Syncollisional basin development in the Appalachian orogen—The Saint-Daniel Mélange, southern Québec, Canada

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ABSTRACT

The Saint-Daniel Mélange is an orogen-scale sedimentary basin of the Québec Appalachians that is commonly interpreted as the remnant of a subduction complex formed during the Taconian orogeny. However, geochronological, structural, and stratigraphical data from Laurentian continental margin rocks and adjacent ophiolitic rocks in southern Québec indicate that the Saint-Daniel Mélange is an olistostromal, syncollisional piggyback basin that represents the base of the Magog Group forearc basin. The regional stratigraphic framework of the Saint-Daniel Mélange and its relationships with underlying and overlying rock units have been established on the basis of six stratigraphic sections from the Thetford-Mines, Asbestos, and Mont-Orford ophiolitic complexes. Our results imply that (1) the Saint-Daniel Mélange is a sedimentary sequence that unconformably overlies different structural and pseudostratigraphic levels of the southern Québec ophiolites; (2) it is made up of four distinct and laterally discontinuous units that record the obduction of ophiolites onto Laurentia and exhumation of basement rocks, followed by subsidence and deposition of the overlying Saint-Victor Formation of the Magog Group; (3) the sedimentary rocks of the Saint-Daniel record a transition from ophiolite-dominated to continental sources, indicating progressive exhumation of both the ophiolite and the continental margin upon which it was obducted; ^{40}Ar/^{39}Ar analysis of muscovite from metamorphic rock fragments in debris flows of the mélange yield an age of 467 ± 2 Ma, which is within the range of Ar ages measured in metamorphic rocks that underlie the ophiolites, and indicates the uplift of metamorphosed continental deposits during or shortly after obduction; (4) the Saint-Daniel Mélange is stratigraphically overlain by the Magog Group and represents the base of a syncollisional basin developed in a forearc setting during the Taconian orogeny.

Keywords: Appalachians, Québec, ophiolite, syncollisional basin, mélange.

INTRODUCTION

Forearc regions are characterized by active plate convergence and related deformation, volcanism, and sedimentation. The distribution of turbiditic and fluviodeltaic sedimentary sequences is controlled by uplift or subsidence of the forearc basement and by variations in the sedimentation rate of material erupted or eroded from the adjacent volcanic arc(s), accretionary prism, and continental margin (e.g., Dickinson and Seely, 1979). Chaotic lithologies, commonly referred to as *mélanges* (here used in the nongenetic sense of Raymond, 1984), are commonly found in trench-forearc environments and are attributed either to large-scale gravity-driven debris flows (also known as olistostromes), diapiric movement of material within the accretionary prism, tectonic deformation and underplating within shear zones, or to subduction-driven viscous flow of poorly lithified sediments within the accretionary wedge (Ewart and Bryan, 1972; Karig et al., 1980; Page and Suppe, 1981; Byrne, 1984; Cloos, 1984; Phipps, 1984; Raymond, 1984; Cowan, 1985; Lagabrielle, 1987; Lash, 1987; Brown, 1990; Lallemand et al., 1992; Orange and Underwood, 1995; among others). Many geologists consider the development of such mélanges to be closely linked to subduction. However, interpreting the genesis of any mélange requires both a detailed description and kinematic interpretation of its fabrics, and independent evidence concerning its paleogeographic and paleotectonic setting. It is particularly inappropriate to conclude, without corroborating evidence, that a unit described in the literature as a mélange must necessarily have formed in a subduction zone. Moreover, in ancient orogens like the Appalachians, where forearc sequences have been accreted to a continental mass, the origin and nature of these mélange units are commonly obscured by multiple periods of overprinting deformation and metamorphism (e.g., Williams and Hatcher, 1983).

Five criteria can be used, however, to discriminate chaotic units of tectonic origin (diapiric and tectonic mélanges; Raymond, 1984; Lash, 1985; Orange and Underwood, 1995) from those of sedimentary origin (polygenetic mélange and olistostrome; Raymond, 1984; Orange and Underwood, 1995; Pini, 1999): (1) the nature of the contact between the chaotic unit and adjacent rock units; (2) the nature and origin of the fine-grained matrix of the chaotic unit; (3) its

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internal structure—e.g., the presence or absence of soft sediment deformation; (4) the nature and origin of rock fragments; and finally, (5) the tectonostratigraphic position of the chaotic unit within the accreted oceanic sequence.

In the southern Québec Appalachians (Fig. 1), metamorphic, structural and geochronological data (summarized by Tremblay and Castonguay, 2002) acquired in the continental margin rocks of Laurentia and the accreted oceanic terranes have been used to constrain their tectonic evolution during the Middle to Late Ordovician Taconian orogeny. Taconian deformation and metamorphism mainly affected the Laurentian margin and were attributed to obduction of a large ophiolitic nappe preserved in the Southern Québec Ophiolite Belt (Pinet and Tremblay, 1995a, 1995b; Tremblay, 1995b; Castonguay, 2002). Our use of the term *obduction* includes both early intra-oceanic thrusting and structural thickening of the ophiolite nappe, and final emplacement onto the continental margin (Gray et al., 2000).

The Saint-Daniel Mélange (i.e., the Saint-Daniel Formation of St-Julien and Hubert, 1975) forms part of the accreted oceanic sequence. On the orogen scale, the Saint-Daniel is part of a belt of Ordovician mélange units that occur discontinuously from Newfoundland to northern New England along the Baie Verte–Brompton line (see following discussion) and correlative structures (Williams and St-Julien, 1982; Doolan et al., 1982; Tremblay, 1992; Kim et al., 2003). In southern Québec, the Saint-Daniel Mélange occurs at or close to the contact between continental (to the NW) and oceanic (to the SE) lithologies (Figs. 1 and 2) and is overlain by the Magog Group, a 10-km-thick sedimentary sequence interpreted as the remnant of a forearc basin (Cousineau and St-Julien, 1994) (Fig. 1). The Saint-Daniel was originally interpreted as a sedimentary unit in depositional contact with underlying ophiolites, constituted of black shales, laminated mudstones with sandstone-siltstone interbeds, and pebbly mudstones (Dérosier, 1971; Lamarche, 1973; St-Julien and Hubert, 1975; Hébert, 1980). On the basis of the presence of serpentinites and ophiolitic mélanges closely related to the Saint-Daniel Formation (Lamothe, 1979; Cousineau, 1990), on its structural position within the Appalachian orogen, and its sedimentological and structural (chaotic) characteristics, it was later identified as a *mélange* and re-interpreted as a Taconian accretionary (subduction) complex formed above an east-dipping subduction zone (e.g., Cousineau and St-Julien, 1992; Tremblay et al., 1995).

In this contribution, we present detailed maps and stratigraphic columns of the Saint-Daniel Mélange in key areas of the southern Québec Appalachians. Our main objective is to document the internal stratigraphy and structure of the Saint-Daniel and its relationships with oceanic units belonging to the ophiolitic belt and to the Magog Group. We will show that the Saint-Daniel is not a subduction mélange but rather represents an olistostromal fining-upward sedimentary sequence that unconformably overlies the ophiolitic basement and is, in turn, unconformably overlain by the Magog Group. Our observations and data suggest that (1) the rocks of the Saint-Daniel were deposited at the base of a piggyback basin (according to Ori and Friend's [1984] classification); (2) that it records the infilling of an inherited topography of the forearc oceanic crust that was induced, at least in part, by tectonic uplift during ophiolite obduction; and (3) that this was followed by synorogenic sedimentation (i.e., the Magog Group) during regional subsidence. This change from uplift to subsidence is recorded by a progressive change from ophiolite-dominated detritus to a sediment source dominated by erosion of the Laurentian margin.

SOUTHERN QUEBEC APPALACHIANS

The southern Québec Appalachians comprise three lithotectonic assemblages (Fig. 1A): the Cambrian-Ordovician Humber and Dunnage Zones (Williams, 1979), and the Silurian-Devonian successor sequence of the Connecticut Valley–Gaspé Trough (Tremblay and Pinet, 2005). The Humber and Dunnage Zones are remnants of the Laurentian continental margin and of the adjacent oceanic domain, respectively. The boundary between the Humber and Dunnage Zones corresponds (on the surface) to a zone of dismembered ophiolites and serpentinite slices defined as the Baie Verte–Brompton line (Williams and St-Julien, 1982). The Dunnage Zone is locally overlain unconformably by Upper Silurian and Devonian rocks of the Gaspé Belt.

The Humber Zone is subdivided into External and Internal Zones (St-Julien and Hubert, 1975; Tremblay and Castonguay, 2002). The External Humber Zone consists of very low grade sedimentary and volcanic rocks deformed into a series of northwest-directed thrust nappes (Fig. 1A). The Internal Humber Zone is made of greenschist to amphibolite facies metamorphic rocks (the Sutton-Bennett Schist in Fig. 1A) that represent distal facies of the External Humber Zone units. The highest-grade metamorphic rocks occur in the cores of doubly plunging dome structures (i.e., the Sutton Mountains and Notre-Dame Mountains anticlinoria; Fig. 1A). Regional deformation phases include an S_{1-2} schistosity and synmetamorphic folds and faults that were overprinted by a penetrative crenulation cleavage (S_3 of Tremblay and Pinet, 1994), which is axial-planar to hinterland-verging (southeast) folds and ductile shear zones rooted along the northwestern limb of the Internal Humber Zone (Pinet et al., 1996; Tremblay and Castonguay, 2002) (Fig. 1B). Amphibole and mica $^{40}Ar/^{39}Ar$ ages from the Internal Humber Zone vary between 431 and 410 Ma (Fig. 3; Castonguay et al., 2001). Ordovician high-temperature step ages (462–460 Ma) suggest that the geochronologic imprint of typical Taconian metamorphism is only locally preserved (Castonguay et al., 2001; Tremblay and Castonguay, 2002). To the southeast, the Internal Humber Zone is bounded by the Saint-Joseph Fault (Pinet et al., 1996) and the Baie Verte–Brompton line, which form a composite east-dipping normal-fault system marking a boundary with fewer metamorphosed rocks in the hanging wall (Fig. 1B). East of the Saint-Joseph–Baie Verte–Brompton line fault system, continental metamorphic rocks, which yielded Middle Ordovician $^{40}Ar/^{39}Ar$ muscovite ages (469–461 Ma; Whitehead et al., 1995; Castonguay et al., 2001; see following discussion), are locally exposed in the core of Acadian-related antiformal inliers, such as the Bécancour and Carinault antiforms (Fig. 2).

The Dunnage Zone occurs in the hanging wall of the Saint-Joseph–Baie Verte–Brompton line fault system and comprises ophiolites, mélanges, volcanic arc sequences, and marine flysch deposits. In southern Québec it is made up of four lithotectonic assemblages (Fig. 1A): (1) the southern Québec ophiolites, represented by three main massifs, the Thetford-Mines, Asbestos, and Mont-Orford ophiolitic complexes; (2) the Saint-Daniel Mélange; (3) the Magog Group forearc basin; and (4) the Ascot complex volcanic arc (see Tremblay et al., 1995, for a review).

The ophiolites of the Thetford-Mines and Asbestos complexes are characterized by well-preserved mantle and crustal sections, whereas only the crustal part of the oceanic lithosphere is exposed in the Mont-Orford ophiolitic complex. U-Pb zircon dating from felsic rocks of the Thetford-Mines and Asbestos ophiolitic complexes yielded ages of 479 ± 3 Ma and 478–480 +3/–2 Ma, respectively (Dunning et al., 1986; Whitehead et al., 2000). Both ophiolites are characterized by magmatic rocks with mixed (tholeiitic and boninitic) affinities and were interpreted as having been formed in a forearc setting (Oshin and Crocket, 1986; Laurent and Hébert, 1989; Olive et al., 1997; Hébert and Bédard, 2000). The Mont-Orford ophiolitic complex also shows a mixed magmatic affinity (boninitic, tholeiitic, and transitional-alkaline) that has been attributed

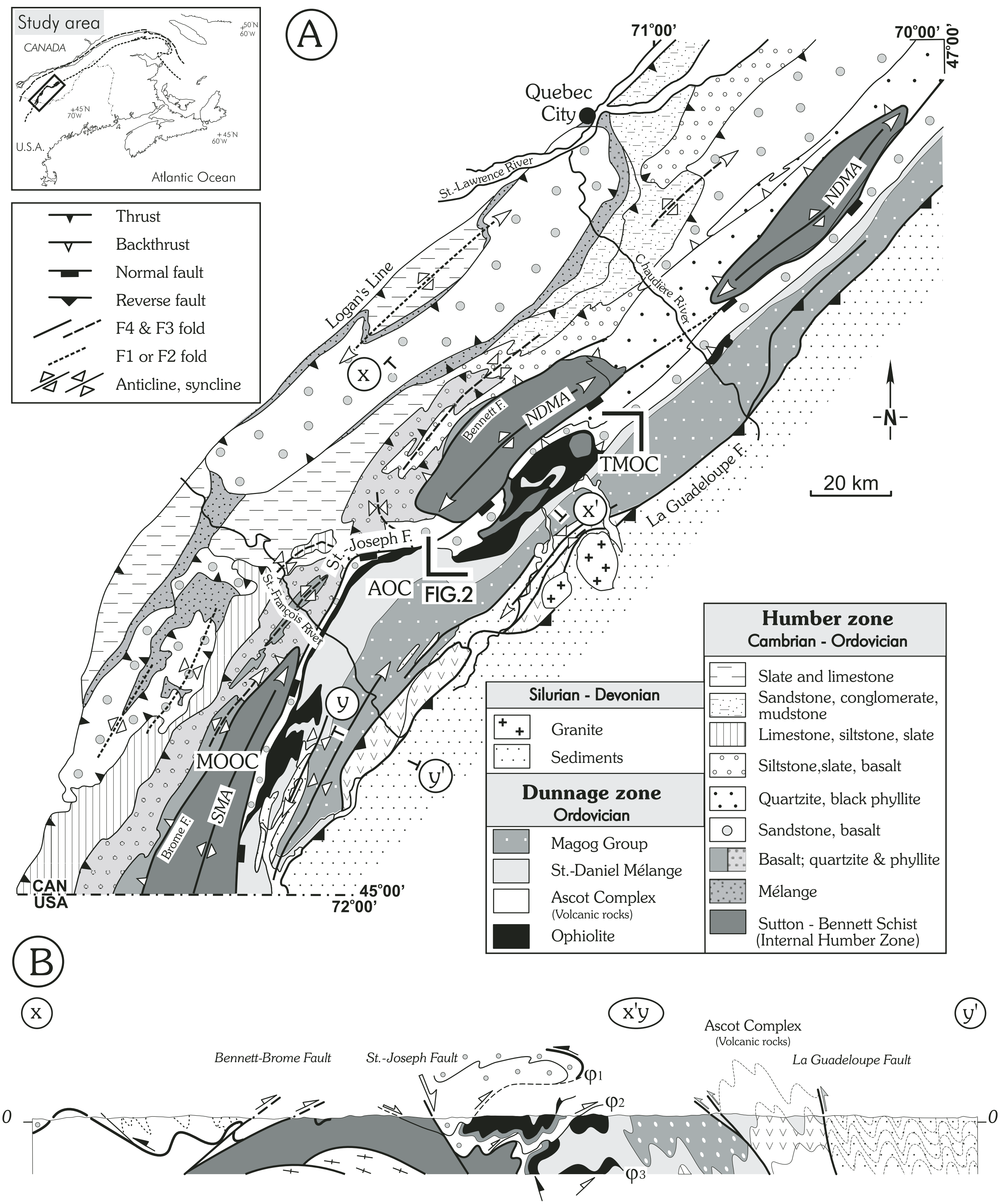

Figure 1. (A) Geological and structural map of the southern Québec Appalachians and location of Figure 2. Modified from Tremblay and Castonguay (2002). SMA—Sutton Mountains anticlinorium; NDMA—Notre-Dame Mountains anticlinoria; TMOC—Thetford-Mines ophiolitic complex; AOC—Asbestos ophiolitic complex; MOOC—Mont-Orford ophiolitic complex. (B) Schematic composite structural profile x–y′ across the Laurentian margin and the adjacent oceanic domain. From Schroetter et al. (2005).

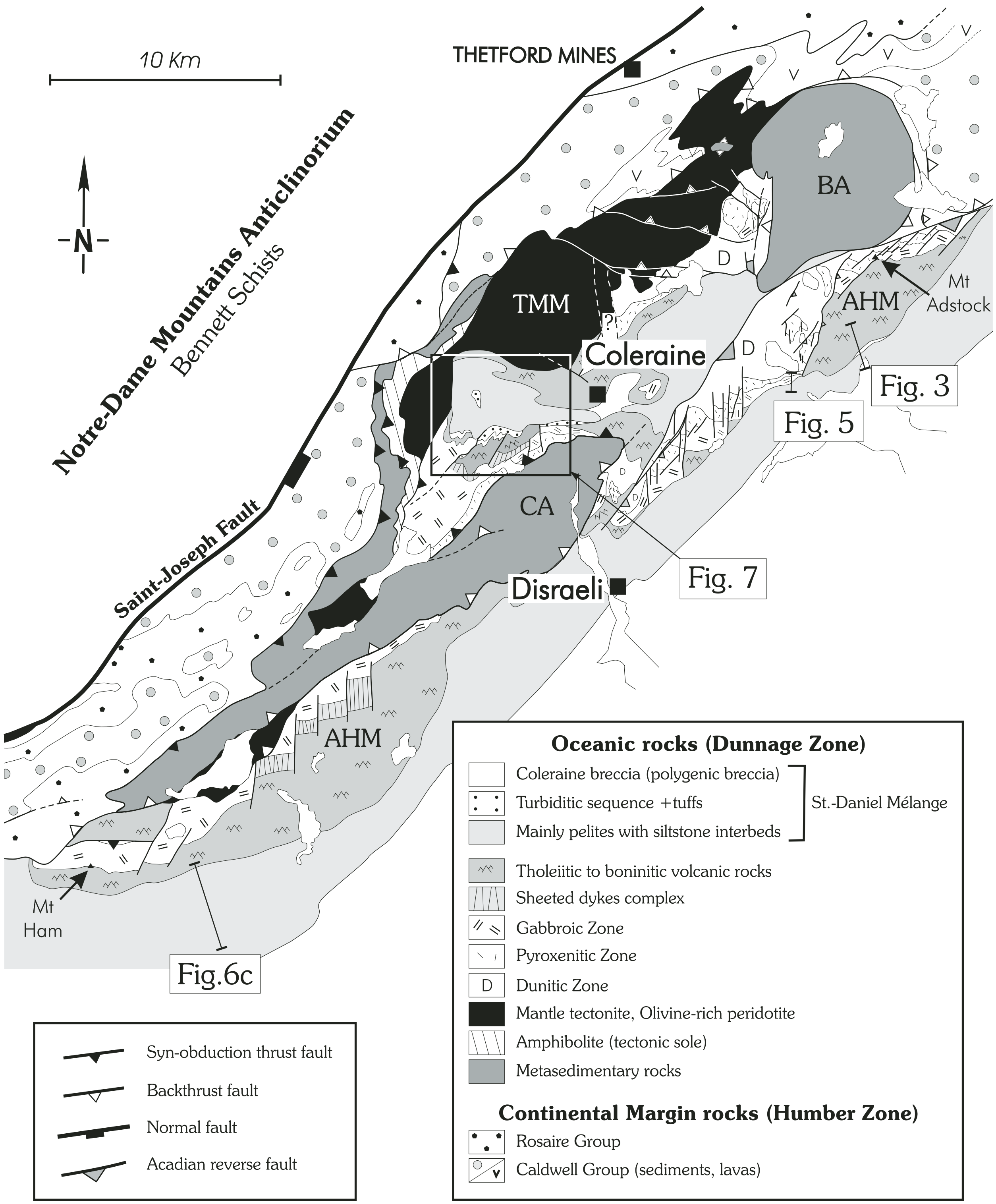

Figure 2. Geological map of the Thetford-Mines ophiolitic complex and locations of stratigraphic sections mapped in the area. TMM—Thetford-Mines Massif; AHM—Adstock-Ham Massif; BA—Bécancour antiform; CA—Carinault antiform. See Figure 1 for location.

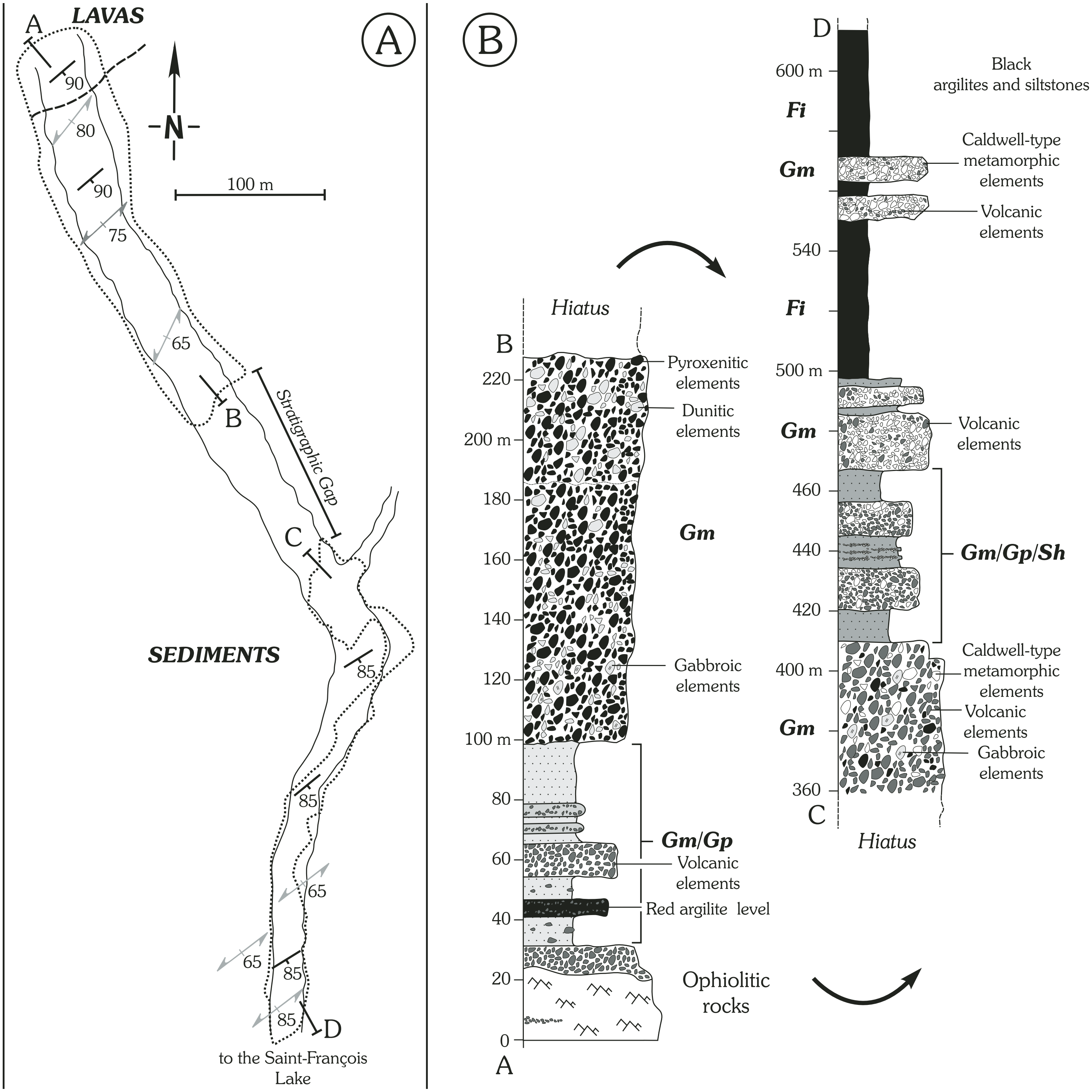

Figure 3. (A) Location map of the Rivière-de-l'Or section, showing the orientation of bedding and schistosity. (B) Stratigraphic section of the Saint-Daniel Mélange as exposed in the Rivière de l'Or. See text for details and Figure 2 for location. Gm—massive breccia and pebble conglomerate; Gp—interbedded pebbly conglomerate and coarse-grained sandstone; Sh—planar-bedded, coarse- to fine-grained sandstone; Fi—fine-grained sandstone, siltstone, and laminated mudstone-mudslate.

to arc-, forearc-, or backarc-related settings (Rodrigue, 1979; Harnois and Morency, 1989; Laurent and Hébert, 1989; Huot et al., 2002). U-Pb zircon dating of a trondhjemite from the Mont-Orford ophiolitic complex yielded 504 ± 3 Ma (David and Marquis, 1994). Amphibolites from the dynamothermal sole of the Thetford-Mines ophiolitic complex and adjacent continental mica schists yielded $^{40}Ar/^{39}Ar$ ages of 477 ± 5 Ma (Whitehead et al., 1995) and 469–461 Ma (Castonguay et al., 2001; Whitehead et al., 1995), respectively, suggesting that intra-oceanic detachment of the ophiolite (ca. 477 Ma; Whitehead et al., 1995) occurred immediately after oceanic crust formation (ca. 480 Ma), with emplacement against continental margin rocks and associated metamorphism having occurred afterward (ca. 470–460 Ma).

Cousineau and St-Julien (1992) identified four lithotectonic assemblages in the Saint-Daniel Mélange: (1) a black shale unit; (2) a pebbly mudstone unit, which represents only 10%–15% of the mélange; (3) a well-bedded, sandstone and black shale unit; and (4) a black shale unit with fragments of the Laurentian margin. On the basis of its relationships with adjacent ophiolitic rocks and the Magog Group, the age of the Saint-Daniel Mélange is believed to be Early to Middle Ordovician (St-Julien and Hubert, 1975). The Magog Group (Cousineau and St-Julien, 1994) overlies the Saint-Daniel Mélange. It is made up of four units: (1) lithic sandstones and black shales of the Frontière Formation; overlain by (2) a series of purple to red shales, green siliceous siltstones, and fine-grained volcaniclastic rocks of the Etchemin Formation; overlain by (3) pyritiferous black shales and volcaniclastic rocks of the Beauceville Formation; overlain by (4) a thick succession of sandstones, siltstones, and shales, with occurrences of tuff and conglomerate, constituting the Saint-Victor Formation, which makes up >70% of the thickness of the Magog Group. Graptolites, *Nemagraptus gracilis,* found in the Beauceville and Saint-Victor Formations are late Llandeilian to early Caradocian (Middle Ordovician). The Ascot complex has been interpreted as the remnant of a 460 ± 3 Ma volcanic arc sequence (Tremblay et al., 1989; David et al., 1993; Tremblay et al., 2000). It is made up of various metavolcanic rock series in fault contact with laminated and pebbly phyllites that have been correlated with the Saint-Daniel Mélange (Tremblay and St-Julien, 1990).

In the southern Québec Dunnage Zone, regional deformation and metamorphism are related to the Middle Devonian Acadian orogeny (Tremblay, 1992; Cousineau and Tremblay, 1993). Peak metamorphism varies from greenschist grade (biotite to chlorite zones) in the south (i.e., in the vicinity of the Québec-Vermont border), to prehnite-pumpellyite grade in the Chaudière River area (Fig. 1). $^{40}Ar/^{39}Ar$ dating of greenschist-grade metamorphic rocks of the Ascot complex yielded 380–375 Ma (Tremblay et al., 2000). The Magog Group is characterized by tight regional folds, generally overturned to the NW. Folds plunge gently or moderately to the SW or the NE. Evidence for intense Ordovician (Taconian) metamorphism and deformation is absent, but it has been suggested that the chaotic nature of the Saint-Daniel Mélange originated from Taconian-related accretionary processes (Cousineau and St-Julien, 1992).

Schroetter et al. (2005) showed that the Humber Zone, the southern Quebec ophiolites, and the overlying Saint-Daniel Mélange share a similar structural evolution. Detailed mapping and structural analysis, particularly in the Thetford-Mines ophiolitic complex, have been used to discriminate pre-, syn-, and postobduction structures. Synobduction (Taconian) structures include shear zones and ductile fabrics developed in the ophiolitic metamorphic sole of the Thetford-Mines complex and in the directly overlying mantle and underlying continental margin rocks. Two generations of postobduction structures are recognized: (1) SE-verging backthrusts and backfolds correlated with the Late Silurian–Early Devonian deformational episode recorded in the Humber Zone, and (2) NW-verging folds and reverse faults attributed to the Acadian orogeny (Tremblay and Castonguay, 2002). However, as a result of normal faulting along the Saint-Joseph–Baie Verte–Brompton line fault system (see Fig. 1B), the backthrust deformation found in the ophiolites has a lower metamorphic grade than the backthrust deformation found in the margin. The structural synthesis of the southern Québec ophiolitic belt suggests, moreover, that the various ophiolitic massifs represent the remnants of the obduction (during the Taconian orogeny) of a single, coherent (although polygenetic) slab of a suprasubduction oceanic lithosphere extending for hundreds of kilometers of strike length (Schroetter, 2004; Schroetter et al., 2005).

SAINT-DANIEL MÉLANGE

In southern Québec, the stratigraphic relationships between the oceanic crust and its sedimentary cover, including the Saint-Daniel Mélange, are most clearly exposed in the Thetford-Mines ophiolitic complex (Fig. 2). We illustrate these relations with four stratigraphic columns and a composite stratigraphic diagram covering the supracrustal sequence of the Thetford-Mines ophiolitic complex and the base of the Saint-Daniel Mélange. Along-strike variations of the stratigraphy of the Saint-Daniel and its relations with the Magog Group are illustrated by field data gathered from regions surrounding the Asbestos and Mont-Orford ophiolitic complexes.

The Thetford-Mines ophiolitic complex crops out as a NE-trending belt 40 km long and 10–15 km wide (Fig. 2). It is divided into the Thetford-Mines massif to the northwest and the Adstock–Ham Mountains massif to the southeast. The Thetford-Mines massif is characterized by a thick mantle section (~5 km, according to Laurent et al., 1979) and a 0.5–1.5 km thick crustal section (Schroetter et al., 2003). The oceanic mantle is not preserved in the Adstock–Ham Mountains massif. The crustal section is similar in both massifs and consists of dunitic, pyroxenitic, and gabbroic cumulates, crosscut by mafic to ultramafic dikes. The extrusive sequence is variable, both in thickness and lithology (Fig. 2; Schroetter et al., 2003), but boninitic lava flows and felsic pyroclastic rocks predominate. The ophiolitic volcanic rocks are overlain by laterally discontinuous debris flows characterized by centimeter- to meter-scale angular fragments of ultramafic, volcanic, sedimentary, and metasedimentary rocks (Coleraine Group of Riordon, 1954; and Coleraine breccia of Hébert, 1980). These coarse-grained units locally wedge out laterally into fine-grained siliciclastic rocks (red argillites and siltstones, and green tuffs). This basal sequence grades upward progressively into turbidites, argillites, siltstones, and pebbly mudstones (Schroetter, 2004; see following discussion).

Four informal stratigraphic units characterize the Saint-Daniel Mélange in the Thetford-Mines area: (1) a chaotic and heterogeneous basal unit (U1), which can be subdivided into a lower detrital sequence (U1a), and an upper volcano-sedimentary sequence (U1b); (2) a lithic sandstone and black shale unit (U2); (3) a pyritiferous (rusty) shale unit (U3) associated with greenish shale-slate and dolomitic siltstone; and (4) a pebbly mudstone unit (U4) containing clasts of rocks similar to, and presumably derived from, U2 and U3. Three stratigraphic sections (Figs. 3, 4, 5, 6, 7, and 8; see Fig. 2 for location) illustrate the relations between U1 and the underlying ophiolitic sequence in both the Thetford-Mines and Adstock-Ham massifs. A fourth stratigraphic section (Fig. 6C) in the southern part of the Adstock-Ham massif (see Fig. 2 for location) illustrates the relation between U1 and overlying units. Two stratigraphic sections have been mapped in the vicinity of the Asbestos and Mont-Orford ophiolitic complexes (Figs. 8, 9, and 10) to allow regional extrapolation of our stratigraphic analysis.

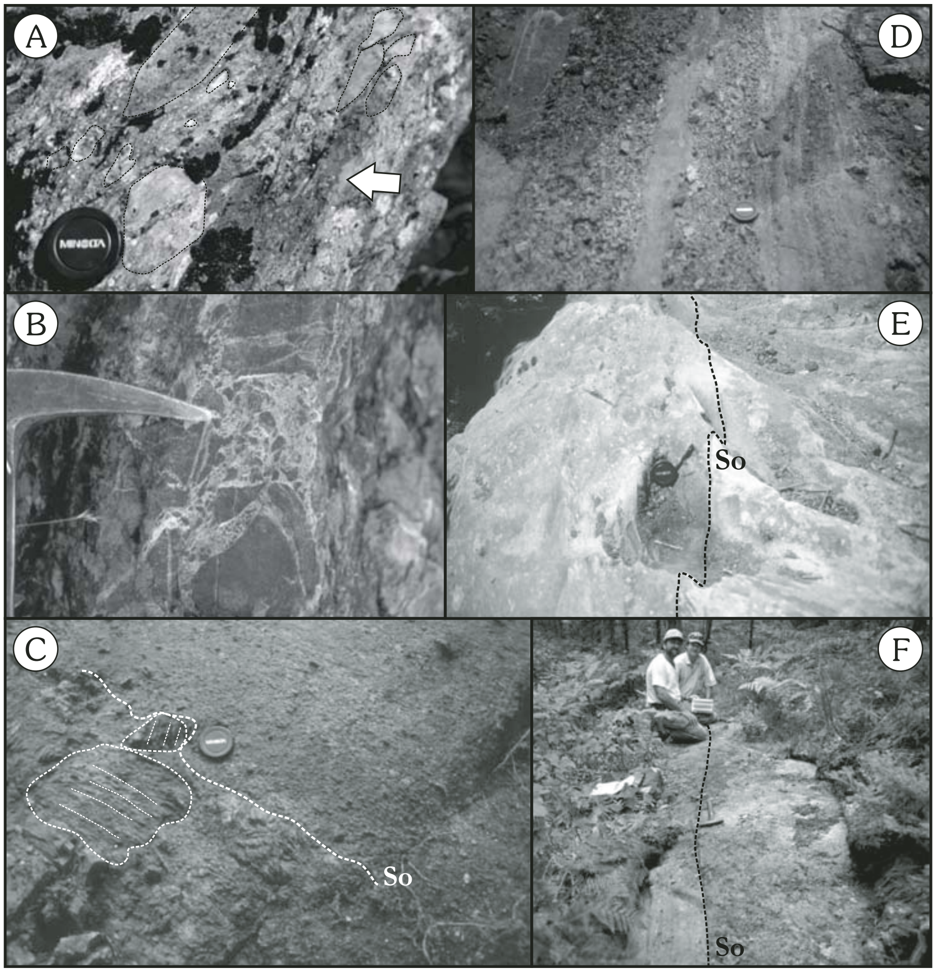

Figure 4. (A) Basal breccia with small amount of red argillite matrix (arrow) in the Rivière-de-l'Or section. (B) Fragments of serpentinized dunite and pyroxenite in breccia. Rivière-de-l'Or section. (C) Centimeter-size fragments of continental metamorphic rocks in breccia of the Rivière-de-l'Or section. (D) Interbedded breccia and coarse-grained sandstone of similar composition. Rivière-de-l'Or section. (E) Scoured contact between coarse-grained sandstones (left) and greenish siltstones, Petit-Lac–Saint-Franąois section. (F) Erosional contact between polygenetic breccia (right) and sandstones (left), Petit-Lac–Saint-Franąois section.

Rivière-de-l'Or Section (Thetford-Mines Ophiolitic Complex)

This section (Fig. 3) is 600 m thick, with a 120 m gap in outcrop halfway up. The bedding is now subvertical and is parallel to the regional schistosity. At the base of the section the sedimentary rocks overlie an ophiolitic substrate made up of pillow basalts, volcanic breccias, and intermediate to felsic pyroclastic rocks. Sedimentary facies show an evolution (base to top) from massive clast-supported breccias, to interbedded matrix-supported microconglomerates and sandstones, to well-bedded and fine- to coarse-grained sandstones, and finally to interbedded fine-grained sandstones, siltstones, and mudstones.

The basal breccia of the stratigraphic section is characterized by fragments derived from the ophiolitic substratum. The lower part (from 0 to 100 m) of the section (A–B in Fig. 3) consists of alternating deposits of ophiolite-derived breccia (5–15 m thick) and mafic volcanic sandstone (5–10 m thick). Clasts in the breccia are composed of felsic lava, gabbro ± pyroxenite, and fine- to coarse-grained sandstone. The first sandstone contains ~20% of 10–20 cm sized subangular volcanic and gabbroic clasts in a crystal-rich matrix composed of altered pyroxene and plagioclase, epidote, and chlorite. A 4 m thick breccia unit that is intercalated with sandstones near the base of the sequence (Fig. 3) contains 10–20 cm sized subangular clasts similar to the first breccia zones, but with a reddish mudstone matrix (Fig. 4A). Above another 5 m of volcanogenic sandstone, a massive 13 m thick breccia contains ~80% 10–20 cm sized subangular fragments of lava and gabbro, with rare pyroxenitic clasts up to 70 cm in diameter. The coarse-grained matrix is compositionally similar to the clasts. The upper part of this breccia unit is interbedded with a 0.5–1.5 m thick sandstone and is then overlain by a massive, 20 m thick sandstone. Another 120 m thick breccia unit follows (from 100 to 220 m in Fig. 3B), which contains angular to subangular (5–50 cm) clasts of altered dunite (Fig. 4B), pyroxenite, and rare gabbro. A 120 m gap in outcrop separates this breccia from the upper part of the section (C–D in Fig. 3B).

The upper part of the Rivière-de-l'Or section (C–D in Fig. 3) starts with ~50 m of massive polygenic breccia with angular (typically 5–10 cm) fragments consisting of, in order of decreasing abundance, felsic volcanics, pyroxenite, gabbro, and generally larger (20–70 cm) clasts of quartzite and mica schist (Fig. 4C). Over the next 90 m or so (from 410 to 500 m in Fig. 3B), similar breccia units are interbedded with 5–30 cm thick beds of microconglomerate and sandstone (Fig. 4D) characterized by well-developed planar laminations and size grading. The proportion of metamorphic rock fragments increases toward the top of the section, whereas the proportion of ophiolitic plutonic fragments decreases (Fig. 3). At the top of the section (from 500 to 600 m in Fig. 3B), breccias containing both ophiolitic and metamorphic rock fragments are interbedded with black mudslates typical of the Saint-Daniel Mélange. The last observed breccia beds have a black shale matrix.

Petit-Lac–Saint-Franąois Section (Thetford-Mines Ophiolitic Complex)

This section is ~3.5 km west of the Rivière-de-l'Or section (Fig. 2), and corresponds to a similar stratigraphic level, although the ophiolitic basement here consists of massive and brecciated gabbros, whereas the upper contact with black slates (i.e., typical Saint-Daniel Mélange) is not exposed. The bedding trends east-west and is steeply inclined toward the south. The Petit-Lac–Saint-François section can be subdivided into two subsections, A–B and C–D (Fig. 5).

The lower part of the section (A–B in Fig. 5) exposes ~60 m of polygenetic breccia with centimeter sized angular clasts of ophiolitic and metamorphic rocks. Ophiolitic clasts are composed of felsic lavas and various types of gabbro and pyroxenite. The matrix of the breccia is a medium- to coarse-grained sandstone with an average composition corresponding to that of the

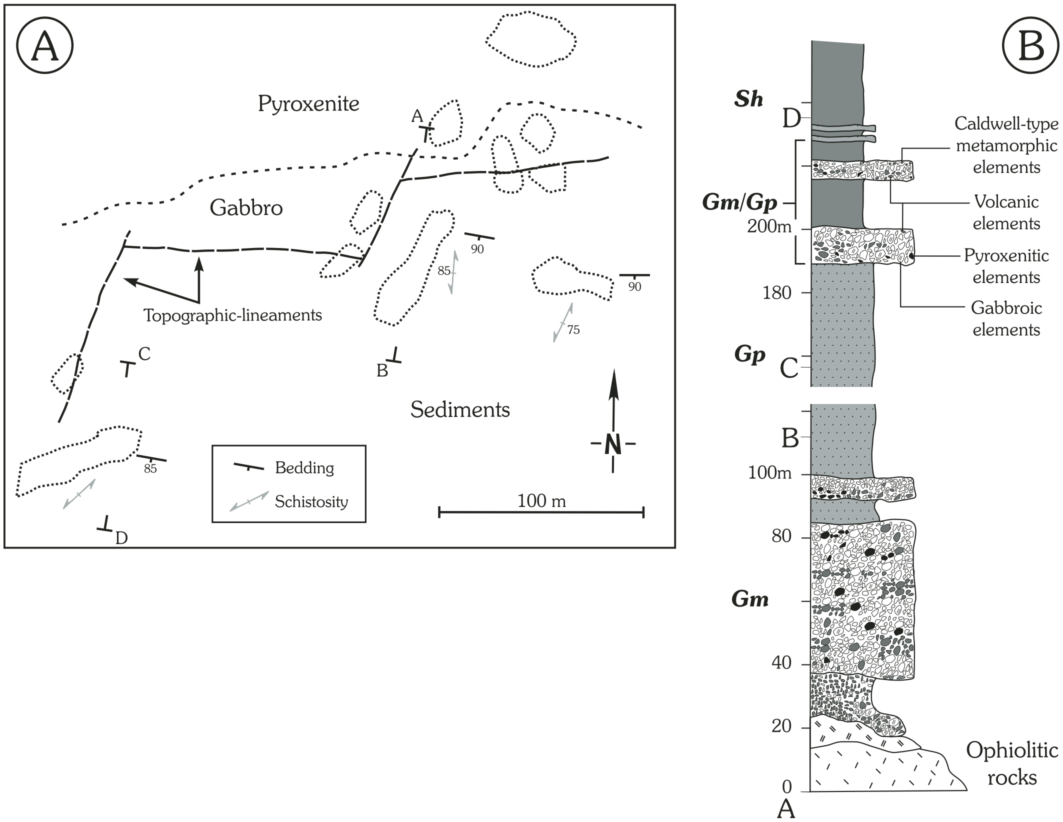

Figure 5. (A) Location map and structural features of the Petit-Lac–Saint-Franąois section. (B) Stratigraphic section of the Saint-Daniel Mélange as exposed in the Petit-Lac–Saint-Franąois section. Same symbols as in Figure 3. See text for details and Figure 2 for location.

larger clasts. Some breccia units are dominated by angular clasts of metamorphic rocks. The contacts between breccia and sandstone beds are commonly scoured (Fig. 4E). In the upper part of the section (C–D in Fig. 5), breccias are overlain by well-bedded, medium- to fine-grained sandstones and tuffaceous greenish sandstones. The bases of some of these sandstone beds are composed of microconglomerate (Fig. 4F).

Lac-de-l'Est Section (Thetford-Mines Ophiolitic Complex)

This section corresponds to the type section of the upper volcanic series and overlying sedimentary rocks of the Thetford-Mines ophiolitic complex as described by Oshin and Crocket (1986) and Laurent and Hébert (1989). It is on the north shore of Lac-de-l'Est and crops out over ~450 m along western and eastern subsections (Fig. 6A and B) that are ~300 m apart. The bedding trends 110° N and dips 50° to 60° toward the north (Fig. 7). The sedimentary sequence overlies an ophiolitic basement made up of pillow basalts and volcanic breccias. There are three distinct sedimentary facies, all of which are included in unit U1 of the Saint-Daniel Mélange. These facies consist of (1) polygenetic breccias, (2) interbedded coarse- to fine-grained sandstone and red mudslate-mudstone, and (3) interbedded fine-grained tuff and red argillite.

The base (0–90 m) of the sedimentary sequence (unit U1a) exposed in the western subsection (Fig. 6A) consists of polygenetic breccia characterized by centimeter to decimeter sized fragments in a fine-grained matrix of red argillite (Fig. 8A and B). Fragments include, in decreasing order of abundance, gabbro, lava, pyroxenite, and quartzofeldspathic metamorphic rocks. Large fragments (up to 1 m) of red mudstone, showing soft-sediment deformation structures, are found locally within the breccia and are interpreted as large rafts or rip-up clasts. The breccias are overlain by, and interbedded with, a sequence of 10–50 cm thick beds of alternating sandstone and red mudstone (Fig. 8C) that attain >50 m of thickness (i.e., from 90 to ~140 m in Fig. 6A). Sandstone beds are commonly size graded, with basal channeling and parallel-laminated tops that grade up into laminated red mudstones (Fig. 8C). This series of interbedded sandstone and mudstone resembles a typical fine-grained turbidite sequence.

In the eastern subsection (Fig. 6B), polygenetic breccias are absent, and the ophiolitic basement is directly overlain by ~200 m of interbedded sandstone and red mudstone, constituting unit U1b of the Saint-Daniel Mélange. The sandstone beds are thicker than in subsection A–B (up to 50 cm), but overall they show similar turbiditic facies and structures (channels, graded bedding, and parallel laminations). The upper part of the eastern subsection is devoid of sandstone, being characterized instead by interbedded red mudstone and green, tuffaceous, parallel-laminated siltstone beds up to 1 m thick. The upper sequence is at least 100 m thick (Fig. 6B).

The area surrounding the northern shore of Lac-de-l'Est represents a structural basin (Fig. 7), formed as an interfering fold pattern between an east-west–trending syncline and a series of younger (Acadian) NE-trending folds (Schroetter et al., 2005). Although exposure is poor in this structural basin, unit U1 rocks in its core are stratigraphically overlain by rocks typical of Saint-Daniel units U2, U3, and U4, a stratigraphic sequence that correlates with the well-exposed Mont-Ham section (see following description). Field data from the area north of Lac-de-l'Est clearly show that the contact between units U1b and U2 is gradational and is essentially characterized by a color change in the fine-grained rocks—i.e., from red mudstones of unit U1b to black mudstones-mudslates of the overlying unit (U2).

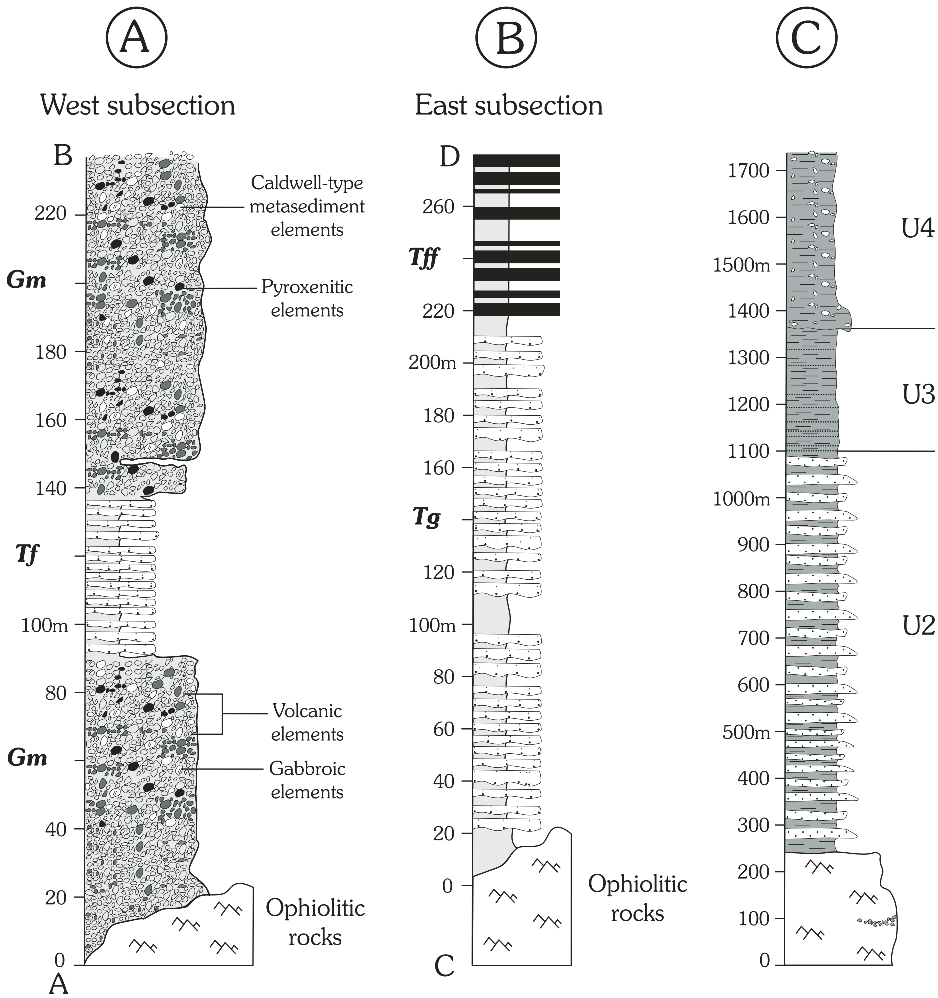

Figure 6. (A, B) Stratigraphic section of the Saint-Daniel Mélange as exposed in the Lac-de-l'Est area. See text for details and Figure 7 for location. Tf—fine-grained turbidites; Tg—coarse-grained (silt-sized) turbidites; Tff—fine-grained tuff. Other symbols as in Figure 3. (C) Stratigraphic section of the Saint-Daniel Mélange as exposed in the Mont-Ham section. See text for details and Figure 2 for location.

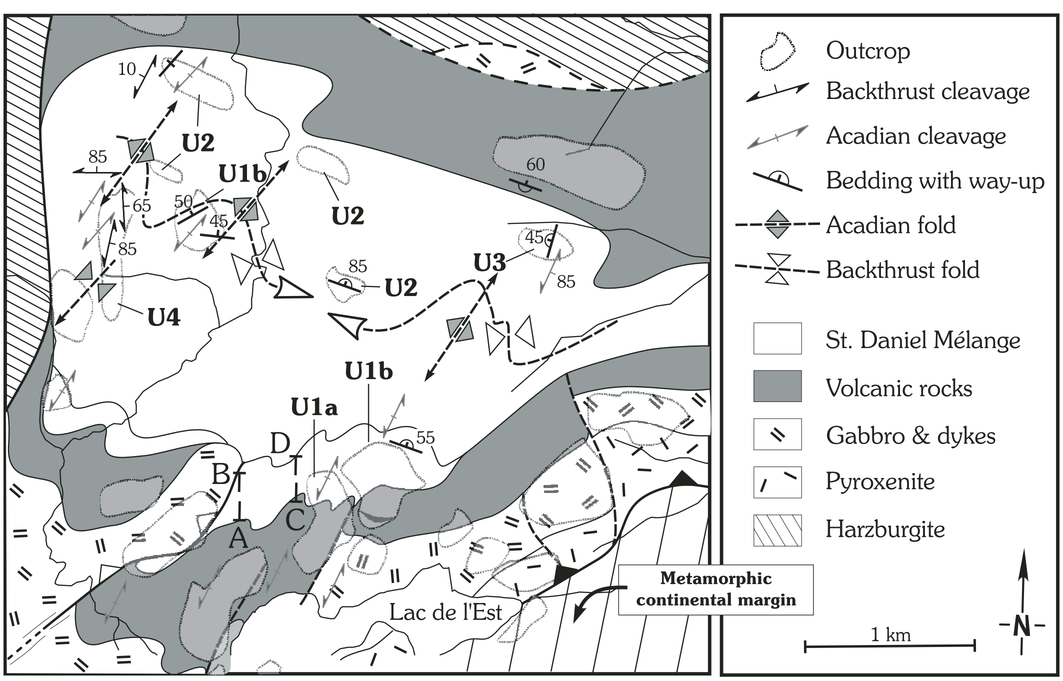

Figure 7. Geological map of the Lac-de-l'Est area. See text for details and Figure 2 for location.

Mont-Ham Section (Thetford-Mines Ophiolitic Complex)

This section lies along the southern flank of Mont-Ham (Fig. 2) and illustrates the relations between units U2, U3, and U4 (Fig. 6C). The ophiolitic basement here is made up of the upper volcanic series of the Thetford-Mines ophiolitic complex (Hébert, 1980) and consists of massive to brecciated mafic volcanic rocks and felsic pyroclastic rocks.

At Mont-Ham, the ophiolite is directly overlain by interbedded black sandstone and laminated black and green argillite of unit U2 (Fig. 6C). These rocks correspond to the S3 subfacies of the Saint-Daniel Mélange as described by Cousineau and St-Julien (1992). The black sandstone beds (fine to coarse grained, 0.1–2 m thick) show basal channeling, cross-bedding, and parallel laminations. The argillite beds (5–80 cm thick) show evidence of synsedimentary deformation (Fig. 8D). A similar sedimentary succession at the same stratigraphic level was described in the Asbestos area by Lavoie (1989), who interpreted it as a marine turbidite sequence. The sandstones are Cr-rich (40–60 ppm), suggesting an ophiolitic contribution (Lavoie, 1989).

Unit U2 (Fig. 6C) grades up into a sequence of pyritiferous, black and dark-green argillites with thin (<5 cm) interbeds of quartzitic siltstone and laminated dolomitic siltstone (unit U3), which was interpreted as a hemipelagic deposit by Lavoie (1989). Cross-bedding, parallel laminations, and graded bedding are commonly observed.

Rocks of the overlying unit (U4) are pebbly mudstones with a black shale matrix and represent the archetypical lithology of the Saint-Daniel Mélange (Cousineau and St-Julien, 1992), which is recognizable for >200 km of strike length in the southern Québec Appalachians (see Tremblay et al., 1995, for a review). Unit 4 rocks have conformable contacts against underlying U-3 rocks (Fig. 6C). Typically, 60%–70% of a black shale matrix contains pebble to cobble sized clasts of sedimentary rocks (Fig. 8E), such as black sandstone clasts similar to those of unit U2, and siltstone, dolomitic siltstone, and mudstone clasts identical to those of unit U3. Mudstone fragments are flattened, whereas sandstone and siltstone fragments are subangular to subrounded. Cousineau and St-Julien (1992) suggested that such chaotic lithologies represent mud volcanoes formed within an accretionary prism. However, we did not find crosscutting relationships between pebbly mudstones and other types of lithologies, which would have been evidence for mud volcano chimneys. These rocks could also be interpreted

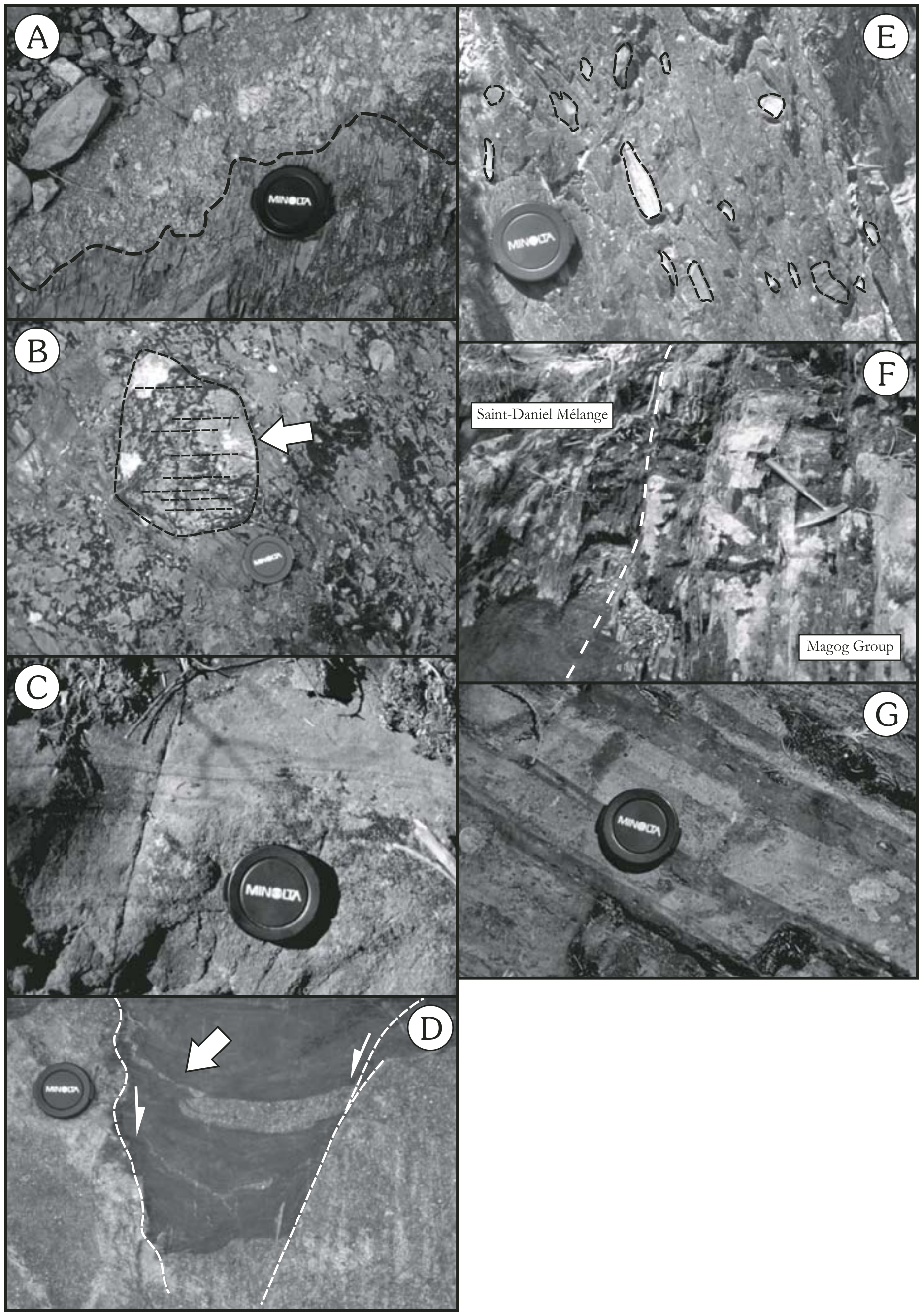

Figure 8. (A) Erosional contact between polygenetic breccia and red argillite of the Lac-de-l'Est section. Note the schistosity transecting the bedding at a high angle. (B) Metamorphic rock fragment (white arrow) in breccia with a matrix of red argillite, Lac-de-l'Est section. (C) Fine-grained turbidite facies (unit U1a) of the Lac-de-l'Est section, showing alternating siltstone and red argillite. (D) Synsedimentary deformation (slump, white arrow) in turbidites of unit U2, Mont-Ham section. (E) Typical pebbly mudstone facies of the Saint-Daniel Mélange, unit U4 of the Mont-Ham section. (F) Conformable contact (broken line) between the Saint-Daniel Mélange (unit U4) and the Saint-Victor Formation (Magog Group) as exposed in the Ruisseau-Castle section. (G) Typical lithologies, consisting of fossiliferous graphitic slates and gray siltstones, of the Saint-Victor Formation near Disraeli.

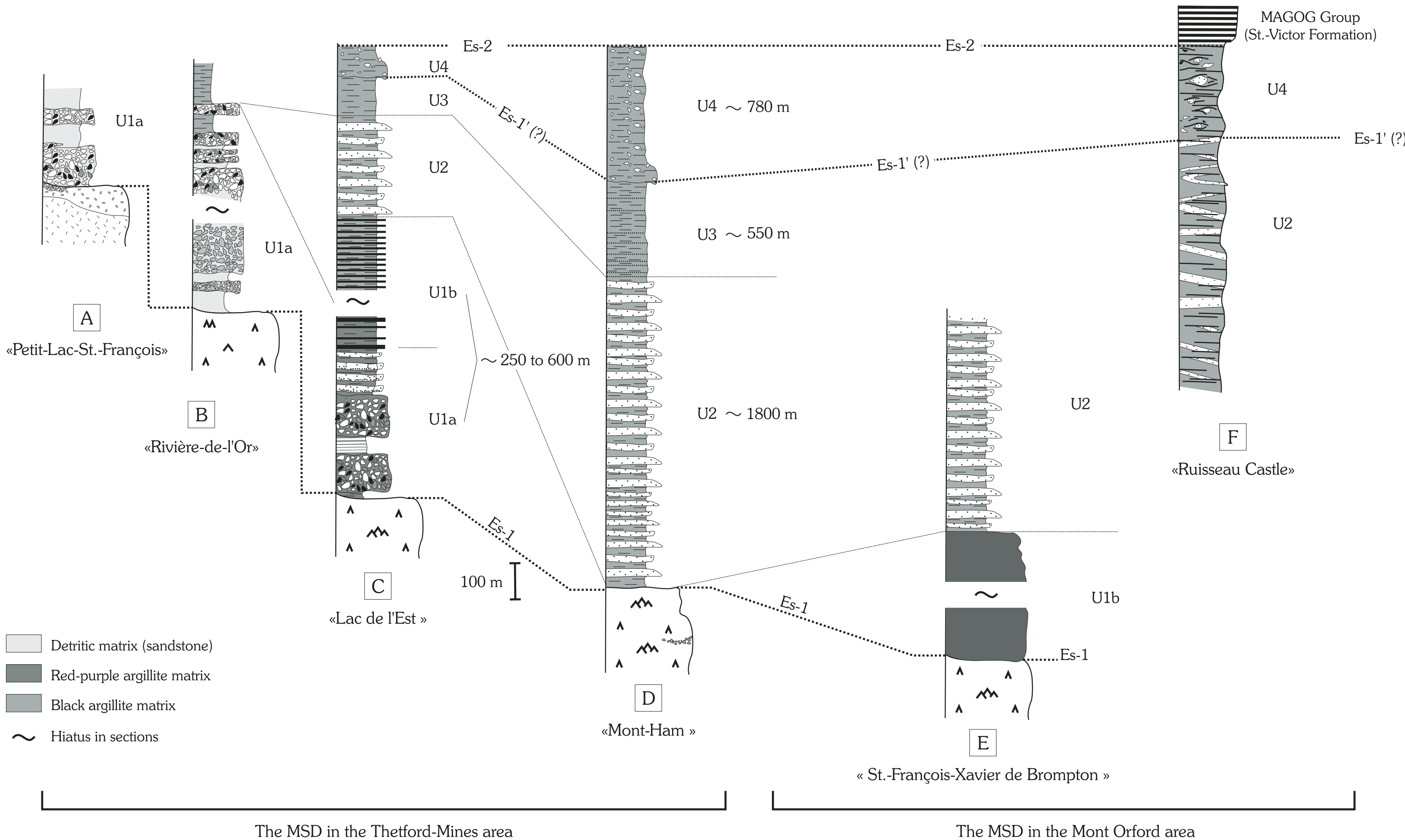

Figure 9. Synthetic diagram for the stratigraphy of the Saint-Daniel Mélange in the Thetford-Mines area and correlation with Saint-Daniel facies mapped along the Saint-Franąois–Xavier (Fig. 9E) and Ruisseau-Castle (Fig. 9F) sections in the Mont-Orford area. See Figure 10 for locations of sections shown in Figure 9E and F; see text for discussion and description of these sections. Es-1—erosional surface at the top of ophiolitic magmatic rocks; Es-2—erosional surface at the base of the Magog Group; MSD—Saint-Daniel Mélange.

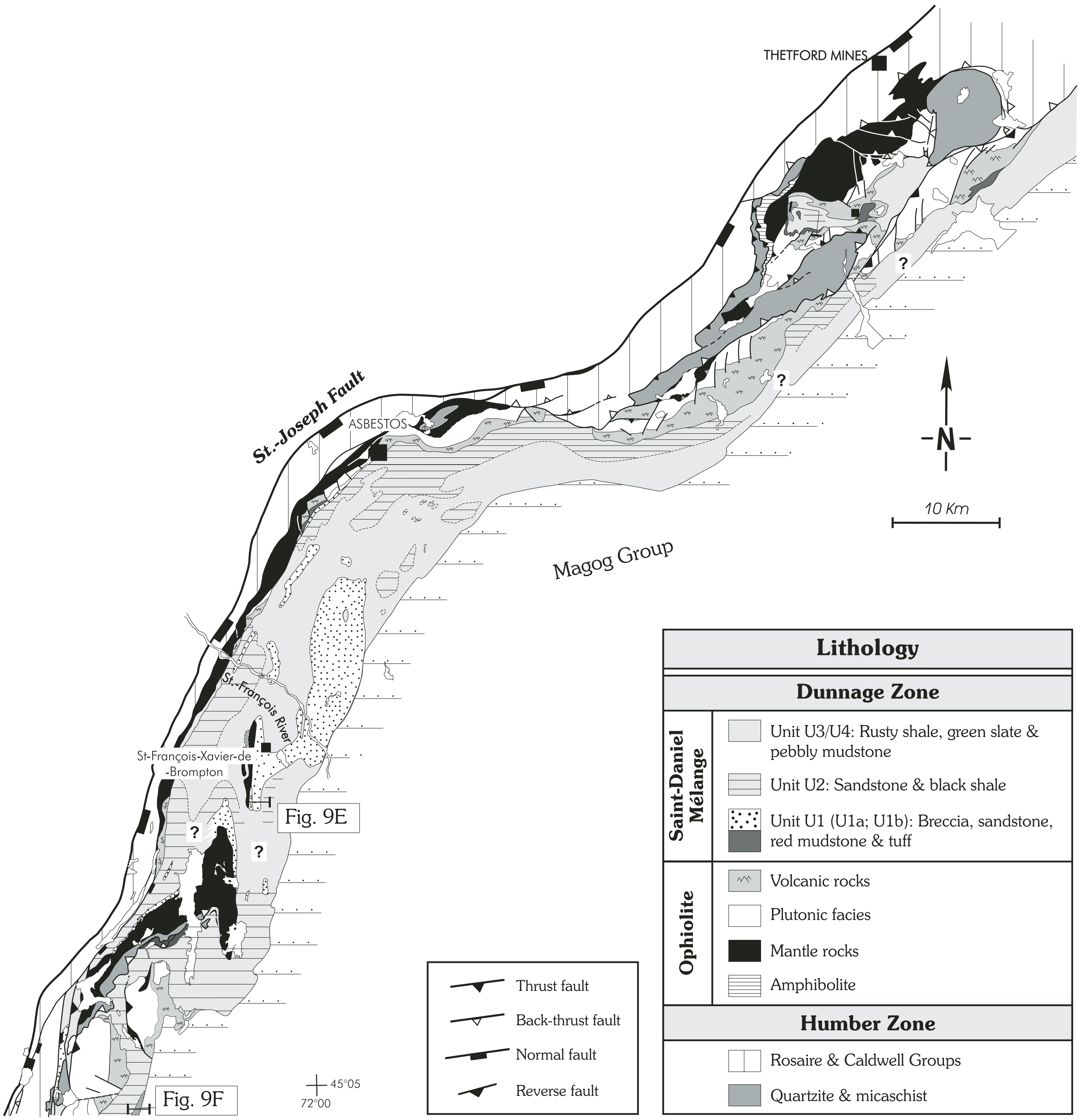

Figure 10. Geological map showing the inferred distribution of the various facies of the Saint-Daniel Mélange in the southern Québec Appalachians. Compiled from mapping by Cooke (1938, 1950), Brassard and Tremblay (1999), St-Julien and Slivitsky (1985), and Schroetter (2004). See text for discussion.

as mudflows that reworked the underlying sedimentary units.

Saint-Franąois–Xavier Section (Asbestos Ophiolitic Complex)

The Saint-François–Xavier section (Fig. 9E) trends east-west and is ~20 km south of the main mass of the Asbestos ophiolitic complex (Fig. 10). It is associated with mafic cumulates and volcanic rocks that were previously considered as a fault slice within the Saint-Daniel Mélange (e.g., Tremblay et al., 1995), which we now re-interpret as an Acadian-related structural inlier exposing the contact between the mafic volcanic rocks of the ophiolite and the overlying Saint-Daniel strata. The ophiolitic substrate is directly overlain by fine- to coarse-grained volcaniclastic rocks (Fig. 9E) that show graded bedding, parallel laminations, and synsedimentary deformation structures, and which were interpreted as reworked pyroclastic deposits by Lavoie (1989). These volcaniclastic rocks are overlain by a sequence of interbedded black sandstone and mudstone (unit U2; Fig. 9E). We attribute the volcaniclastic sequence to unit U1b, as defined in the Thetford-Mines area, because they occur at the same stratigraphic level (between the ophiolite and unit 2) and, although debris flows of unit U1a are absent, they conformably overlie the ophiolite.

Ruisseau-Castle Section (Mont-Orford Ophiolitic Complex)

The Ruisseau-Castle section (Fig. 9F), in the vicinity of the Mont-Orford ophiolitic complex (Fig. 10), is one of the few localities of the southern Québec Appalachians where the contact between the Saint-Daniel Mélange and the overlying Magog Group is exposed (Fig. 9F). Here, the Saint-Daniel–Magog contact is seen to be unequivocally depositional (Fig. 8F), with black mudstones containing centimeter to decimeter sized clasts of black sandstones, typical of unit U4 of the Saint-Daniel Mélange, being overlain by a sequence of fossiliferous (graptolites) graphitic slates and gray siltstones (Fig. 8G) belonging to the Saint-Victor Formation of the Magog Group (Cousineau and St-Julien, 1994).

SYNTHESIS, REGIONAL CORRELATIONS, AND AGE CONSTRAINTS

The different stratigraphic columns for the Saint-Daniel Mélange are synthesized in Figure 9, which also illustrates the inferred lithological correlations and lateral facies variations from different sites. The composite stratigraphic sections clearly show that (1) unit U1 is essentially made up of debris flows (breccias) that can form sections several hundreds of meters thick (in the Rivière-de-l'Or section) but that can also be entirely absent (in the Mont-Ham section); (2) unit U1 unconformably overlies various pseudostratigraphic levels of the Thetford-Mines ophiolitic complex (gabbro at the Petit-Lac–Saint-François section and lava in the other sections), suggesting that its lower contact is an erosional surface (Es-1 in Fig. 9); and (3) units U2, U3, and U4 show thickness variations that are inversely correlated with those of the underlying debris flows of U1 (e.g., units U2 and U4 are significantly thicker in the Mont-Ham and Saint-François–Xavier sections than elsewhere; Fig. 9), which is consistent with the horst-and-graben geometry of the oceanic crust inferred by the analysis of pre-obduction structures (Schroetter et al., 2003). This preexisting topographic relief appears to have had a profound influence on the nature and distribution of overlying sedimentary rocks.

As shown in the previous section, ophiolitic massifs of the southern Québec Appalachians form the basement over which the Saint-Daniel Mélange was deposited, implying a lower age limit of ca. 480 Ma (Arenigian; see previous discussion) for the mélange. The Ruisseau Castle section shows that the Saint-Daniel Mélange is overlain by the Magog Group, although an erosional unconformity probably is present between these two units. In terms of age constraints, it is important to note that the Ruisseau-Castle section is one of few localities where Llandeilian–Caradocian (464–449 Ma) graptolites are found in the Magog Group strata directly overlying the mélange. In summary, stratigraphic relationships clearly indicate that the Saint-Daniel Mélange is late Arenig to Llanvirn (ca. 480–464 Ma).

To obtain age constraints on the source of metamorphic rock fragments found in basal breccia deposits overlying the ophiolitic substrate, $^{40}Ar/^{39}Ar$ analyses of two samples of mica schist were performed. The mica schist samples were taken from breccias at the base of the Petit-Lac–Saint-François section (Fig. 5). Relevant Ar data and details of analytical procedures are available in the GSA Data Repository.[1] One mica schist sample yielded muscovite grains of very poor quality, with abundant yellow and brown staining, and yielded no discernible plateau age in either of the two aliquots analyzed (not shown). The other sample yielded reproducible $^{40}Ar/^{39}Ar$ muscovite plateau ages for two aliquots, providing a robust 467 ± 2.6 Ma age (Fig. 11). Pressure and temperature conditions of the Acadian regional metamorphism, mentioned previously, in the Petit-Lac–Saint-François area were well below the Ar retention temperature proposed for muscovite (e.g., 350–400 °C), indicating that 467 ± 2.6 Ma represents an inherited age. This implies that, for this particular site, Unit U1 is ca. 467 Ma, which is within the range of $^{40}Ar/^{39}Ar$ muscovite ages (469–461 Ma) obtained from the continental metasedimentary rocks that structurally underlie the Thetford-Mines ophiolitic complex. This indicates not only that metamorphic rocks underlying the ophiolite are the most probable source for metamorphic fragments, but more significantly, that these metamorphic source rocks were rapidly exhumed (uplifted) to the surface during or shortly after the emplacement of the oceanic crust onto the continental margin, a key constraint for the paleogeographic interpretation of the Saint-Daniel Mélange.

[1]GSA Data Repository item 2005xxx, argon data, is available on the Web at http://www.geosociety.org/pubs/ft2005.htm. Requests may also be sent to editing@geosociety.org.

INTERPRETATION AND DISCUSSION

The stratigraphy of the Saint-Daniel Mélange shows that it is a fining-upward sequence that represents the lower part of a syncollisional sedimentary basin. This basin was transported on top of the ophiolitic slab(s) as it was emplaced onto the continental margin. Three main tectono-sedimentary phases (or events) are therefore recorded in the Saint-Daniel sedimentary sequence: (1) Exhumation and erosion of both ophiolitic and metamorphic continental margin material, with variations from ophiolite dominated to continental margin dominated

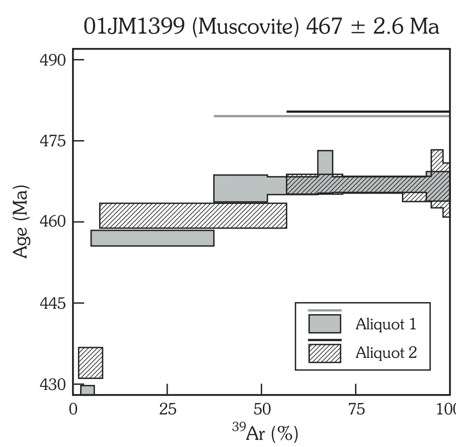

Figure 11. $^{40}Ar/^{39}Ar$ incremental age spectra (1 σ relative uncertainties) for two aliquots of muscovite sample 01JM1399. See text for discussion.

erosional sources. Muscovite $^{40}Ar/^{39}Ar$ dating (Fig. 11) implies that exhumation of metamorphosed continental rocks (ca. 467 Ma) was more or less coeval with both the final emplacement of ophiolites onto the Laurentian margin (ca. 470–460 Ma; Tremblay and Castonguay, 2002) and arc volcanism (preserved in the Ascot complex; ca. 460 Ma). (2) Reworking of turbiditic sedimentary facies of the lower part of the base of the Saint-Daniel basin to form mudflow deposits (unit U4). (3) Development of a more mature, tectonically stable, onlapping forearc basin in Llandeilian–Caradocian (464–449 Ma) time (i.e., the Magog Group).

Lateral facies and thickness variations in the Saint-Daniel Mélange are most prominent in the basal unit (U1). This basal unit is 250–600 m thick in the Thetford-Mines area (Fig. 9A, B, and C) but is absent from the Mont-Ham and Saint-François–Xavier sections (Fig. 9D and E). The stratigraphic sections show that the lower contact of the mélange is depositional and corresponds to an erosional unconformity (Es-1). The lack of sedimentary structures and the overall chaotic aspect of the breccias suggest that they formed as debris flows. The predominance of angular pebble and cobble sized fragments indicates a relatively proximal erosional source. Thickness variations of unit U1 can be attributed to a horst-and-graben topography of the oceanic basement (Schroetter et al., 2003). This topography may have been inherited from synoceanic crustal extension. Alternatively, it could be attributed to irregular isostatic uplift induced by the underplating of low-density (continental) material during the emplacement of the ophiolites onto the margin (Fig. 12). The similarity between the ophiolite-derived clasts in the U1 debris flows and the underlying ophiolite implies that the ophiolitic basement (or a lateral extension of it) was itself being eroded (Fig. 12). The continentally derived clasts in unit U1 are mica schists lithologically and geochronologically identical to Laurentian margin metasediments occurring directly beneath the ophiolites that were metamorphosed by emplacement of hot ophiolitic mantle (Schroetter et al., 2005). The occurrence of these metasedimentary clasts indicates that the oceanic lithosphere was already emplaced upon the continental margin as unit U1 was being deposited. Lateral and vertical variations toward increasing proportions of continentally derived debris therefore suggest that parts of the Laurentian margin upon which the ophiolite was emplaced were being uplifted, presumably through compression of the margin during the Taconian orogeny (Fig. 12), while other parts of the ophiolite were being progressively buried beneath these deposits.

The breccias that characterize the basal part of unit U1 grade up into, and are interbedded with, black shales typical of the Saint-Daniel Mélange

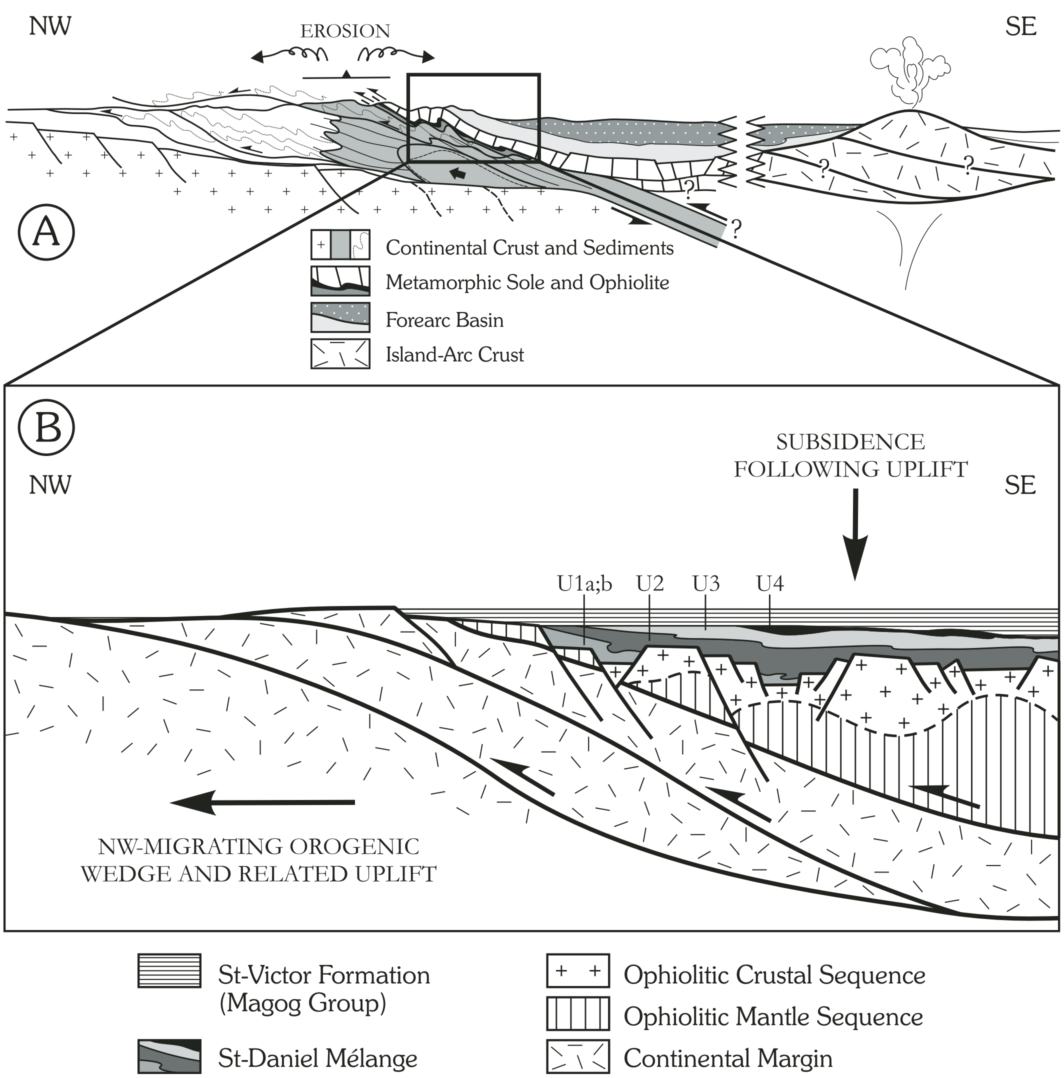

Figure 12. (A) Inferred regional tectonic setting of the southern Québec Appalachians during the Taconian orogeny. (B) Schematic sedimentary and tectonic evolution of the Saint-Daniel Mélange and the Magog Group along the western edge of the syncollisional forearc basin. Neither sketch is to scale. See text for details

(e.g., Rivière-de-l'Or section; Fig. 9B), which we believe demonstrates that unit U1 is the lowermost member of the Saint-Daniel Mélange. This basal unit (U1) is a fining-upward sedimentary sequence, which suggests a deepening basin. On the basis of data from the Mont-Ham section (Fig. 9D), the maximum thickness of unit U2 is estimated at ~1600 m. The relatively elevated abundance of Cr in the sandstones (Lavoie, 1989) suggests that ophiolitic material was still present in their source. The similarity of lithologies of units U2 and U3, and the transition from the thickly bedded sequence (U2) to the thinly bedded series (U3), suggest that these two units probably represent proximal-to-distal variations of sedimentary facies (Fig. 9C and D). The overall fining-up succession from U1 to U3 implies a period of tectonic subsidence following uplift. We believe that accretion-related uplift of the ophiolite and its metamorphic basement was followed by subsidence shortly thereafter. Subsidence may have been a response to sedimentary loading (Ingersoll, 1988) in the transported forearc basin as the evolving orogenic wedge moved progressively northwestward into the continental margin (Fig. 12).

Unit U4 occupies the uppermost part of the Saint-Daniel Mélange. Its lower contact presumably represents an erosional unconformity (Es-1 in Fig. 9), because fragments in the pebbly mudstone of unit U4 are similar to lithologies characteristic of the underlying units (U2 and U3) and plausibly represent reworking of this substrate. This pebbly mudstone facies can be interpreted either as the product of mud volcanoes or as large-scale mudflow deposits. The reworking of underlying units (U1, U2, U3) suggests that the protracted Taconian compression of the continental margin and the accreted ophiolites led to localized uplift and erosion of the lowermost sedimentary sequences, which were redeposited in the basin as the pebbly mudstones (mudflows) and associated finely laminated mudstones of unit U4. Unit 4 is overlain by rocks of the Magog Group (Fig. 9F; Es-2), which represent the infilling of a tectonically more stable sedimentary basin (Fig. 12). Stratigraphical and geochronological data also suggest that the final stages of ophiolite obduction (facilitated by the partial subduction of the Laurentian margin), and deposition of both the Saint-Daniel Mélange and the Magog Group, were coeval with arc volcanism preserved in the Ascot complex. The occurrence of volcaniclastic rocks interbedded with turbidites in the Magog Group is evidence for ongoing arc-volcanic activity and is consistent with a forearc basin interpretation (Cousineau and St-Julien, 1994). As an explanation for such relationships, we envisage a tectonic setting similar to the northern part of the present-day Papuan Ultramafic Belt, where arc volcanism continued for some time after the Eocene to Miocene emplacement of a boninitic ophiolite onto the Australian continental margin, therefore accounting for the interfingering of volcanic rocks with continentally derived sediments (see Milsom, 2003).

In summary, our study of the Saint-Daniel Mélange indicates that it unconformably overlies the ophiolite basement, as was previously proposed by Dérosier (1971), Lamarche (1973), and Hébert (1980). Such a stratigraphic position, with deposition onto the ophiolites and a gradation up into overlying rocks of the Magog Group, is not compatible with its genesis as a package of sediments deposited within a trench or inner trench–slope basin that was then scraped off to form a subduction complex (Ingersoll, 1988). Our interpretation of the Saint-Daniel Mélange and its relationships with adjacent ophiolites and flysch deposits is similar to those of the basal Great Valley Supergroup and the Coast Range Ophiolite of northern California (Phipps, 1984; Suchecki, 1984; Pessagno et al., 2000), of the upper part (i.e., the clast mélange) of the Batinah mélange above the Semail ophiolite in Oman (Robertson and Woodcock, 1983), and of olistostromes and mélanges (i.e., the Simoni mélange of Bortolotti et al., 1996) overlying Albanian and Dinaridic ophiolites (e.g., Robertson and Shallo, 2000; Pamic et al., 1998). Albanian mélanges, for instance, are matrix-supported conglomerates with blocks of both continentally and ophiolite-derived lithologies (including mica schist fragments), interpreted as cohesive debris flows and turbidites (Robertson and Shallo, 2000).

Similarities with the basal Great Valley Supergroup are particularly striking. Phipps (1984) described a widely distributed, mappable chaotic unit conformably overlying the Coast Range Ophiolite and directly overlain by a well-bedded sequence of mudstone, sandstone, and conglomerate that make up the major part of the Great Valley forearc basin. The chaotic unit overlying the Coast Range Ophiolite has been interpreted as an ophiolitic olistostrome and shares the following lithological characteristics with the Saint-Daniel Mélange: (1) it is up to 1 km thick and extends tens of kilometers along strike; (2) it contains clasts that represent samples of metamorphic rocks and all parts of an ophiolite; (3) it has a fine-grained matrix of thin flakes of serpentinite and clay mudstone, apparently continuous with and indistinguishable from that of the overlying bedded sequence; (4) it lies everywhere on an ophiolitic basement, although most commonly on serpentinized harzburgites in California; and (5) it is directly overlain by well-bedded rocks interpreted as the remnants of a forearc basin. Phipps (1984) suggested that the Coast Range Ophiolite was eroded during or soon after obduction, owing to isostatic uplift of the accretionary wedge, and that its erosional products were redeposited on top of the upper plate (i.e., the ophiolite). Such a tectonic and sedimentary history, which has been documented in modern convergent margins such as, e.g., the Mariana forearc region (Fryer et al., 2000), is almost exactly what we propose for the basal Saint-Daniel Mélange (Fig. 12).

In the study area, the Saint-Daniel Mélange is overlain by the Saint-Victor Formation, a thick (~7 km; Cousineau and St-Julien, 1994) succession of turbiditic siliciclastic rocks. This suggests that the pelagic sedimentation making up the upper part of the Saint-Daniel Mélange was overwhelmed by a sudden influx of voluminous siliciclastic turbidites that originated mainly from the erosion of the uplifted Laurentian continental margin during the climax of the Taconian orogeny. Such a stratigraphic succession also implies that the lowermost units of the Magog Group are missing in the western part of the forearc basin. Three hypotheses can account for such a stratigraphic gap: (1) there is a major erosional unconformity at the contact between the Saint-Daniel and the Magog in the study area, and ~2500 m of rocks have been eroded; (2) during sedimentation of the Magog Group, a major topographic high developed in the western part (present coordinate) of the forearc basin, and the lower sequences of the Magog Group were not deposited; or (3) the different units of the Saint-Daniel Mélange are actually facies correlative with the lower units of the Magog Group. Although we cannot disprove the first two hypotheses, lithological resemblances lead us to suspect that the upper Saint-Daniel Mélange is facies correlative with the basal units (Frontière, Etchemin, and Beauceville Formations) of the Magog Group. We are also confident that the Saint-Victor Formation, which represents ~70% of the Magog Group (Cousineau and St-Julien, 1994), does not have correlative facies in the Saint-Daniel Mélange because it makes up the uppermost series of the synorogenic flysch that overlies and onlaps both the Saint-Daniel Mélange and the lower Magog Group.

CONCLUSIONS

The stratigraphic and structural analysis of the Saint-Daniel Mélange in the southern Québec Appalachians implies the following:

1. The Saint-Daniel Mélange is a Llanvirn lithostratigraphic unit that represents the lowermost series of the western (present coordinates)

part of a forearc basin that lies stratigraphically on a partly eroded ophiolite basement and is mostly represented by the Magog Group. Throughout the study area, the Saint-Daniel Mélange lies directly above various levels of this basement. The lower contact of the mélange thus represents an erosional unconformity that marks the base of the forearc basin. The processes that formed the chaotic and breccia units of the mélange were the successive uplift, erosion, and burial by heterogeneous and localized debris flows of different parts of the ophiolite and of the underlying metamorphic rocks during the emplacement of the ophiolite. The 467 Ma $^{40}Ar/^{39}Ar$ muscovite age measured in metamorphic fragments of the basal debris flows of the Saint-Daniel Mélange is within the age range of regional metamorphism in metamorphic rocks structurally below the ophiolites and implies that the exhumation of these rocks occurred during or shortly after the emplacement of the ophiolite onto the Laurentian continental margin.

2. The Saint-Daniel Mélange is characterized by significant lateral and vertical facies variations that can be attributed to the paleotopographic relief of the ophiolitic basement. This paleotopography could have been inherited (related to synoceanic extension and the formation of the obducted oceanic crust) or, alternatively, attributed to isostatic uplift of both the ophiolite and underlying metamorphic rocks during the development of a NW-migrating orogenic wedge made up of both continental and oceanic lithologies. Typical chaotic, mélange-like (blocks in mud matrix) rocks of the Saint-Daniel Mélange are restricted to unit U4, which is not representative of >20% of its lithologies. Unit U4 is more representative of olistostromal deposits rather than tectonic mélange and is likely the result of mudflows (reworking the underlying sediments) that formed in a tectonically active forearc basin.

3. The mélange is stratigraphically overlain by the Llandeilian–Caradocian Saint-Victor Formation of the Magog Group, which represents an onlapping sedimentary sequence and records a significant period of regional isostatic subsidence. The Saint-Daniel Mélange is probably facies correlative with the lowermost parts of the Magog Group (Frontière, Etchemin, and Beauceville Formations), but the lack of exposure and the requirement for more detailed sedimentological analysis preclude a definitive correlation scheme between the mélange and the Magog Group at this time.

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