated with siliciclastics in rhythmic succession. The unfossiliferous clayey lime mudstone lithofacies consists of 2 to 8 cm-thick beds of dark grey, parallel-laminated, clay-rich lime mudstone. Locally, this lithofacies can be silty and is at the limit of a limy mudstone.

The lime mudstone lithofacies consists of 1 to 6 cm-thick beds of brownish lime mudstone. Siliciclastics and macrofossils are conspicuously absent in this lithofacies. The dolomudstone lithofacies is made up of 2 to 10 cm-thick beds of dark grey dolomitic mudstone. This rock type is locally parallel laminated and can be rich in clay and silt-sized quartz particles. Its dolomitic nature is the sole distinction from the clayey lime mudstone lithofacies.

Paleoenvironmental interpretation

The fine-grained siliciclastic and carbonate lithofacies form rhythmic successions dominated by siliciclastic mudstone. The facies are devoid of fairweather- or storm-induced wave sedimentary structures and slow suspension sedimentation is suggested by grain size. These represent below storm-wave base deposits in a setting affected by turbidity currents.

Limestone conglomerate

Even though this lithofacies is volumetrically minor, its paleogeographic significance is major at the regional scale. Two conglomerate intervals are recognized although fine correlations between sections are difficult because of the lenticular nature of these conglomerates.

The limestone conglomerate lithofacies consists of lenticular beds ranging from 50 cm up to 5 m in thickness (Stop figure 3.1.2), these beds are embedded in the above described rhythmic successions. The conglomerate is commonly clast-supported. The lithofacies is devoid of internal sedimentary structures and the conglomerate consists of a structureless chaotic accumulation. The lenticular nature of the conglomerate is well displayed at Cap Canon where a 5 m thick conglomerate (the “Logan Monument”; Stop figure 3.1.2) passes 100 m eastward, to a 1.5 m thick bed along the coastal cliff exposure, this conglomerate is capped by a 10 cm-thick calcarenite.

Stop figure 3.1.2. Murphy Creek Formation at the Logan Monument. Five meters thick limestone conglomerate exposed onshore at Cap Canon. This unit laterally passes to a 1.5 meter thick interval at the shore cliff.

The matrix of the conglomerate (average 20% of rock volume) consists of a sand-sized mixture of sub-angular carbonate particles, with subordinate quartz and mudstone fragments. The size of the fragments ranges from 2 mm up to 12 cm with an average of 8 cm. Most of these are roughly equant, and elongated clasts are few. Large clasts have well rounded margins, smaller size material is sub-rounded to sub-angular. The conglomerate is dominated by carbonate fragments with more than 95% of clasts being limestones with the remaining consisting of rare quartz, sandstone and mudstone.

Four major lithofacies are recognized in the limestone fragments, these are, in decreasing order of abundance: thrombolite and microbial-derived limestone (40%), oolitic grainstone (35%), lime mudstone (15%) and bioclastic (trilobite, brachiopod, crinoid) wackestone to packstone (10%). Rare resedimented limestone conglomerate fragments are locally seen. The lime mudstone clasts consist of ribbon-like facies similar to fine-grained limestones found in the encasing succession. The other lithofacies are not seen in the rhythmic succession and are exotic to the depositional setting. The dominant lithofacies is the thrombolite and associated microbial-limestone, these clasts are sometimes characterized by growth cavities filled by geopetal sediment and cement crusts.

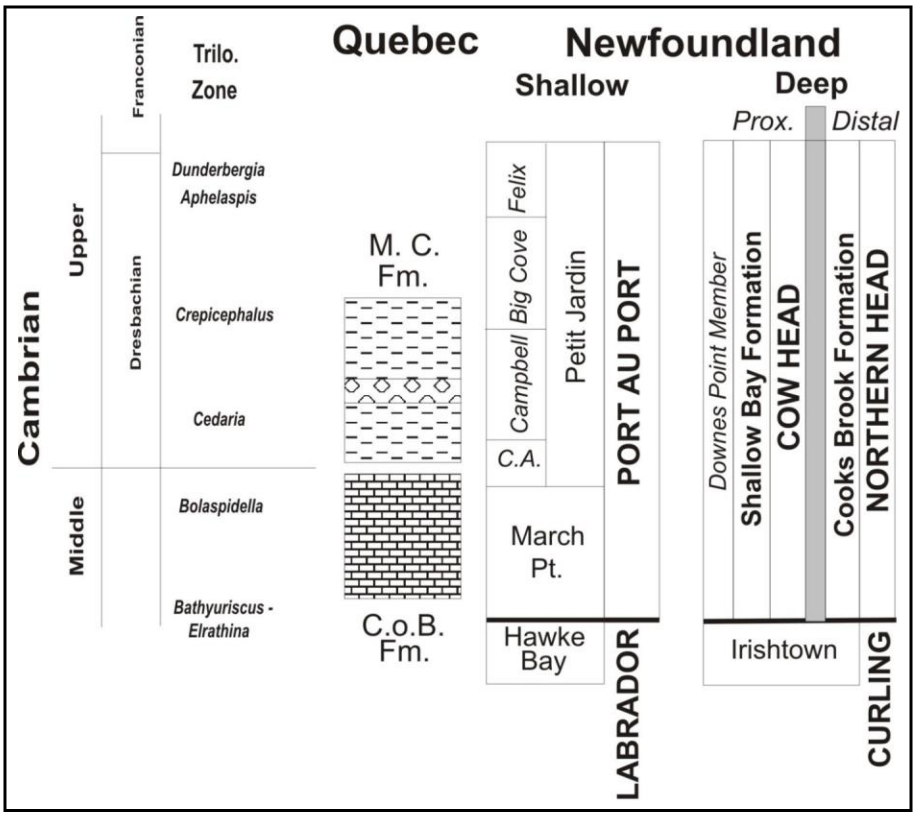
Paleoenvironemental interpretation of the limestone conglomerate

The limestone conglomerate is embedded in a rhythmic succession and as such, was deposited under the same paleoenvironmental conditions characterized by the lack of fairweather and storm waves. These conglomerates are the result of rapid debris flow deposition, most likely on a slope, without subsequent remobilisation. A significant amount of the fragments are exotic to the depositional setting and therefore, a shallow marine upslope source has to be found.

A source for exotic limestone clasts

Exotic clasts are dominated by thrombolite and associated microbial-derived limestones as well as oolitic grainstones; the bioclastic limestones are less abundant. In Late Cambrian, shallow marine carbonate platforms at the eastern seaboard of Laurentia were rimmed by a belt of high energy facies such as thrombolite boundstones and oolitic sand shoals (James *et al.*, 1989). Exotic clasts in the Murphy Creek conglomerates were derived from these margin facies.

The conglomerates of the Murphy Creek Formation are time-wise correlatives with the other major Upper Cambrian conglomerates seen at Saint- Simon (Day 1) although the Murphy Creek is lacking clasts of the pre-carbonate platform succession (basal sandstone, rift volcanics and metamorphic basement). These conglomerates in the Percé area are more direct correlatives with the coeval conglomerates derived from late highstand shedding in the Cow Head Group of western Newfoundland (Lavoie, 2001) (Stop figure 3.1.3).



Stop figure 3.1.3. Regional correlation for the latest Middle – earliest Late Cambrian Percé succession with coeval intervals in western Newfoundland. See Lavoie (2001) and Lavoie *et al.* (2003) for details of correlations. *Member*, Formation and **GROUP** are distinguished. C.o.B.: Corner-of-the-Beach. M.C.: Murphy Creek. From Lavoie (2001).

STOP 3.2. - Cambrian siliciclastics, Murphy Creek Formation– Cap Canon, Percé

Location: Parking lot in the village of Percé, walk along the shore (Figure 1).

Strata cropping out along the beach at Cap Canon are part of the Cambrian Murphy Creek Formation of the Percé area (Kirkwood, 1989), which consits locally of dark grey mudshales with 2-4 cm grey to brown calcilutites, minor amount of thicker silty dolomitic limestones, and 2 m thick beds of limestone conglomerate with an oolitici matrix. These conglomerates are similar to those at the Logan monument to the west (see above). Rocks of he Murphy Creek Formation at Cap Canon are unfossiliferous and higly deformed compared to younger rocks to the north.

STOP 3.3. - Silurian turbidites of a prograding delta, Indian Point Formation– Mont-Joli, Percé

Location: Parking lot in the village of Percé, walk along the shore (Figure 1). Park in the car park atop the Mont-Joli, and take the steep stairway that leads to the beach.

The Indian Point Formation succession is incomplete in the Percé area. In the Forillon Peninsula where the succession is complete (Russell, 1946; Bourque, 1977), the formation is divided into four members: the Rosebush Cove Member composed of green thick-bedded structureless fine-grained siliciclastites; the Petit Portage Member consisting of the same fine-grained siliciclastites but containing fine-grained sandstone turbidites; the Quay Rock Member, a slumped muddy limestone; and the Cape Road Member, a recurrent turbiditic unit very similar to the Petit Portage Member.

The Mont-Joli which is the cape facing the Rocher Percé, exposes a vertically dipping turbidite sequence assigned to the Cape Road Member of the Indian Point Formation (Bourque, 1977; Stop figure 3.3.1). The base of the member is faulted against the Upper Ordovician White Head Formation (Matapédia Group). A 140 m thick section of thin-bedded turbidites was measured by Hesse and Sawh (1982). Dominant sedimentary structures are parallel lamination, ripple cross-lamination, convolute lamination and sand or silt-volcanoes. Sole marks such as flute and groove casts as well as trace fossils are abundant.

Flute casts indicate a general westward sediment transport, whereas ripples observed on bedding planes rather suggest transport in an opposite direction. The Cape Road Member together with the Roncelles Formation and the other members of the Indian Point Formation have been interpreted as facies of a westward prograding delta that has buried the shallow platformal limestones of the West Point Formation (Bourque *et al.,* 1986).

Stop figure 3.3.1. Turbidite sequence of the Cap Road Member of the Indian Point Formation at Mont-Joli.

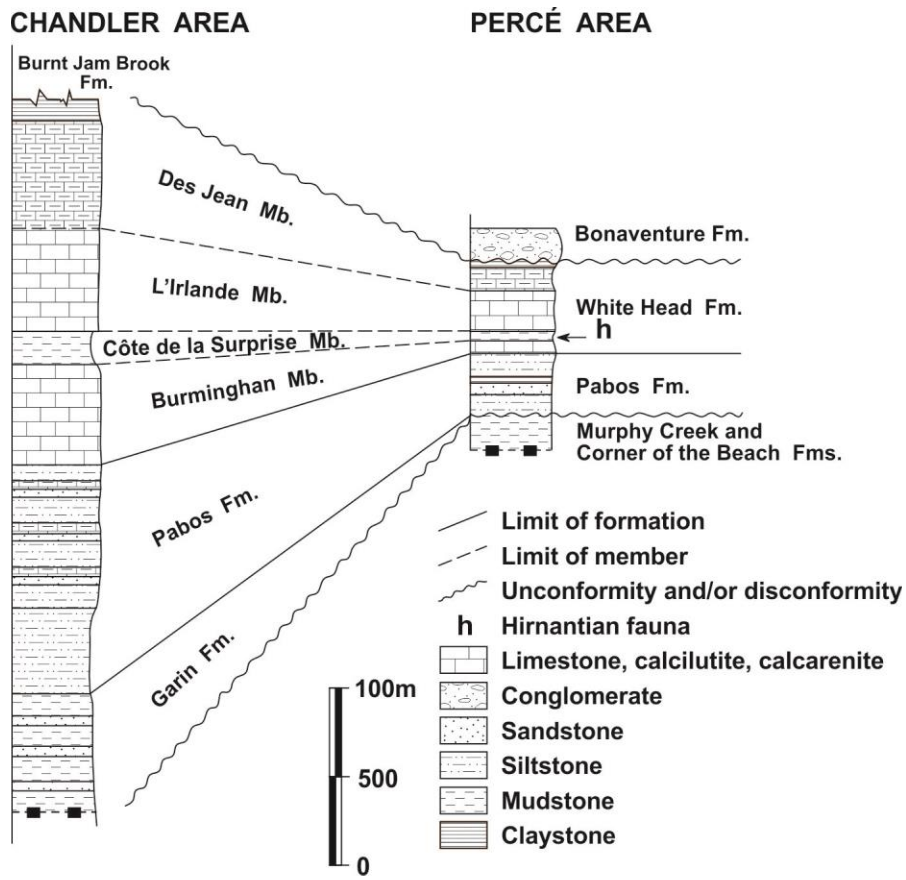
STOP 3.4. - Ordovician-Silurian turbidite limestones, White Head Formation– Cap Blanc, Percé

Location: Parking lot in the village of Percé, walk along the shore to the west, towards Cap Blanc (Figure 1).

Stratigraphy of the Ordovician and Silurian rocks in the Percé area

The White Head Formation consists of a continuous limestone sequence of Ordovician (Ashgillian) to Silurian (Llandoverian). It is the upper formation of the Matapédia basin (Malo, 2004) of the Gaspé Belt which crops out mainly in the Aroostook-Percé anticlinorium (Stop figure 2.3.2 and Figure 23). The Matapédia basin is comprised of the Honorat and Matapédia groups, Pabos and White Head formations (see sections 9.2.1.c and 9.2.1.d for the description). The Percé area contains the type section the White Head Formation, as well as the type sections of its four members (see below) and of the Rouge Member of the Pabos Formation (Lespérance *et al.*, 1987).

The Honorat Group comprises only one formation, the Upper Ordovician Garin Formation (Malo, 1988b). It is a typical turbiditic sequence which yields gratolites from the *Climacograptus spiniferus* and *Uticagraptus pygmaeus* Zones (Riva and Malo, 1988). In the Percé area, the Garin Formation is locally present in fault slices on the northeast side of Troisième Lac fault (Figure 30). The continuous sequence of Ordovician-Silurian rocks on the southwestern side of the Troisième Lac fault starts with the Rouge Member of the Pabos Formation which is composed of calcareous mudstone and siltstone, calcarenite, sandy limestone, and calcilutite (Lespérance *et al*., 1987). The Asghillian fauna of the Rouge Member is dominated by brachiopods of the *Dalmella*, *Catazyga*, *Sowerbyella* and *Epitomyonia* communites (Lespérance *et al*., 1987).



Stop figure 3.4.1. Lithostratigraphic correlations of the Ordovician-Silurian rock units of the Percé area and Chandler area. Fm.: Formation, Mb.: Member. Modified from Malo (2004).

The White Head Formation in the Percé area consists of two Ordovician members, Burmingham and Côte de la Surprise, and two Silurian members, L'Irlande and Des Jean (Lespérance *et al*., 1987; Stop figure 3.4.1). The Burmingham and L'Irlande members are two calcilutite-dominated units separated by the Côte de la Surprise member, a fine-grained siliciclatic unit. This latter member contains Hirnatian fauna (Lespérance *et al*., 1987), and the first limestone beds of the overlying L'Irlande Member are considered as the base of the Silurian.

The lower part of the Des Jean Member consists of limestone conglomerate, calcilutite, calcarenite, whereas the upper part comprises silty and argillaceous limestone, calcareaous shale and rare calcarenite beds (Lespérance *et al*., 1987). Brachiopods and trilobites faunas of the White Head Formation are described in detail in Lespérance *et al*. (1987), whereas conodonts faunas are listed in Nowlan (1981). The Burmingham Member has yielded a *Catazyga* Community and a *Sowerbyella*-like Community (Lespérance *et al*., 1987). A brachiopod-dominated community described as *Hirnantia* Community and a trilobite-dominated community, *Mucronaspis* Community, are found in the Côte de la Surprise Member (Lespérance *et al.*, 1987). The Llandoverian L'Irlande and Des Jean members have yielded brachiopods, trilobites and graptolites. They are ascribed to an *Acernaspis* Community because the trilobite genus *Acernaspis* is the most common fossils within these two members (Lespérance *et al*., 1987).

The White Head Formation at the type section, Cap Blanc (from Lespérance et al., 1987)

The Cap Blanc section begins at its northern end with strata from the Rouge Member which consist of mudshale, sandy limestone and calcilutite. Strata overlying the Rouge Member represent the unit of the White Head Formation. The Burmingham Member consists of a 130 m thick sequence of thin-bedded, grey to brown calcilutites with thinner interbeds of brown calcareous mud shales, rare bioclastic and sandy calcarenites (Lespérance *et al*., 1987). Dark green calcareous mudstone is the main rock type of the overlying 32 m thick Côte de la Surprise. The upper contact with the L'Irlande Member is faulted and the quartz arenite at the top is missing. This quartz arenite is exposed on the Deuxième Rang (Stop 3.4). L'Irlande Member is composed of grey to brown calcilutite in regular 7-15 cm beds with 2-5 cm mud shale interbeds, bioclastic thin-bedded calcarenite are locally present. A clay shale zone of 36 m thick is present in the middle of the L'Irlande Member. This clay shale zone is mappable in the entire Percé area (Kirkwood, 1989) and further west in the Aroostook-Percé anticlinorium north of Chandler (Malo, 1988a).

STOP 3.5. - Hirnantian Côte de la Surprise Member of the White Head Formation– Deuxième Rang, Percé

Location: Parking lot in the village of Percé, walk along the shore (Figure 1).

The Hirnantian Côte de la Surprise Member is a 44 m thick sequence of siliciclastic rocks between the two calcilutite-dominated members of the White Head Formation, the Ashgillian Burmingham Member and the Llandoverian L'Irlande Member (Stop figure 3.4.1). The upper and lower contacts are conformable. The Côte de la Surprise Member consists of 3 m of a sandy calcareous mudstone, 38 m of a slightly calcareous dark green mudstone, and 3 m of a well sorted, light grey, quartz arenite (Lespérance *et al*., 1987). Brachipods from the Hirnantiaa community were found in the mudstone, as well as in the arenite (Lespérance and Sheehan, 1976).

STOP 3.6. - Forillon Formation of the Upper Gaspé Limestons – Rocher Percé, Percé

Location: parking lot in the village of Percé, go to the shore and walk (Figure 10).

The jetty between the Mont-Joli and the Rocher Percé permits access to the famous rock even at high tide. The Rocher Percé is made up of vertically dipping limestone of the Forillon Formation, the basal units of the Upper Gaspé Limestones (*sensu* Lespérance, 1980a), which conformably overlies the Indian Point Formation of the Mont-Joli. In the past, it was known as the Murailles Limestone (Stop figure 3.6.1). It is a pink weathered light brown to greyish brown lime mudstone, cherty in places. For tens of years, it has attracted fossil hunters and has yielded a rich Early Devonian (Praguian) brachiopod and trilobite fauna. Trilobites as big as 30 cm long were found!

Stop figure 3.6.1. The “Rocher Percé”, made up of vertical strata of the Lower Devonian Forillon Formation, a Quebec patrimonial site.

DAY 4

SILURIAN CARBONATE UNITS – PORT-DANIEL – NEW RICHMOND AREA

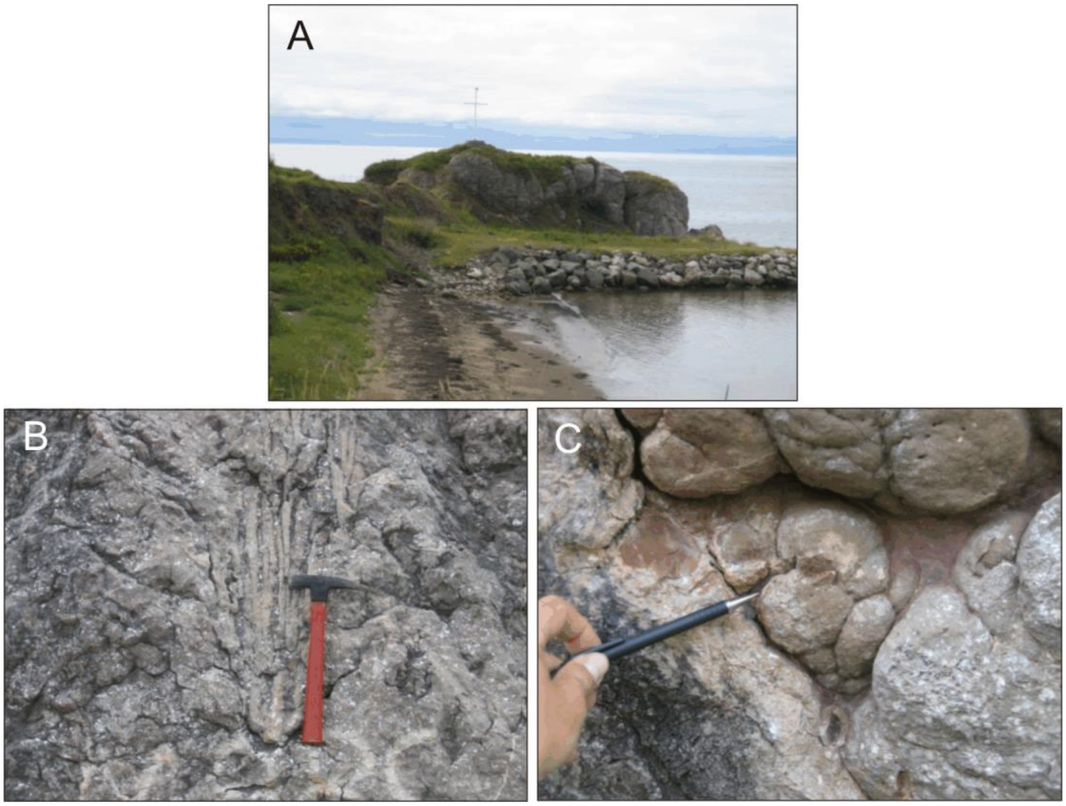
STOP 4.1. - Fore-reef facies, lower reef complex at Pointe-aux-Bouleaux, Gascon

Location: In the small village of Gascon, on road 132 going west, take the left road that goes to the shore (Figure 19).

The stop will allow to examine the foundations of the Silurian West Point Formation as well as a large blocs derived from the reef margin from the lower reef complex (Laliberté, 1982). The visited section is a shore succession; the large block is accessible even at high tide.

A mixed fine-grained siliciclastic and limestone unit is immediately underlying and surrounding the large limestone block. The fine-grained facies constitute the foundation of the West Point reefs and they record the first occurrence of limestone in the predominantly deep marine clastic shelf environment that was established at the onset of the T1 event. This succession has been named the Bouleaux Member of the West Point Formation (Bourque *et al.*, 1986). The succession consists of alternating more or less calcareous mudstone and fine-grained sandstone with some micrite beds. Rugose corals and laminar to tabular stromatoroids are scattered in the succession and form the nuclei for the deep marine mounds of the Gros Morne Member (Bourque *et al.*, 1986; Bourque and Gignac, 1983; Bourque and Raymond, 1989). Early sea floor calcite cementation has been proposed a critical element for the colonization of the sea bottom by metazoans (Bourque *et al.*, 1986).

The Pointe-aux-Bouleaux is characterized a large (40 meters by 100 meters by 3 meters visible; Stop figure 4.1.1A) limestone block. The block is set within a deep marine, syn-sedimentary deformed, fine-grained succession and is clearly exotic (see further) to this setting, therefore it can be best described as a large olistolih. The limestone is massive and non-bedded and consists predominantly of lime mud with few scattered stromatoporoids (Stop figure 4.1.1B), corals and bryozoans. Some spectacular botryoidal calcite cements are filling large cavities (Stop figure 4.1.1C); similar cements are found in modern fringing reef front (James and Ginsburg, 1976). The block is derived from the shallow marine reef facies of the Anse-à-la-Barbe Member (seen at the next stop). Under the microscope, the facies consists of microsparite with locally abundant peloids interpreted to be algal and microbial in origin (Bourque and Raymond, 1989). This framework is “cement-supported” and the block has been interpreted to be derived from a shallow (photic zone) reef margin with some significant synoptic relief (Bourque *et al.*, 1986).



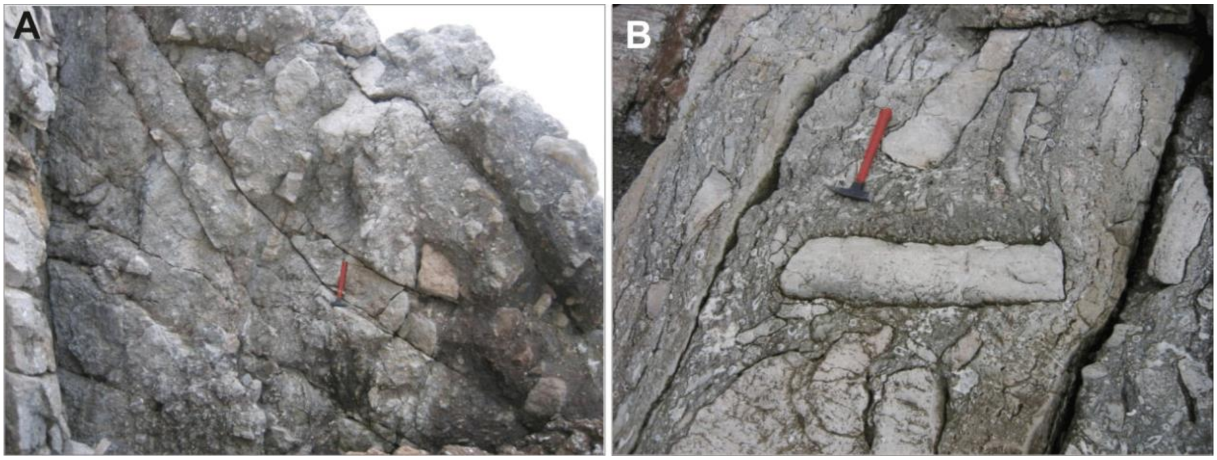
Stop figure 4.1.1. A) Large block of the algal reef facies (Anse-à-la-Barbe member) in fore-reef fine-grained clastics. B) Rare metazoan (stomatoporoid) in a predominantly micrite and cement reef facies. C) Botryoidal marine calcite cement in pore space.

STOP 4.2. - Fore-bank facies; middle bank complex, Cap de l'Enfer, Port-Daniel

Location: On road 132 going west, before getting in Port-Daniel, take the left entrance for Cap de l'Enfer (Figure 19).

This locality exposes the fore-bank facies of the crinoid-stromatoporoid biostromes middle reef complex of the West Point Formation (Anse McInnes Member; Gosselin, 1981; Bourque *et al.,* 1986). This succession has been designated the Cap de l'Enfer Member. The visited section is a shore succession and can only be entirely accessible at low tide. Of interest is the presence of water-polished stromatactis-bearing red mud blocks that are used to protect the road from wave activity, exposure of that facies at the next field trip stop are less exquisite.

The succession consists of limestone debris beds with fine-grained siliciclastic interbeds. The limestone debris beds range in thickness from 10 centimeters up to 4 meters; these beds make roughly 80% of the accessible section. The thicker limestone beds are internally highly disorganized and are interpreted as debris flow units (Bourque *et al.,* 1986) (Stop figure 4.2.1A). The nature of the debris is fairly homogeneous and consists of isolated crinoid pieces of variable sizes and shapes to large rafts of crinoidal grainstone beds; the size of the embedded bank-derived beds ranges from a few centimeters to up to 2 meters (Stop figure 4.2.1B). The presence of isolated bioclastic fragments in the matrix and blocks of the same composition argues for an early cementation of the bank margin sediments.



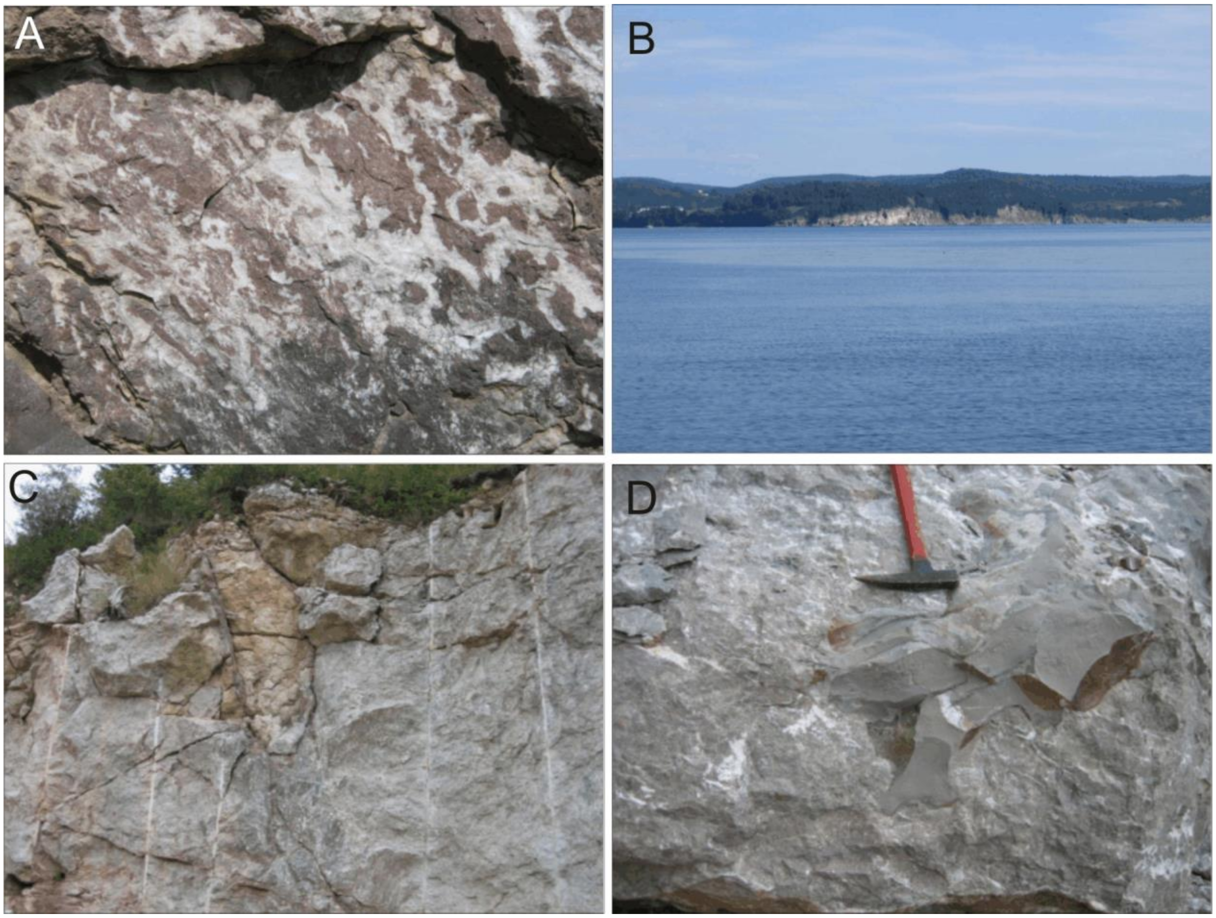
Stop figure 4.2.1. A) Disorganized debris flow units of the middle reef complex fore-reef facies (Cap de l'Enfer member). B) Large crinoidal grainstone raft set in a crinoidal-rich matrix.

The middle reef complex of the West Point is fairly thin (30 meters) and was built at the time of the major Pridolian sea level lowstand that generated the Salinic unconformity (Bourque, 2001). High frequency sea level fluctuations are recognized in the shallow marine biostromes of the bank complex (Gosselin, 1981; Bourque *et al.*, 1986) and the coarse nature of the off-bank facies are suggestive of very instable environmental conditions. A diagenetic study of the biostromes resulted in the recognition of early mixed marine and freshwater diagenesis (Bourque *et al.*, 2001b). The Anse McInnes Member underwent some major freshwater dissolution although, from the available data set, the secondary porosity was rapidly occluded by meteoric calcite cement.

STOP 4.3. - Port-Daniel quarry – Gros Morne and Anse-à-la-Barbe members

Location: Along road 132 going west, when entering Port-Daniel, to the right side near the base of the small hill going down, take the paved entrance (Figure 1). Drive less than 300 meters, the quarry is to your left.

The visited quarry is located on the north side of road 132 in Port-Daniel East. In this quarry, we will examine the lower reef complex of the West Point Formation and the effect of the Salinic sub aerial exposure on the carbonates of the lower reef complex.



Stop figure 4.3.1. A) Close-up on the stromatactis structure that is characteristic of the Gros Morne Member Width of view is 1.5m. B) The mound shape Gros Morne Member at distance. Height of the structure is close to 50m. C) Solution pipes in the algal-microbial reef facies of the Anse-à-la-Barbe Member, solution related to the Late Silurian Salinic exposure. Solution pipe is 1.75m high and 50cm wide. D) Grey siltstone infill in solution cavities of the Anse-à-la-Barbe Member.

The Anse-à-la-Barbe Member abruptly overlies the red micrite facies; it consists of grey, massive micrite facies that is largely devoid of metazoans. The microfacies consists of a cement-supported pelletoidal framework, the latter being interpreted as microbial in origin (Bourque *et al.*, 1986, 2001b; Bourque, 2001). Within the framework, isopachous crusts of fibrous marine calcite cement are recognized (Bourque *et al.*, 2001b). The Anse-à-la-Barbe Member has been interpreted as a very shallow (fringing) algal-microbial-cement reef (Bourque *et al.*, 1986). The succession from deep marine (below wave base) Gros Morne mud mound to the shallow marine Anse-à-la-Barbe reefs occurred near the end of the R2 shallowing upward event.

In the upper meters of the exposed sections of the Anse-à-la-Barbe Member in the quarry, it is possible to see a significant number of sink holes (Stop figure 4.3.1C), solution-enlarged fractures and vugs (Stop figure 4.3.1B) that are filled either by grey coloured marine sediments or by meteoric calcite cements (Bourque *et al.*, 2001b). The features are related to the Pridolian sub-aerial exposure that followed shortly after the inception of burial of the Anse-à-la-Barbe

Member; the effects of percolation of meteoric waters down to the underlying Gros Morne Member have been documented petrographically and geochemically (Bourque *et al.,* 2001b).

STOP 4.4. - The upper reef complex of the West Point Formation at Pointe du sud-ouest, Port-Daniel

Location: When exiting Port-Daniel, along road 132 going west, take the entrance for "Chalet Chaleurs", follow the road up to the lodge building (Figure 1). This is private land; ask permission to the owner to walk the path to go to the lighthouse at "Pointe de l'Ouest" (West Point).

This locality is the type section of the West Point Formation and probably the most famous section for its superb exposure of the upper reef complex of the West Point Formation. At low tide, it is possible to walk along the beach, from the west towards the point to the east and examine the transition and lateral relationships between the various fore-reef debris and background fine-grained sedimentation (various units of the Indian Point Formation) and the reef margin facies of the Colline Daniel Member. The transition resulted from lateral progradation of the reef margin over the deeper fore-reef environment (Bourque *et al.,* 1986; Bourque, 2001).

Our stop will focus on the facies of the reef margin itself, the Colline Daniel Member and the back reef or lagoonal facies known as the Sandy Cove Member. The 600 meters high Colline Daniel Member is the result of an initial prograding phase followed by an upright growth phase (Bourque and Amyot, 1989). An internal cyclicity has been recognized within each of these phases; 3 prograding events are recognized (and one local last vertical aggradation event). These events, called divisions by Bourque *et al.* (2006), relate to various relationships between rates of reef growth and sea level rise (Bourque *et al.,* 1986: Bourque, 2001). Divisions 1 to 3 are observed below the lighthouse. The lower facies assemblage (division 1; 32 meters) occurs at the base of the rocky cliff, it consists of a detrital succession with fragments of framebuilders of division 3 (e.g., various stromatoporoids); locally a cladoporid (coral) bindstone can be seen. The top of that division is marked by a coarse debris flow unit. The middle assemblage (division 2; 10 meters) consists primarily in loosely-bind coral facies with growth cavities filled by dark mud and grey micrite. Petrographic examination of the facies (Amyot, 1980; Bourque *et al.*, 1986) has revealed the presence of *Renalcis* which will eventually provide much of the binding in the upper division. Finally, the upper assemblage (division 3, 30 meters) consists of a stromatoporoid bindstone which can be associated with the high energy reef margin itself (Stop figure 4.44.1A). The facies is dominated by laminar stromatoporoids, a shape that is best adapted to the high hydrodynamic conditions experienced by the reef margin. The metazoan frame is strengthened by abundant crusts of *Renalcis* and other laminar pelletoidal material. The growth cavities are filled either by grey micrite or by isopachous crust of fibrous marine calcite cements; no pore space is visible in outcrop. Diagenetic study of the bindstone facies has demonstrated the lack of any meteoric diagenesis on the reef facies in southern Gaspé Peninsula and that primary pore space was occluded under relative shallow burial depths (1.2 km; Savard and Bourque, 1989; Bourque *et al.,* 2001b).

Stop figure 4.44.1. Upper Reef complex. A) Massive stromatoporoids-cement framestone facies forming the core of the reef margin of the Colline Daniel Member. B) Well-bedded succession of the Sandy Cove Member forming the back-reef facies. C) Rippled fine-grained sandstone of the Sandy Cove Member. D) Stacked stomatoporoid biostromes in the back-reef facies of the Sandy Cove Member. A-B photos are from Port-Daniel area and C-D photos are from northern Gaspé (Dartmouth River).

The transition from divisions 1 to 3 is interpreted to result from the progradation of a fringing reef margin (division 3) over progressively shallower settings (divisions 2 and 1); at any given specific localities, the succession records a shallowing upward trend.

Laterally equivalent to the upper bindstone facies and observed in the cove to the southwest, are well bedded facies that belong to the Sandy Cove Member (Stop figure 4.44.1B). The succession is interpreted as a back reef or lagoonal facies assemblage. The succession is divided into a lower siliciclastic rich assemblage and an upper limestone-dominated assemblage. A succession of well bedded bioclastics limestone overlies the massive bindstone of division 3, this first 10 meters thick interval is overlain by thick succession (30 meters) of nearshore mudcracked siliciclastic laminites and fine grained and rippled sandstones (Stop figure 4.44.1C) with local limestone rubbles and small *amphipora* and *Clathrodictyon* bioherms (Stop figure 4.44.1D) which are interpreted as small lagoonal patch reefs. The rest of the section (170 meters) consists of various limestone facies in which stromatoporoids and corals are abundant either as bioherms constituents or as loose elements in calcarenite beds (Bourque *et al.*, 1986).

STOP 4.5. - The Anse Cascon – Anse-à-Pierre-Loiselle – La Vieille succession at the New Richmond wharf

Location: This stop is located along the shore of the Chaleurs Bay just southwest of the wharf at New Richmond (Figure 19).

This locality is famous for the superb exposures of intertidal to supratidal lithofacies and algal/microbial structures in the La Vieille Formation. The stop will also allow us to examine the uppermost beds of the Anse Cascon Formation and walk through the Anse-à-Pierre-Loiselle Formation which separates the Anse Cascon from the La Vieille. The base of the visited section (the Anse Cascon sandstone) can be reach at fairly low tide.

The Anse Cascon Formation is Llandoverian C4–C5 in age (Bourque and Lachambre, 1980). The exposed beds consist of quartz and feldspar rich fine to coarse grained sandstone. The sandstones are calcareous with fine parallel and cross-laminations. The beds range in thickness from 10 to 50 cm (Stop figure4.5.1A). There is no detailed paleoenvironmental analysis for the Anse Cascon sandstone, although, based on its mineralogical composition, sedimentary structures, brachiopods benthic and trace fossil assemblages, the succession has been interpreted to represent a lower shoreface to shallow subtidal setting (Bourque and Lachambre, 1980; Bourque, 2001). The unit is near the end of the first 2^{nd} order regressive (R1) event in the depositional environment. The diagenetic evolution of the formation is totally unknown and its potential to form hydrocarbon reservoir needs to be better addressed given the general conclusions reached for other Lower Silurian sandstones (Lavoie and Chi, 2002).

The lower part of the exposed section is dominated by facies of the Anse-à-Pierre-Loiselle Formation, which are exposed for roughly 85 m. The formation is Llandoverian C6 in age (Bourque and Lachambre, 1980). The Anse-à-Pierre-Loiselle Formation is a siliciclastic mud dominated unit which is characterized by deeper subtidal to offshore brachiopod benthic communities (Bourque and Lachambre, 1980; Bourque, 2001); within this mud dominated assemblage, beds and lenses of Anse Cascon-type sandstone are found in the lower half of the formation and after a small (5 m) covered interval, nodules, lenses and wavy beds of impure calcilutite are found in the mud-dominated succession and heralds the overlying La Vieille Formation (Stop figure4.5.1B). The Anse-à-Pierre-Loiselle Formation is a transition unit between nearshore sandstone and mudstone of the Anse Cascon Formation and the subtidal-intertidal ramp carbonates of the La Vieille Formation (see further). A similar transition unit is not developed in northern Gaspé where the shoreface clean quartz sands of the Val Brillant Formation are immediately overlain by shallow subtidal-intertidal carbonates of the Sayabec Formation (Lavoie *et al.*, 1992 and further in guidebook).

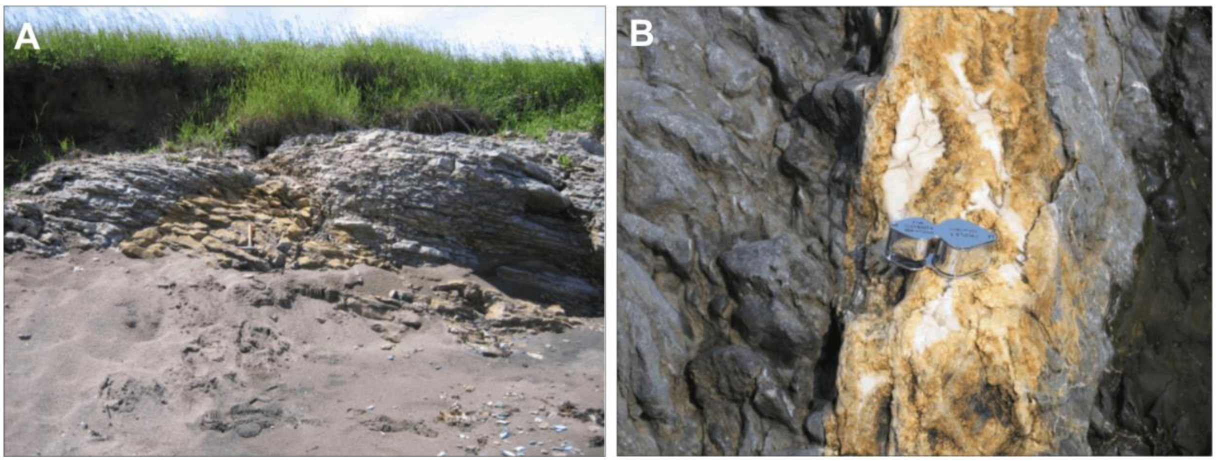
Stop figure4.5.1. A) Cross-laminated sandstone beds of the Anse-Cascon Formation. B) Typical nodular limestone of the Anse-à-Pierre-Loiselle Formation. C) Columnar stromatolites. D) Massive thrombolite (under hammer) overlain by laminated stromatolite. E) Oncolites of the cauliflower type. F) Massive thrombolite cut by numerous dolomite-filled fractures. C to F are from the New Richmond wharf section.

The limit between the Anse-à-Pierre-Loiselle and the La Vieille formations has been fixed where the fine-grained mixed limestone-mudstone succession is dominated (>50%) by limestone (Bourque and Lachambre, 1980). In southern Gaspé, the La Vieille Formation has been divided into 3 members (Bourque and Lachambre, 1980; Desrochers, 1981; Lavoie *et al.*, 1992). At this section, the lower member consists of roughly 115 meters of wavy-bedded to nodular argillaceous lime mudstone with subordinate limy mudstone interbeds. Both the limestone and mudstone are fauna-rich with brachiopods, stromatoporoids, crinoids, tabulate and rugose corals, the succession has been dated as Llandoverian C6 and the fauna is interpreted as an open marine predominantly offshore assemblage (Desrochers, 1981). It is noteworthy that in the upper most meters of the lower member, a coral-rich dark mudstone facies is developed with local pyritization of corals; this peculiar facies has been interpreted as a restricted, possibly lagoonal facies (Bourque *et al.,* 1986). Rock Eval analysis of this black facies has yielded slightly-enriched TOC value (0.6%).

The transition with the middle member of the La Vieille Formation is abrupt as well bedded limestone facies sharply overlies the nodular-wavy bedded unit. The middle member is roughly 80 meters thick and is dominated by an intertidal-supratidal assemblage of mudcracked (?) laminite, oncolite, stromatolite, thrombolite and dense micrite (Facies I of Bourque *et al.*, 1986). Subordinate facies include peloidal and intraclastic packstone to grainstone calcarenite and rare oolitic grainstone. The microbial-dominated stromatolite / thrombolite structures are particularly well developed with the internally laminated stromatolites forming thin cm-crusts, low relief heads, closely-packed cm-high columns, and elongated mounds up to half a meter in relief (Stop figure4.5.1C). The non laminated, massive to internally digitate thrombolite form decimeter to meter-high mound-shaped structures (Stop figure4.5.1D) which in many places form the substrate for overlying stromatolites (Stop figure4.5.1D). The petrographic examination of the stromatolite / thrombolite assemblage has revealed the abundance of peloidal material with a clotted texture; these are interpreted as cryptomicrobial in origin (Lavoie, 1988; Lavoie *et al.*, 1992). In these structures, true algal material (green algae) is present but only constitutes a minor component of the rock. On the other hand, Codiacean green algae are abundant in the oncolites, most of which are of the cauliflower type (Stop figure4.5.1E). The entire succession is largely devoid of macrofauna, with few ostracods and gastropods being associated with the predominantly algal-microbial facies. Near the base of the middle member, some of the limestone facies (thrombolites, stromatolites and dense micrite) are intensely fractured and brecciated (Stop figure4.5.1F); the fractures are filled with calcite and coarse-grained brownish saddle dolomite, the study of which has yet to be initiated (see further).

The transition with the upper member is abrupt as the well-bedded limestone is overlain by nodular to wavy-bedded fine-grained limestone. This upper unit is roughly 30 m thick and resembles the lower member of the La Vieille Formation with the noticeable distinction that the upper member is significantly less fossiliferous than the lower one. This has been interpreted by Bourque *et al.* (1986) as the result of a rapid sea level rise that did not allow stable conditions enough for organism to establish themselves. This rapid sea level rise marks the onset of the T2 event in the basin (Bourque *et al.,* 2001a) and has been associated with extensional tectonics related to the inception of Acadian foreland basin (Bourque *et al.,* 2001a). The limestone component of the upper member rapidly disappear and the succession passes into the below wave base mudstone-siltstone facies of the Gascon Formation.

The La Vieille Formation occurs in northern New Brunswick and recent work allowed to recognize a significant hydrothermal dolomitization event affecting its middle member (Lavoie and Chi, 2006). High temperature saddle dolomite has been documented as well as fracture-controlled pervasive dolomitization of the facies (Stop figure 4.5.2). The dolomitization of the La Vieille only occurs (from the limited available field outcrops) where the carbonate facies stratigraphically overlies the Ordovician mafic volcanics of the Fournier Group in the Elmtree Inlier (Lavoie and Chi, 2006; Lavoie and Pinet, 2008), suggesting a nearby source for Mg+2. The dolomite-filled fractures seen at this stop could indicate that dolomitization of the Lower Silurian carbonate might be more regional in scope than previously assumed.



Stop figure 4.5.2. A) Pervasive dolomitization of the La Vieille Formation with a well defined dolomitzation front away from a central feeder. B) Brownish saddle dolomite with late white calcite cements in a fracture that cuts through the La Vieille Formation. Both photos are from Northern New Brunswick exposures and details can be found in Lavoie and Chi (2006).

DAY 5

LATE DEVONIAN – MIGUASHA, CHALEURS BAY AREA

STOP 5.1. - The Devonian Miguasha Fossil Site.

Location: Miguasha National Park, Miguasha.

Information on the Miguasha fossil site can be found on these two websites:

Parc national de Miguasha (http://www.sepaq.com/pq/mig/) and Wikipedia

(https://en.wikipedia.org/wiki/Miguasha_National_Park#Miguasha_Natural_History_Museum).

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The Organizing Committee acknowledges financial support from the following organisations :