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Structural style and tectonostratigraphy of the external-internal Humber zone boundary in the Sainte-Marie–Saint-Sylvestre area, Quebec Appalachians[1]

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Abstract

The geology of the Sainte-Marie-de-Beauce–Saint-Sylvestre area depicts a tectonostratigraphic, structural, and metamorphic transition that characterizes the boundary between the external and internal Humber Zone. It also corresponds to a region of reversal in structural vergence and tectonic transport, i.e. from foreland-directed structures in the northwestern part to hinterland-directed structures in the southeastern part. A series of thrust nappes make up tectonostratigraphic packages that are correlated to various stratigraphic units: the Sainte-Hénédine, Rivière Filkars, Richardson, and Oak Hill nappes comprise rocks units of the Île d'Orléans, Saint-Roch, Armagh, and Oak Hill groups, respectively. To the southeast, the Bennett Fault separates these nappes from *metamorphosed and polydeformed lithologies of the Rosaire Group and Bennett Schists. The Bennett Fault is a southeast-directed backthrust fault, which best corresponds to the dominant structure representing the boundary between the external and internal Humber Zone.*

Résumé

La géologie de la région de Sainte-Marie-de-Beauce–Saint-Sylvestre représente une transition tectono-stratigraphique, structurale et métamorphique qui caractérise la limite entre la zone de Humber externe et interne. Elle correspond aussi à une région d'inversion de la vergence structurale et du transport tectonique dominant, c.-à-d. où les structures dirigées vers l'avant-pays dans le nord-ouest passent à des structures dirigées vers l'arrière-pays dans le sud-est. Une série de nappes de chevauchement forment des assemblages tectonostratigraphiques qui sont mis en corrélation avec diverses unités stratigraphiques : les nappes de Sainte-Hénédine, de Rivière Filkars, de Richardson et d'Oak Hill comprennent des unités lithologiques des groupes de l'Île d'Orléans, de Saint-Roch, d'Armagh et d'Oak Hill, respectivement. Vers le sud-est, la Faille de Bennett sépare ces nappes des lithologies métamorphisées et polydéformées du Groupe de Rosaire et des Schistes de Bennett. La Faille de Bennett est une faille de rétrochevauchement dirigée vers le sud-est qui correspond le mieux à la structure dominante représentant la limite entre la zone de Humber externe et interne.

INTRODUCTION

The transition between external and internal (i.e. foreland-hinterland) domains represents key areas for a better understanding of orogenic belt architectures. In such regions, sudden or major breaks in tectonostratigraphic assemblages, structural style, and metamorphic grade often occur, thus creating an apparent discontinuity in tectonic style and evolution. In the Quebec Appalachians, such a transition zone occurs 50 km south of Québec, where the northwest-directed Richardson Fault has been classically identified as the boundary between the external and internal domains of the Humber Zone (St-Julien and Hubert, 1975; St-Julien et al., 1983); however, recent studies in southern Quebec (Tremblay and Pinet, 1994; Pinet et al., 1996a, b; Castonguay, 2000) have shown that the structural style and metamorphic characteristics of the internal Humber Zone have been greatly influenced by a major hinterland-directed tectonic event that includes southeast-verging backfolding, backthrusting, and normal faulting. This contrasts strongly with the classical foreland-directed structural evolution of the fold and imbricated thrust belt constituting the Humber Zone. In terms of tectonostratigraphy, the study area lies in a region where lithostratigraphic facies and nomenclatures of the Lower St. Lawrence area and southern Quebec Appalachians converge, and where metamorphic and tectonic overprint has obscured original stratigraphic relationships. In addition, rock assemblages vary significantly between each of the thrust nappes (e.g. Slivitsky and St-Julien, 1987; Lebel and Hubert, 1995a, b), and offer only sparse age constraints, thus resulting into a complex regional tectonostratigraphic framework that hinders regional (across- and along-strike) stratigraphic correlations.

This ongoing study aims to clarify and better understand the structure, stratigraphy, and tectonic evolution of the external and internal Humber zone boundary along transect #2 (Québec–Chaudière) of the Geological Bridges of Eastern Canada Project. The study area lies in the eastern half of the NTS 21 L/6 map area (Saint-Sylvestre) in the Quebec Appalachians. It occurs at the northeastern periclinal termination of the Notre-Dame anticlinorium, a prominent feature of the internal Humber Zone, and encompasses the transition zone between the external and internal domains of the Humber Zone (Fig. 1).

GEOLOGICAL SETTING

The Quebec Appalachians comprise two tectonostratigraphic rock packages of pre-Silurian age, the Humber and Dunnage zones (Fig. 1; Williams, 1979) that are juxtaposed along the Baie Verte-Brompton Line (Williams and St-Julien, 1982). The Humber Zone is made of Eocambrian to Ordovician rift-drift, continental passive margin, and foreland basin and olistostromal rock sequences, whereas the Dunnage Zone comprises ophiolitic complexes, volcanic rocks, mélange, and synorogenic flysch deposits. To the southeast, Silurian–Devonian successor basin units of the Gaspé Belt (Bourque et al., 1995) unconformably and structurally overlie the Dunnage Zone. The Humber Zone is the result of the destruction of the Laurentian continental margin by the accretion of units of oceanic affinities (i.e. the Dunnage Zone), during a tectonic event that is classically referred to as the Taconian Orogeny (Middle–Late Ordovician; St-Julien and Hubert, 1975; Pinet and Tremblay, 1995). Along the Humber Zone, the Taconian event is manifested by foreland-directed thrust faulting, nappe emplacement, and regional prograde metamorphism. A renewal of tectonic activity during the Silurian–Early Devonian has consisted of hinterland-directed deformation, mainly backthrusting and extensional faulting, and pervasive metamorphic retrogression associated with the tectonic exhumation of the internal Humber Zone (Castonguay et al., 1997, 2001). The Humber and Dunnage zones were also variously affected by the Middle to Late Devonian Acadian Orogeny, which caused greenschist-grade regional metamorphism and deformation along the Gaspé Belt (Pinet and Tremblay, 1995; Tremblay et al., 2000).

Regional structures and major faults of the Quebec Appalachians south of Québec, from north to south (Fig. 1, 2), are described below.

1. Logan's Line defines the limit between the allochthons of the external Humber Zone and parautochthonous and autochthonous rocks of the St. Lawrence Lowlands platform (St-Julien and Hubert, 1975).

2. A series of thrust sheets (generally referred to as nappes) lies to the south of Logan's Line — the Chaudière, Sainte-Hénédine, Rivière Filkars (new term), Richardson, and Oak Hill nappes. The Richardson nappe is underlined by the Richardson Fault, a folded thrust that carries the Sainte-Marguerite Complex (Vallières, 1971; Vallières et al., 1978) that contains granitic gneiss and amphibolitic and quartzite fault slivers of Grenvillian age and affinity. The southwestern extension of the Richardson Fault in the study area is uncertain and will be discussed below.

3. The Bennett Fault (Pinet et al., 1996a) is a southeast-directed backthrust fault that delineates the northwestern limb of the Notre-Dame Mountains anticlinorium.

4. The St-Joseph Fault is a southeast-dipping system of normal faults and shear zones (Pinet et al., 1996b) marking the southeastern limb of the Notre-Dame Mountains anticlinorium.

5. The Pennington sheet (St-Julien, 1987) is a discontinuous and folded segment of brecciated and sheared serpentinite and talc-carbonate schist occurring in two perpendicular branches. The northeastern branch delineates the St-Joseph Fault, whereas the northwestern branch is associated with the Bennett Schists as it shares analogous structural complexity and metamorphic facies (Tremblay and Pinet, 1994).

Among these faults, the Bennett and St-Joseph faults are characterized by significant metamorphic breaks, with low-grade to sub-greenschist-grade rocks in their hanging wall and middle-greenschist- to locally lower-amphibolite-grade rocks in their footwall (i.e. within the Notre-Dame Mountains anticlinorium; Birkett, 1981; Castonguay, 2000).

STRATIGRAPHY

The stratigraphy of the study area can be summarized into lithological packages resting on both sides of the Bennett Fault (Fig. 3). Four packages form nappes lying northwest of the Bennett Fault: from northwest to southeast, the Sainte-Hénédine, Rivière Filkars, Richardson, and Oak Hill nappes. Two rock packages outcrop southeast of the Bennett Fault — the Rosaire and Caldwell groups, and the Bennett Schists (Notre-Dame Mountains anticlinorium). The lack of exposure in the northwestern corner of the study area has made difficult lithological descriptions and mapping. That region has been designated as part of the Saint-Bernard and Coulombe nappes by St-Julien (1995); it includes the Rivière Etchemin olistostrome, and the Lévis and Bullstrode formations (Slivitsky and St-Julien; 1987; P. St-Julien, unpub. map, 1970; J. Müller, unpub. map, 1970).

Northwest of the Bennett Fault

Sainte-Hénédine nappe

Three main rock assemblages are recognized in the Sainte-Hénédine nappe (Fig. 3), and are correlated to the Île d'Orléans Group (Slivitsky and St-Julien, 1987). From the inferred base to top, they are described in Table 1.

Rivière Filkars nappe

Four main rock assemblages are regionally recognized in this newly defined nappe (Fig. 2, 3). They are correlated to the Saint-Roch Group (Vallières, 1984) and are described in Table 2.

Richardson nappe

The Richardson Nappe is dominantly constituted of green quartzitic sandstone, locally red, with silty interbeds, and subordinate green and purple slate beds (unit AR in **Fig. 2**, **3**), which are correlated to the Armagh Group (Béland, 1957).

Oak Hill nappe

The Oak Hill Nappe is made of five lithological assemblages, correlative to the Oak Hill Group (Clark, 1936), that outcrop along the hanging wall of the Bennett Fault (Fig. 2, 3). These units make a thin band of roughly 900 m, which prevents us from differentiating all of them on Figure 2. From base to top, they are described in **Table 3**.

Southeast of the Bennett Fault

Rosaire and Caldwell groups

The Rosaire Group (unit RO in Fig. 2, 3; Béland, 1957; Benoit, 1958) occupies the southeastern part of the study area, northeast of the axial termination of the Notre-Dame Mountains anticlinorium, and along the hanging wall of the St-Joseph Fault (Fig. 3). It comprises monotonous successions of interbedded white to medium grey orthoquarztite and medium to dark grey phyllite, both locally greenish (**Fig. 4G**). Occasional quartzitic siltstone and feldspathic metasandstone also occur. The matrix of some quartzite beds is dolomitic, especially in the southeastern part of the study area. Metamorphism increases from northeast to southwest within the Rosaire Group along the Notre-Dame Mountains anticlinorium axis, so that rocks generally become richer in chlorite, and sericite is gradually transformed into muscovite. The Caldwell Group (unit CW, Mackay, 1921) occurs southeast of the St-Joseph Fault, either in its immediate footwall or as structural windows through the Rosaire Group. The Caldwell Group is made of alternating succession of purplish-red and green feldspathic sandstone and slate, with minor orthoquartzite beds. Regionally, volcanic rocks are also present at the base of the succession. Southeast of the St-Joseph Fault (i.e. hanging wall), rock units of the Rosaire and Caldwell groups are faintly metamorphosed and have preserved primary structure, which marks a strong contrast with similar units along the footwall of the fault.

Bennett Schists

Traditionally, within the Notre-Dame Mountains anticlinorium, intensely deformed and metamorphosed lithologies have been undifferentially called the Bennett Schists (St-Julien and Hubert, 1975); however, a careful examination allows to distinguish three lithostratigraphic facies that are equivalent to stratigraphic units occurring in areas surrounding the Notre-Dame Mountains anticlinorium, namely the Oak Hill, Caldwell, and Rosaire facies (**Fig. 3**). Metaquartzite and dark grey phyllite of the Rosaire facies (unit BSro) and metasandstone and purple and green phyllite of the Caldwell facies (BScw) become micaceous schist units that have developed a penetrative metamorphic differentiation. The Oak Hill facies occurs along the footwall of the Bennett Fault southwest of the study area.

STRUCTURE AND METAMORPHISM

Three deformation and metamorphic events have affected rocks of the study area. All these events (D_1 to D_3) are associated to mesoscopic structural features such as fabrics and folds. Except for the D_3 phase, they are also characterized by a metamorphic paragenesis (e.g. M_1 and M_2) that generally increases in grade from northwest to southeast and from northeast to southwest, towards the Notre-Dame Mountains anticlinorium.

The oldest phase, D_1, is characterized by a regionally developed foliation. The metamorphic grade increases from prehnite-pumpellyite to lower greenschist grade toward the southeast as the S_1 fabric evolves from a slaty cleavage into a penetrative metamorphic schistosity (Birkett, 1981; Castonguay, 2000). Associated folds vary accordingly in style from open to isoclinal. The S_1 fabric is marked by a metamorphic assemblage of sericite+chlorite in the Rivière Filkars nappe and muscovite+chlorite+albite±chloritoid in metapelite or chlorite+epidote±magnetite±amphibole in metavolcanic rocks of the Oak Hill nappe and southeastward in the footwall of the Bennett Fault (**Fig. 2**). In central and southeastern part of the study area, and especially along the Notre-Dame Mountains anticlinorium, the D_1 fabrics have been severely overprinted by a D_2 deformation event. The intensity of D_2 features rapidly increases towards the southeast, with an abrupt gradient in the southeastern part of the Rivière Filkars nappe. The S_2 fabric evolves from a fracture cleavage (Sainte-Hénédine nappe) or a crenulation cleavage (Rivière Filkars nappe) in the northwestern part of the study area, to a penetrative foliation along and southeast of the Bennett Fault (Fig. 2; compare **Fig. 4A**, **C**, and **E**). The M_2 metamorphic paragenesis, mainly chlorite and white mica, is retrogressive compared to M_1, and appears along the S_2 fabric in the southeastern part of the Rivière Filkars nappe. On the northwestern limb of the Notre-Dame Mountains anticlinorium, the S_2 fabric dips to the northwest and is axial-planar to southeast-verging folds that evolve from open to close (**Fig. 4D**), and become mostly isoclinal in the vicinity of the Bennett Fault (**Fig. 4G**). Along the southeastern limb of the Notre-Dame

Mountains anticlinorium, the S_2 fabric dips southeastward, is associated to southeast-verging folds, and is locally affected by southeast-dipping brittle-ductile shear zones that have been interpreted as structures related to the St-Joseph Fault (**Fig. 4H**; Pinet et al., 1996b). Southeast of the Bennett Fault, both D_1 and D_2 structures and fabrics are affected by northeast-trending, gently northeast-plunging open folds that are associated to a S_3 axial-planar fracture and/or crenulation cleavage that does not contain any metamorphic minerals. In the footwalls of the Bennett and St-Joseph faults, pre-existing fabrics, wrap around the axis of the Notre-Dame Mountains anticlinorium, which is interpreted as a major D_3 structure (Tremblay and Pinet, 1994).

Recent studies have provided isotopic age constraints on the timing of metamorphism and deformation in and around the internal Humber Zone (Whitehead et al., 1996; Castonguay et al., 1997, 2001; Castonguay, 2000). The D_1 event is dated by muscovite and amphibole $^{40}Ar/^{39}Ar$ analyses at 462 ± 3 Ma (late Middle Ordovician) and is interpreted to represent the timing of Taconian metamorphism. Amphibole, biotite, and muscovite $^{40}Ar/^{39}Ar$ plateau ages have established the timing of hinterland-directed deformation (D_2) between 431 Ma and 411 Ma (Silurian to Early Devonian).

DISCUSSION

Tectonostratigraphic correlations

The lithostratigraphic nomenclature of the Humber Zone south of Québec is complex, and has been a controversial subject since the end of the 19th century (Ells, 1889). The numerous appellations have essentially come from a misunderstanding of the regional structure and lack of chrono- and biostratigraphic constraints. A recent overview concerning the evolution of the stratigraphic nomenclature is provided by Lebel and Hubert (1995b). In the study area, most rock packages, or nappe stratigraphy, have been assigned different appellations. More intense deformation and higher metamorphic grade in the southeastern regions have also hindered formal stratigraphic assignments. A tentative clarification, essentially based on regional lithological correlations and tectonostratigraphic setting, is presented below.

Sainte-Hénédine nappe

Rock units of the Sainte-Hénédine nappe have been called the Sainte-Hénédine Formation by St-Julien and Osborne (1973), and include the “Ordovician Pelites” of Vallières (1984) (Slivitsky and St-Julien, 1987). Depending on the authors, two main rock assemblages and/or up to eight facies were identified, although no type sections have ever formalized the Sainte-Hénédine appellation. North of the study area, in the Saint-Malachie region, Lebel and Hubert (1995a) have undifferentially ascribed these units to the Île d’Orléans Group (Slivitsky and St-Julien, 1987), based on lithological similarities, tectonostratigraphic correlations, and similar structural position of the Sainte-Hénédine and Bacchus nappes. Although units of the Sainte-Hénédine nappe are more deformed and metamorphosed, they possibly represent distal equivalents of the Bacchus nappe lithologies, we thus agree with such a lithostratigraphic correlation. Therefore, assemblages SH1, SH2, and SH3 described herein are correlated to the l’Anse-Maranda, Lauzon, and Pointe-de-la-Martinière formations, respectively.

Rivière Filkars and Richardson nappes

In the study area, rock assemblages lying in the hanging wall of the Sainte-Hénédine nappe have either been assigned to the Oak Hill and Saint-Roch groups (Slivitsky and St-Julien, 1987) or to the Armagh Group (Benoit, 1958; Armagh Formation of Lebel and Hubert (1995b)). The Saint-Roch and Armagh groups are traditionally considered as lateral equivalents. The Armagh Group is, however, coarser (90% sandstone, 10% slate) than the Saint-Rock Group (50% sandstone, 50% slate; Lebel and Hubert, 1995a, b), and apparently occurs exclusively in the hanging wall of the Richardson Fault. No formal internal stratigraphy of the Armagh Group has been defined, although a series of cyclical lithofacies have been recognized (Lebel and Hubert, 1995a, b). Therefore, rocks units of the Richardson nappe are undifferentially assigned to the Armagh Group. As for the Rivière Filkars nappe, a tentative correlation is made with the Saint-Roch Group (Vallières, 1984) that constitutes most of the Rivière Boyer nappe northeast of the study area (Lebel and Hubert, 1995a, b). As such, the basaltic volcanic rock unit (unit SR1) is correlated to the Montagne Saint-Anselme Formation. The purple and green slate and phyllite beds and associated coarser sandy and conglomeratic units (unit SR2) are associated to the Orignal Formation (Lajoie, 1972; Vallières, 1984).

Oak Hill nappe

Benoit (1958) and Charbonneau (1981) have correlated lithological assemblages of the Oak Hill nappe to the Oak Hill Group. We acquiesce with this correlation. As such, rock units are respectively assigned to the Tibbit Hill Formation (unit OH1), Pinnacle Formation (unit OH3), which includes Call Mill Member (unit OH2), and the White Brook (unit OH4) and West Sutton (unit OH5) formations.

Structural style and tectonic evolution

The study area lies in a zone of rapid changes in style and intensity of structural and metamorphic features, which characterize the transition between the external and internal Humber Zone in southern Quebec. The area also corresponds to a region of reversal in overall tectonic vergence and transport, i.e. from foreland-directed structures in the northwestern part to hinterland-directed structures in the southeastern part. Based on our observations, the Bennett Fault (not the Richardson Fault) represents the dominant structure that controls this transition. North of the study area, the Richardson Fault marks the contacts between the Richardson and Sainte-Hénédine nappes, and is delineated by the Sainte-Marguerite Complex and the Rivière Boyer Mélange (Lebel and Hubert, 1995a), both of which have not been recognized in the study area. We therefore think that the Richardson Fault is most probably truncated by the Bennett Fault, which is delineated by intense D_2 shear fabrics just east of Sainte-Marie-de-Beauce (Fig. 2, 4G). Southwestward in the study area, the contact between the Rivière Filkars and Sainte-Hénédine nappes is illustrated as an early thrust fault that is crosscut, to the northeast, by the Richardson Fault. The Rivière Filkars nappe thus lies in a similar structural setting as the Rivière Boyer nappe (Lebel and Hubert, 1995a, b), and is overlain by the Richardson nappe (Fig. 3). As for the Oak Hill nappe, it apparently represents the uppermost nappe of the region, which was subsequently backthrusted by movement on the Bennett Fault (Fig. 2, 3).

The northeastern axial termination of the Notre-Dame Mountains anticlinorium is a complex region that comprises the Pennington sheet, and various polyfolded bands of phyllite, schist, and quartzite assigned to the Bennett Schists or Rosaire Group (St-Julien , 1987; Slivitsky and St-Julien, 1987). The limit between the Bennett Schists and lithologies to the northeast has not been previously defined. We suggest that it lies at the contact separating Rosaire Group facies rocks of the Bennett Schists from a slice of green and red slate and green sandstone, which are inferred to be part of the Saint-Roch Group outcropping along the hanging wall of a folded D_2 backthrust, genetically related to the Bennett Fault (Fig. 2).

On the basis of structural, kinematic, and metamorphic characteristics, and isotopic geochronological data, the tectonic evolution of the Humber Zone can be segmented into three distinct tectonic events. In the study area, the D_1 event comprises foreland-directed thrust faulting, nappe emplacement, and regional metamorphism that increases in intensity towards the southeast. This event is attributed to the classical Taconian Orogeny, which has been related to the obduction and emplacement of large ophiolitic nappes and/or arc collision along the Laurentian margin during the Middle to Late Ordovician (St-Julien and Hubert, 1975; Pinet and Tremblay, 1995). The Silurian to Early Devonian D_2 event depicts a vergence reversal of regional deformation by hinterland-directed faulting, possibly due to the tectonic wedging of basement-cored duplexes, that induced the delamination of supracrustal rocks (Pinet et al., 1996a; Castonguay, 2000). Coeval and subsequent extension along the St-Joseph Fault and related structures has juxtaposed rock units of distinct metamorphic and deformation styles, and favored the exhumation of the footwall metamorphic rocks (Pinet et al., 1996b; Castonguay, 2000). The D_3 event is correlated to the Acadian Orogeny, and has caused arching of pre-existing regional structures and created the actual geometry of the Notre-Dame Mountains anticlinorium.

CONCLUSIONS

This ongoing study has permitted to draw some conclusions that will be further investigated and refined. The most prominent are listed below.

1. The geology of the study area represents a structural and metamorphic transition zone that characterizes the boundary between the external and internal domains of the Humber Zone. It corresponds to a region of reversal in overall structural vergence and tectonic transport, i.e. from foreland-directed structures in the northwestern part to hinterland-directed structures in the southeastern part.

2. The Richardson Fault is folded by F_2 folds and crosscut by the northeastern extension of the Bennett Fault in the Sainte-Marie-de-Beauce area. The Richardson Fault separates dominantly coarser rocks units (Armagh Group) of the Richardson nappe to the north, from generally finer grained rock units (unit SR; Saint-Roch) of the Rivière Filkars nappe to the south.
3. The Bennett Fault best corresponds to the dominant structure representing the boundary between the external and internal domains of the Humber Zone.
4. The rock packages of nappes occurring northwest of the Bennett Fault are correlated to formal stratigraphic units. Assemblages of the Sainte-Hénédine nappe, although more deformed and metamorphosed, are ascribed to the Île d'Orléans Group outcropping in the Bacchus nappe. Assemblages of the Rivière Filkars, Richardson, and Oak Hill nappes are correlative to the Saint-Roch, Armagh, and Oak Hill groups, respectively.
5. The northeastern periclinal termination of the Notre-Dame Mountains anticlinorium is marked by a D_2 backthrust fault, genetically related to the Bennett Fault, which juxtaposes the Saint-Roch Group against the Bennett Schists.

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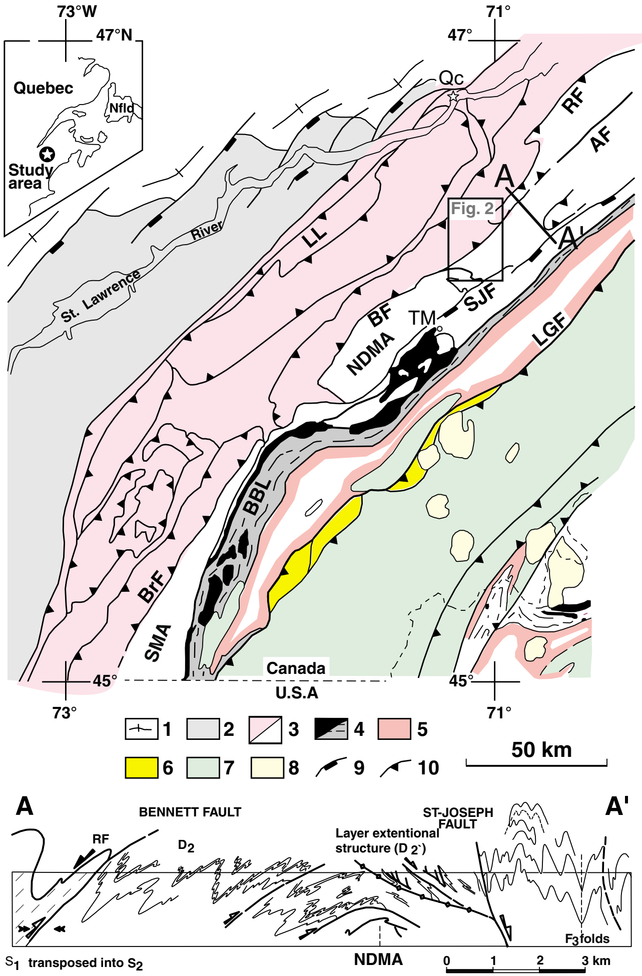

Figure 1. Simplified geological map and schematized cross-section of southern Quebec Appalachians, (*modified from* Castonguay, 2000). 1, Grenvillian rocks; 2, Cambrian-Ordovician rocks of the autochthonous platform sequence; 3, fault-imbricated continental margin rocks (Humber Zone; external subzone is dashed); 4, ophiolitic rocks (in black) and mélange units (St.-Daniel mélange; in grey); 5, syn-Taconian flysch deposits (Magog Group); 6, arc-related volcanic rock; 7, post-Taconian, Late Silurian and Devonian rocks (e.g. Gaspé Velt); 8, syn- to post-Acadian intrusive rocks; 9, normal fault; 10, thrust fault; AF, des Abénaquis Fault; BBL, Baie Verte-Brompton Line; BF, Bennett Fault; BrF, Brome Fault; LGF, La Guadeloupe Fault; LL, Logan's Line; RF, Richardson Fault; SJF, St.-Joseph Fault; NDMA, Notre-Dame Mountains anticlinorium; SMA, Sutton Mountains anticlinorium; Qc, Québec; TM, Thetford Mines. *See* inset for location and text for discussion.

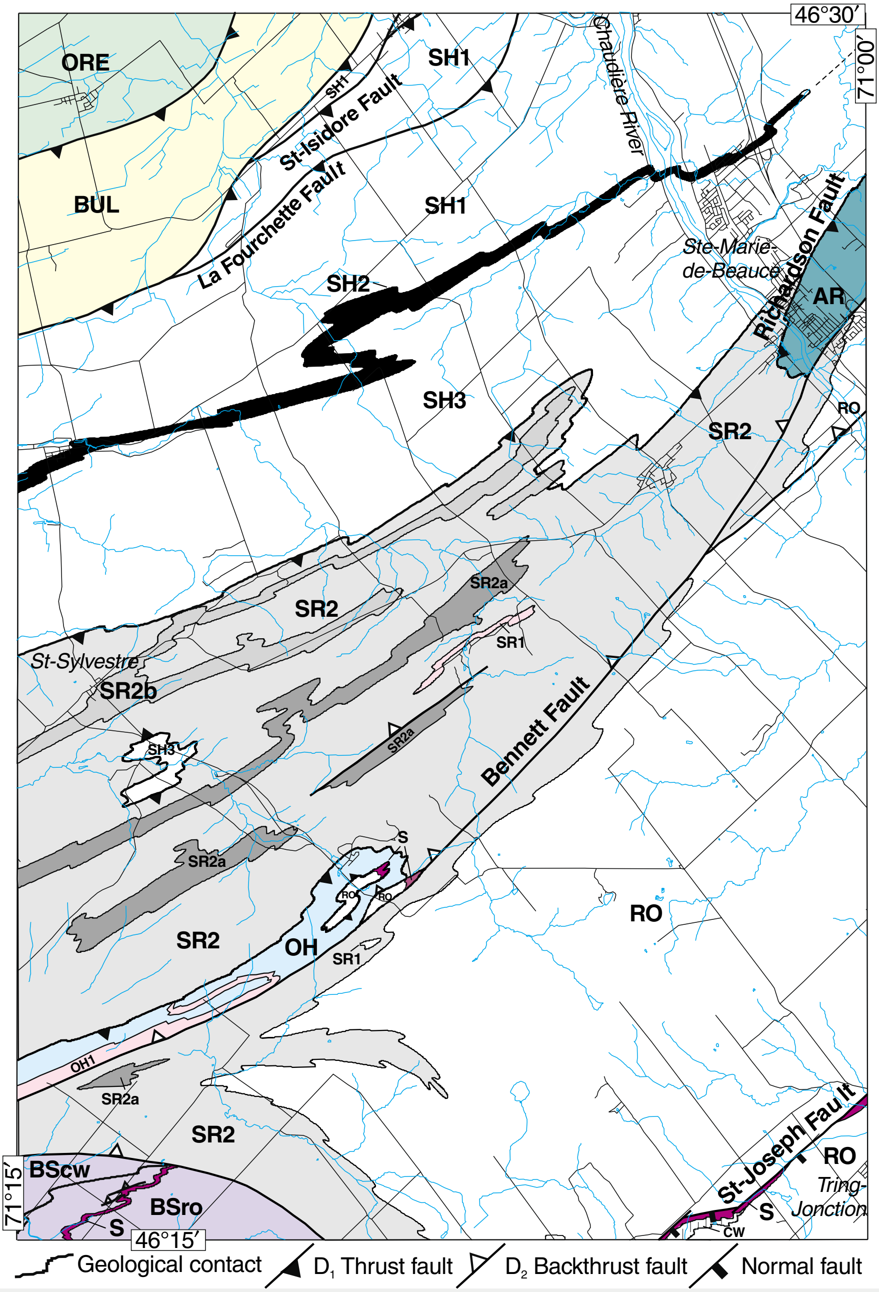

Figure 2. Preliminary geological map of the Sainte-Marie–Saint-Sylvestre area. *See* Figure 1 for location, and refer to text for lithological descriptions. ORE, Rivière Etchemin olistostrome; BUL, Bullstrode Formation; SH, Sainte-Hénédine nappe (SH1, SH2, SH3: Île d'Orléans Group); SR, Rivière Filkars nappe (SR1, SR2a, SR2b: Saint-Roch Group); AR, Richardson nappe (Armagh Group); OH, Oak Hill nappe (undifferentiated Oak Hill Group; OH1, Tibbit Hill Fm.); RO, Rosaire Group; CW, Caldwell Group; BSro, Bennett Schists Rosaire facies, BScw, Bennett Schists Caldwell facies; S, serpentinite.

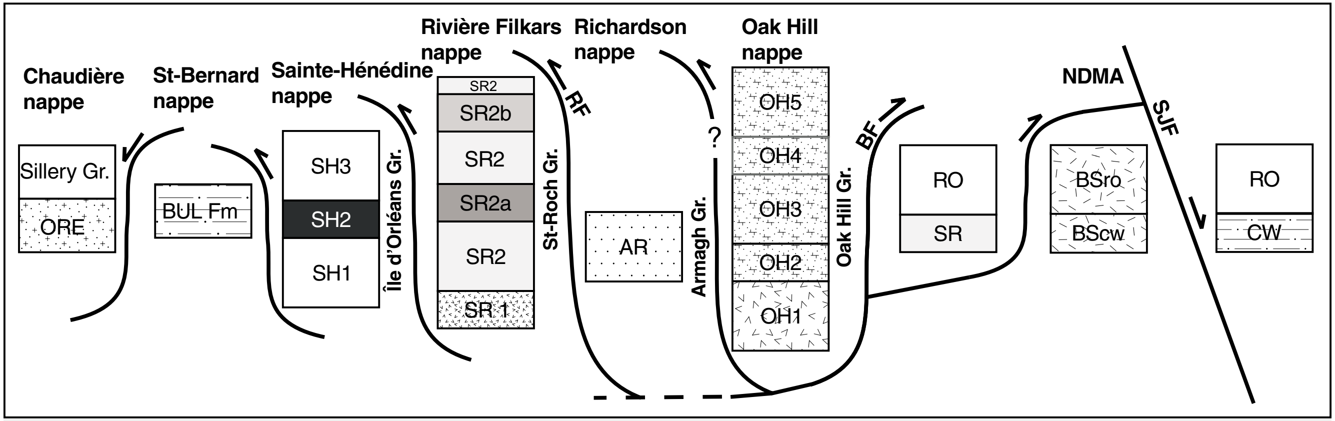

Figure 3. Schematic tectonostratigraphic diagram showing nappe stratigraphy and inferred structural stacking relationships of the Sainte-Marie–Saint-Sylvestre area. Refer to Figure 2 for unit label identifications and text for lithological descriptions. RF, Richardson Fault; BF, Bennett Fault; NDMA, Notre-Dame Mountains anticlinorium; SJF, St-Joseph Fault; ORE, Rivière Etchemin olistostrome; BUL, Bullstrode Formation; RO, Rosaire Group; CW, Caldwell Group; BSro Bennett Schists Rosaire facies, BScw, Bennett Schists Caldwell facies

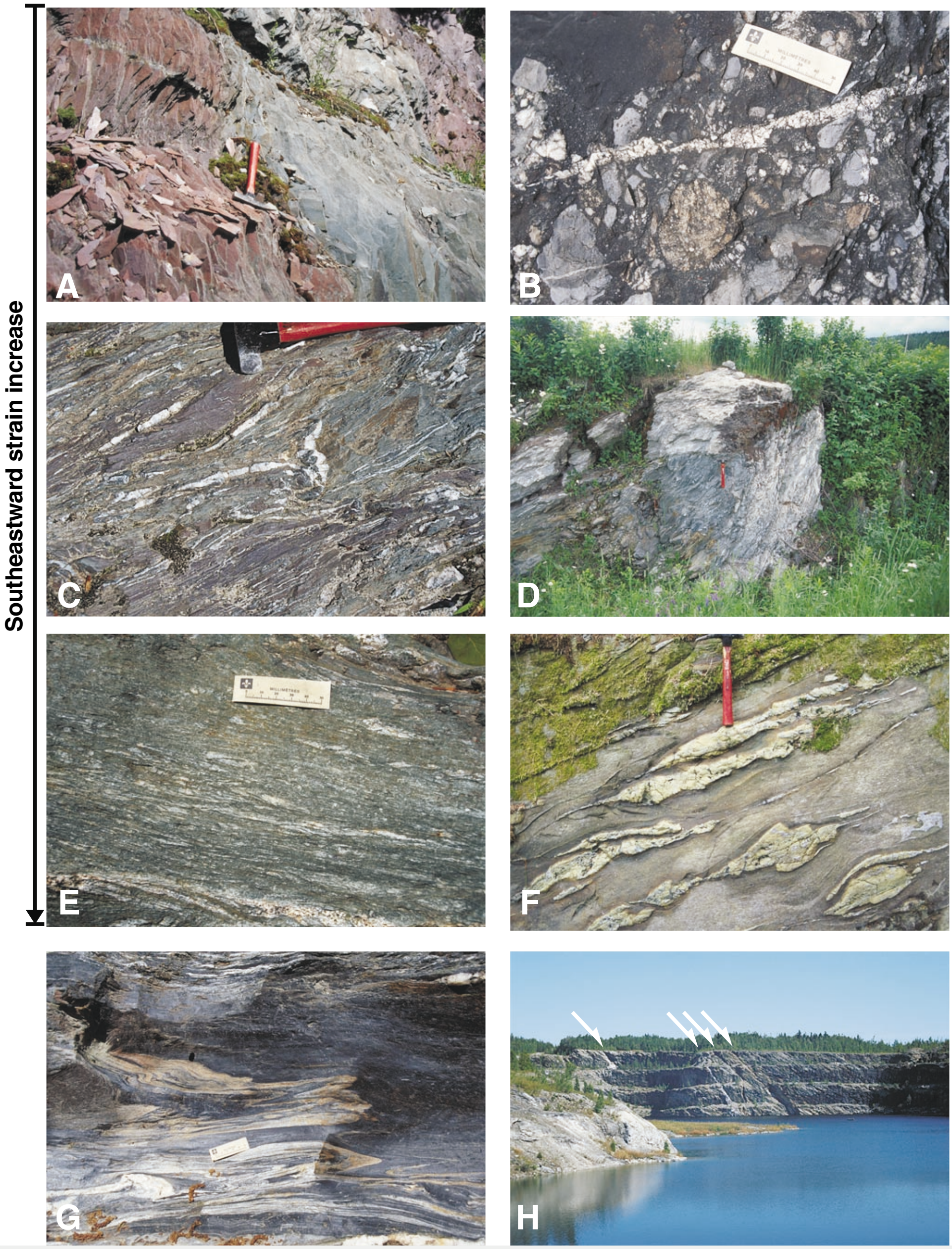

Figure 4. Field photographs of representative stratigraphic or structural features. **A)** Interbedded purplish-red and green silty slate (unit SH1) in the Sainte-Hénédine nappe. **B)** Polymictic conglomerate (unit SH2) in the Sainte-Hénédine nappe. **C)** Sheared purple and green phyllite (unit SR2) in the Rivière Filkars nappe. **D)** Southeast-verging F_2 antiform affecting limestone and quartzitic conglomeratic beds (unit SR2a) in the Rivière Filkars nappe (southeast to the right). **E)** Strongly sheared purple schist and metasandstone (unit SR2) in the Rivière Filkars nappe. Note the D_2 strain increases towards the southeast (i.e. the Bennett Fault) in similar rock types from absent (Fig. 4A) to penetrative (Fig. 4C), and to mylonitic (Fig. 4E). **F)** Metabasalt of the Tibbit Hill Formation (unit OH1) exhibiting epidote-albite-quartz nodules (southeast to the right). **G)** Strongly tectonized black phyllite and quartzite of the Rosaire Group along the northeastern extension of the Bennett Fault. **H)** Normal-sense shear zones (white arrows) in the hanging wall of the Pennington sheet and St-Joseph Fault (southeast to the right; view is approximately 300 m across).

Table 1. Description of units of the Sainte-Hénédine nappe.

Assemblage	Description
SH1	Thin-bedded purplish-red and green slate (Fig.4A), siltstone, and minor calcareous sandstone or limestone, intercalated with some thin-bedded dark grey and green slate, siltstone, and locally calcareous quartzitic sandstone.
SH2	Polymictic greenish-grey conglomerate, with clasts of limestone, dark grey, silty slate, quartzitic sandstone, which vary in size between 2 cm and 7 cm, with blocks exceptionally reaching 50 cm in diameter (Fig. 4B). The conglomeratic unit appears in beds of 3–13 m and is intercalated with quartzitic sandstone that often has a calcareous matrix or cement, and locally calcareous grey slate. The conglomeratic unit is laterally discontinuous; however, the close association of conglomerate and calcareous sandstone represent a marker horizon across the study area.
SH3	Thin-bedded, dark grey, silty slate and medium greenish-grey siltstone and fine sandstone, locally calcareous at the base. Some beds of brick red, silty slate, siltstone, or sandstone are also present.

Table 2. Description of units of the Rivière Filkars nappe.

Assemblage	Description
SR1	A chlorite-epidote-magnetite-albite basaltic volcanic rock.
SR2	Predominant green and purple silty slate, slate, or phyllite, with lesser green sandstone (Fig. 4C, 4E).
SR2a	Conglomerate and conglomeratic sandstone, essentially quartzitic; clasts are made of milky and locally blue quartz; the matrix is a quartzitic sandstone or siltstone.
SR2b	Polymictic conglomerate; beds of limestone conglomerate or quartzitic conglomerate, with calcareous sandstone (Fig. 4D).

Table 3. Description of units of the Oak Hill nappe.

Assemblage	Description
OH1	A metabasalt, often exposed as a medium to dark green chlorite-epidote-albite-actinolite magnetite schist, which locally contains nodules of epidote-albite-quartz (Fig. 4F). Magnetite octahedrons that locally make up to 10% of the rock are also often surrounded by an epidote aureole.
OH2	A greenish-grey quartz-sericite phyllite or schist was observed at the top of the metabasalt. This unit is often absent, thus placing the metabasalt and overlying quartzite in contact.
OH3	A quartzitic metawacke or quartzite, with frequent blue quartz clasts. The base is locally conglomeratic and contains chlorite schist interbeds, whereas a dolomitic cement characterizes the top of the unit.
OH4	A buff to medium brown dolomitic marble, locally brecciated.
OH5	A medium metallic grey, often reddish, hematitic phyllite that occasionally contains banded massive hematite at the contact with the marble.