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Structural evolution of the Thetford Mines Ophiolite Complex, Canada: Implications for the southern Québec ophiolitic belt

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[1] The Thetford Mines Ophiolite Complex (TMOC) preserves a complete ophiolitic sequence, and occupies the hanging wall of a major SE dipping normal fault, the Saint-Joseph fault. Preobduction, synobduction, and postobduction structures can be recognized in the TMOC. NS trending, preobduction, paleonormal faults are parallel to ultramafic minor intrusions, and to sheeted dykes, recording extension related to seafloor-spreading in a pericontinental suprasubduction zone basin. WNW trending synobduction, synmetamorphic fabrics are found toward the base of the TMOC and in the underlying continental margin rocks, but are absent in the upper part of the TMOC and overlying sedimentary rocks. These Ordovician (Taconian) structures record the development of a dynamothermal aureole immediately below the mantle/margin contact, and emplacement of the young ophiolite onto the continental margin. Postobduction structures include Late Silurian/Early Devonian, SE verging backthrusts and back folds that inverted the TMOC; and Middle Devonian (Acadian) NW verging folds and reverse faults. The tectonic history established for the TMOC is consistent with that of the adjacent Laurentian margin, and can be applied to the southern Québec ophiolitic belt as a whole. The structural synthesis of the ophiolitic belt, complemented with new observations and our compilation of stratigraphical, geochemical, geochronological, and petrological data, suggests that the southern Québec ophiolites may represent the remnants of the obduction of a single large slab of suprasubduction oceanic lithosphere extending for over a 100 km of strike length. **Citation:** Schroetter, J.-M., J. H. Bédard, and A. Tremblay (2005), Structural evolution of the Thetford Mines Ophiolite Complex, Canada: Implications for the southern Québec ophiolitic belt, *Tectonics*, *24*, TC1001, doi:10.1029/2003TC001601.

1. Introduction

[2] Ophiolites are the accreted remnants of ancient oceans, and occur as discontinuous massifs within orogenic belts. Ophiolites preserve information about the oceanic crust that formed prior to orogenesis, and also record the tectonic processes by which oceanic lithosphere was accreted onto a continental margin. In most orogens, however, ophiolites exhibit a complex internal geometry, much of which reflects the regional deformational events that postdate obduction. These multiple orogenic overprints typically make it difficult to unravel the sequence and significance of the deformational events that predate the main tectonometamorphic pulses. The southern Québec ophiolitic belt (Figure 1) is constituted of fragments of Ordovician oceanic lithosphere that was accreted to the Laurentian continental margin during the Taconian phase of Appalachian orogenesis. Several features make this region an ideal natural laboratory for the elucidation of the complex structural history of a continental margin during oceanic terrane accretion. Specifically: (1) the numerous southern Québec ophiolites are well preserved because they occupy a continental reentrant where the effects of synaccretion tectonism were minimized [e.g., *Harris*, 1992]; (2) the Devonian (Acadian), postaccretion structural and metamorphic overprint is less severe in southern Québec than in New England [e.g., *Tremblay et al.*, 2000] where critical relations between ophiolites and surrounding rock units are obscured by severe deformation and pervasive, greenschist- to amphibolite-grade metamorphism; (3) most of the southern Québec ophiolites have a near-complete internal stratigraphy (sole, mantle, plutonic rocks, hypabyssal complex, lavas, sediments) and their crystallization ages have been established by U-Pb zircon dating [e.g., *Dunning et al.*, 1986; *David and Marquis*, 1994; *Whitehead et al.*, 2000]; (4) numerous geochemical studies, including paleotectonic discrimination analyses, are available [*Church*, 1977, 1978, 1987; *Oshin and Crocket*, 1986; *Harnois and Morency*, 1989; *Hébert and Laurent*, 1989; *Laurent and Hébert*, 1989; *Olive et al.*,

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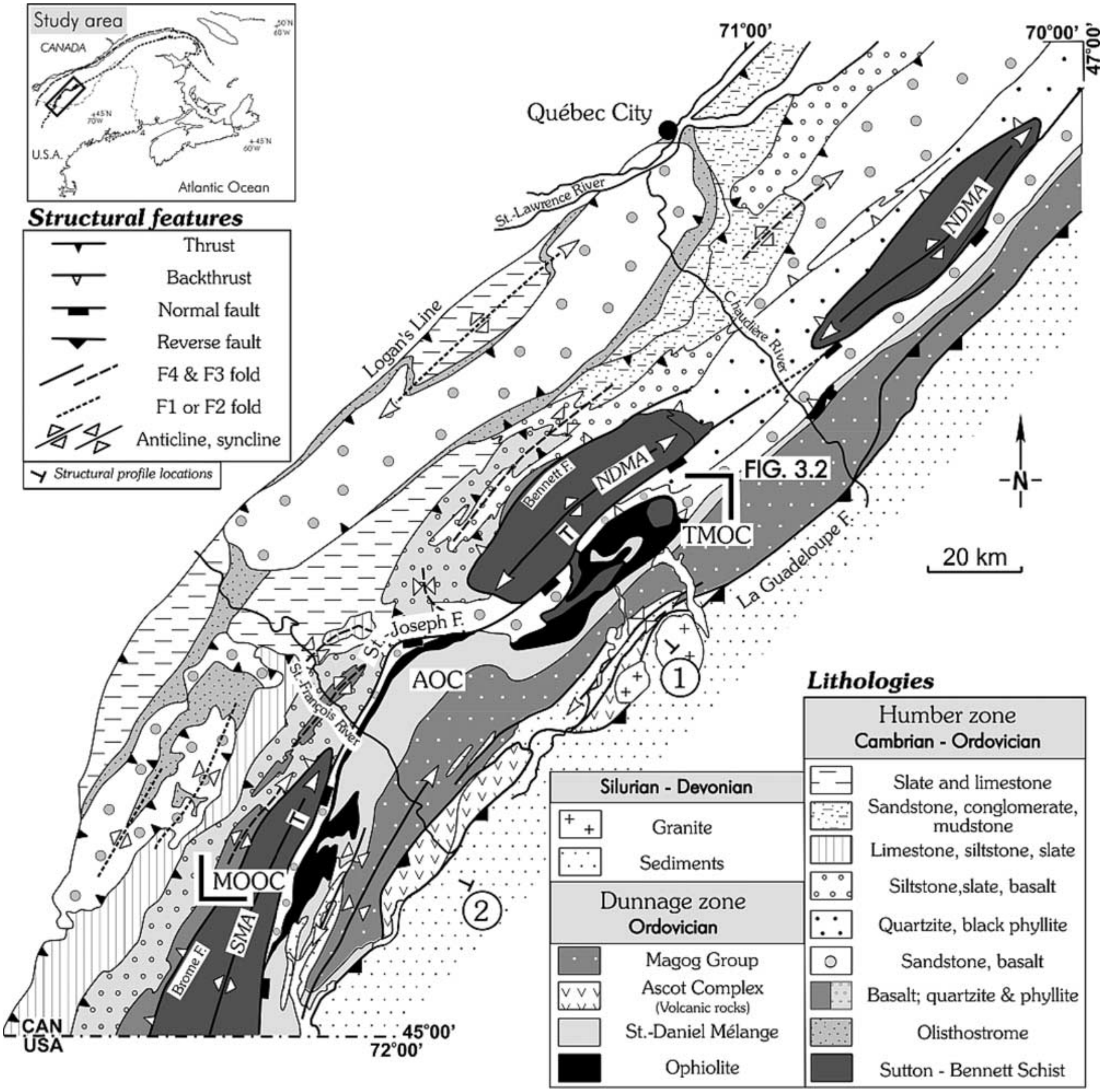


Figure 1. Geological map of the southern Québec Appalachians (modified from *Tremblay and Castonguay* [2002]). Abbreviations are as follows: NDMA, Notre-Dame mountains anticlinorium; SMA, Sutton mountains anticlinorium; TMOC, Thetford Mines Ophiolite Complex; AOC, Asbestos Ophiolitic Complex; MOOC, Mont Orford Ophiolitic Complex. Circled numbers refer to the location of structural profiles of Figure 12.

1997; *Hébert and Bédard*, 2000; *Huot et al.*, 2002; *Bédard and Kim*, 2002]; and finally (5) in southern Québec, the metamorphic and structural evolution of the continental margin is well established [*Tremblay and Pinet*, 1994; *Castonguay and Tremblay*, 2003] and constrained by ^{40}Ar/^{39}Ar isotopic dating [*Whitehead et al.*, 1995; *Castonguay et al.*, 2001; *Tremblay and Castonguay*, 2002], providing a regional framework for structural analysis of the accreted ophiolites.

[3] The detailed structural analysis of the Thetford Mines Ophiolite Complex (TMOC) presented in this paper was executed in tandem with geological mapping [*Schroetter et al.*, 2000, 2001, 2002, 2004] and petrological work [*Bédard et al.*, 2001; *Pagé et al.*, 2003]; providing an integrated view of ophiolite genesis and evolution. We begin by characterizing the various types of fabrics and structures that we have observed in the TMOC. By comparing and correlating the ophiolitic structures with regionally extensive

fabrics developed in rocks of the adjacent continental margin, we can subdivide them into pre obduction, synobduction, and postobduction structures. The framework we establish for the TMOC will then be applied to the rest of the southern Québec ophiolitic belt, allowing along-strike, regional-scale structural correlations.

2. Geological Context

[4] The southern Québec Appalachians comprise three principal lithotectonic assemblages (Figure 1): the Cambro-Ordovician Humber and Dunnage zones, and the Silurian-Devonian volcanic and sedimentary rocks of the Connecticut Valley-Gaspé synclinorium, or trough [*Williams*, 1979]. The Humber zone represents the vestiges of a pre-Cambrian to Early Paleozoic passive continental margin sequence, while the Dunnage zone is an assemblage of Ordovician oceanic terranes (ophiolites), subduction-related volcanic rocks and marine sedimentary deposits. The contact between the Humber and Dunnage zones is the Baie Verte-Brompton Line (BBL), which is loosely defined as a linear zone of discontinuous serpentinites, dismembered ophiolites and mélanges [*Williams and St-Julien*, 1982]. The Humber zone is separated into two subzones (external and internal) on the basis of contrasting deformation style and metamorphic intensity [*Williams*, 1995; *Tremblay and Castonguay*, 2002]. The higher-grade, internal Humber zone comprises the Sutton Mountains anticlinorum (SMA), the Notre Dame Mountains anticlinorum (NDMA; Figure 1), and a series of structural windows to the southeast (e.g., the Bécancour and Carineault anticlines of the Thetford Mines Ophiolite Complex (TMOC; Figure 3) [*Birkett*, 1981; *Tremblay and Pinet*, 1994; *Tremblay and Castonguay*, 2002]. The Dunnage zone comprises (1) a series of Early Ordovician ophiolitic complexes, interpreted as the remnants of oceanic lithosphere, mostly subduction related, (2) the Ascot Complex, a Middle to Late Ordovician composite terrane constituted of volcanic arc sequences, (3) the Magog Group, a forearc sedimentary sequence deposited upon the developing Taconian orogen, and (4) the Saint-Daniel Mélange, representing either a Taconian oceanic accretionary complex, or a part and the base of Magog Group [*Cousineau*, 1988; *Cousineau and St-Julien*, 1992, 1994; *Tremblay et al.*, 1995 J.-M. Schroetter et al., Synorogenic basin development in the Appalachian Orogen—The Saint-Daniel Melange, southern Québec, Canada, submitted to *Geological Society of America Bulletin*, 2004; hereinafter referred to as Schroetter et al., submitted manuscript, 2004].

[5] In southern Québec, the internal Humber zone is characterized by doubly plunging domal structures (the SMA and the NDMA) that expose greenschist- to lower amphibolite-facies metamorphic rocks [*Tremblay and Castonguay*, 2002]. These rocks were affected by a regional $S_{1\text{-}2}$ schistosity and associated synmetamorphic folds and faults, and were then overprinted by a penetrative crenulation cleavage [S_3 of *Tremblay and Pinet*, 1994] that is axial-planar to hinterland-verging (to the SE) folds and ductile shear zones along the northwestern limb of the internal Humber zone, i.e., the Bennett-Brome fault of *Tremblay and Castonguay* [2002]. Amphibole and mica ^{40}Ar/^{39}Ar ages from the internal zone vary between 431 and 411 Ma; however, locally, high-temperature steps of Ordovician age (462–460 Ma) were extracted from amphiboles of the NDMA [*Castonguay et al.*, 2001]. These data have been interpreted as evidence for a composite tectonometamorphic history, with extensive, Silurian age reworking of rocks affected by an earlier, Middle Ordovician orogenic pulse [*Castonguay et al.*, 2001; *Tremblay and Castonguay*, 2002].

[6] To the southeast, the internal Humber zone is limited by the Saint-Joseph fault and the BBL [*Pinet et al.*, 1996; *Tremblay and Castonguay*, 2002], which together constitutes a composite east dipping normal fault system. In the hanging wall of this normal fault system, continental metamorphic rocks very similar to those of the SMA and NDMA are exposed in the cores of Acadian antiforms (the Bécancour and Carineault anticlines), and have yielded Middle Ordovician ^{40}Ar/^{39}Ar muscovite ages (462–460 Ma [*Whitehead et al.*, 1995; *Castonguay et al.*, 2001]) similar to the high-temperature step amphibole ages of the NDMA. All of these Middle Ordovician ages are considered to be the result of Taconian metamorphism and NW verging compressional deformation (circa 490–445 Ma [*St-Julien and Hubert*, 1975; *Stanley and Ratcliffe*, 1985; *Ratcliffe et al.*, 1998; *Tremblay and Castonguay*, 2002]). Existing models attribute the Taconian orogeny to the collision between the Laurentian margin and island arc terranes (the Taconian arcs) developed over either a southeast facing [*Osberg*, 1978; *Stanley and Ratcliffe*, 1985; *Ratcliffe et al.*, 1998], or a northwest facing [*St-Julien and Hubert*, 1975] subduction zone. *Pinet and Tremblay* [1995a and 1995b] argued that the Taconian was the result of obduction of the oceanic lithosphere onto the Laurentian passive margin.

[7] The Silurian-Early-Devonian (431–411 Ma) tectonic event recorded by Humber zone rocks in southern Québec is interpreted in terms of two alternative models. The first model invokes hinterland-directed (to the SE) thrusting in response to the tectonic wedging of a basement-cored complex, which induced the backthrusting of the supracrustal rocks and extension along the Saint-Joseph fault [*Castonguay and Tremblay*, 2003]. The second model involves crustal-scale exhumation by extensional collapse of the internal Humber zone following the Taconian orogeny [*Pinet et al.*, 1996; *Castonguay and Tremblay*, 2003; *Tremblay and Castonguay*, 2002], possibly as a result of slab delamination and isostatic rebound of the subducted plate.

[8] A major Middle Devonian (Acadian) deformational event affected pre-Taconian and post-Taconian rocks [*Tremblay*, 1992; *Tremblay et al.*, 2000], and is characterized in southern Québec by open to isoclinal folds with an axial-planar cleavage and high-angle NW verging reverse faults, corresponding to the D_4 structures of *Tremblay and Pinet* [1994]. The intensity of Acadian deformation and metamorphism decreases toward the NW. The Acadian orogeny is considered to record the final destruction of

Iapetus by a continent/continent collision between the Laurentian margin and Gondwana and/or the Composite Avalon Terrane [*Osberg*, 1978; *Williams and Hatcher*, 1983; *Robinson et al.*, 1998; *van Staal et al.*, 1998].

3. Southern Québec Ophiolitic Belt

[9] The southern Québec ophiolitic belt comprises three major ophiolitic complexes (Figure 1; Thetford Mines (TMOC), Asbestos (AOC), Mont Orford (MOOC)) [e.g., *Laurent et al.*, 1979], as well as a number of smaller slivers. The coeval TMOC and AOC, with U/Pb zircon ages of 479 ± 3 Ma and 478–480 +3/−2 Ma, respectively [*Dunning et al.*, 1986; *Dunning and Pedersen*, 1988; *Whitehead et al.*, 2000], preserve both mantle and crustal rocks, and are dominated by boninitic magmatism (with subordinate tholeiites), a feature which has been attributed to their genesis either in a forearc environment [*Laurent and Hébert*, 1989; *Hébert and Bédard*, 2000], and/or in a back arc setting [*Oshin and Crocket*, 1986; *Olive et al.*, 1997]. In contrast, only the crustal section is present in the MOOC, which contains a greater diversity of magma types, interpreted in terms of arc–back arc [*Harnois and Morency*, 1989; *Laurent and Hébert*, 1989; *Hébert and Laurent*, 1989] or arc-forearc to back arc environments [*Huot et al.*, 2002]. The MOOC has a maximum age of (504 ± 3 Ma [*David and Marquis*, 1994]).

[10] The ophiolites of the southern Québec ophiolitic belt are currently considered to represent kilometer-scale, fault-bounded blocks within the Saint-Daniel Mélange, which has been interpreted as the remnants of a subduction-accretionary complex [*Cousineau and St-Julien*, 1992; *Tremblay et al.*, 1995] that is in fault contact both with the ophiolites and with the Magog Group. In contrast, others have described the contact between the TMOC and the Saint-Daniel Mélange as stratigraphic and depositional in nature [*Dérosier*, 1971; *Hébert*, 1983]. Our detailed mapping of the Saint-Daniel Mélange in key areas [*Schroetter et al.*, 2004; Schroetter et al., submitted manuscript, 2004], indicates that the Saint-Daniel Mélange is a fining upward sedimentary sequence that stratigraphically overlies the ophiolites and is, in turn, depositionally overlain by the sedimentary rocks of the Magog Group. These data suggest that the rocks of the Saint-Daniel Mélange were deposited in a piggyback basin that records the infilling of an inherited topography of the forearc oceanic crust. We address a complementary aspect of this issue here, by documenting the structural history of the ophiolite complexes and Saint-Daniel Mélange, and comparing them to the history of surrounding tectonic elements, including the internal Humber Zone and the sedimentary components of the Dunnage Zone (Figure 2).

4. Thetford Mines Ophiolite Complex (TMOC)

[11] The Thetford Mines Ophiolite Complex (TMOC) outcrops as a NE trending belt, 40 km in length and 10–15 km in width (Figure 3). The TMOC is divided [*Laurent*, 1975] into the Thetford Mines (TM) massif to the northwest and the Adstock-Ham Mountains (AHM) massif to the southeast (Figure 3). The TM massif has a ~5 km thick mantle section [*Laurent et al.*, 1979; *Pagé et al.*, 2003] and a 0.5 to 1.5 km thick crustal section [*Schroetter et al.*, 2004]. The oceanic mantle is not preserved in the AHM massif. The crustal section is similar in both massifs, and consists of dunitic, pyroxenitic and gabbroic cumulates, crosscut by mafic to ultramafic dikes (all of boninitic affinity), which locally grade up into a well-developed sheeted dike complex [*Bédard et al.*, 2001; *Schroetter et al.*, 2004]. The extrusive sequence is extremely variable; both in thickness and lithology, but boninitic lava flows and felsic pyroclastic rocks dominate. Tholeiitic lavas are locally preserved at the base of the Lac de l'Est section and at Mount Ham [*Oshin and Crocket*, 1986; *Laurent and Hébert*, 1989]. The ophiolitic extrusive sequence is overlain by laterally discontinuous debris flows (Coleraine Group of *Riordon* [1954] and Coleraine breccia of *Hébert* [1980]), which are characterized by centimeter- to meter-scale angular fragments, which are typically ophiolite-derived at the base (ultramafic, volcanic, sedimentary clasts), but contain an increasing proportion of continentally derived metasedimentary rocks toward the top. The coarse-grained debrites wedge out laterally into fine-grained siliciclastic rocks (red argillites and siltstones, green tuffs), and grade up progressively into turbidites, argillites, siltstones and pebbly mudstones characteristic of the Saint-Daniel Mélange (Schroetter et al., submitted manuscript, 2004).

4.1. Structural Geology and Deformational Episodes

[12] Several episodes of deformation can be identified in the TMOC and its cover rocks. In the following, these episodes are subdivided into (1) preobduction faults, (2) synobduction shear zones and folds, and (3) two generations of postobduction faults and folds that show significant contrast in timing and structural vergence, and which represent the main phases of regional deformation of the area. The correlation between the terminology used in this paper and the terminology used previously by *Tremblay and Pinet* [1994] is summarized in Figure 4. Herein, we use (S_n)/(S_1) to describe the dynamo-thermal foliation and/or the cleavage associated with Ordovician emplacement of the ophiolite onto the continental margin (D_{1-2} of *Tremblay and Pinet* [1994]); (S_3) when referring to the Silurian backthrusting event (D_3 of *Tremblay and Pinet* [1994]), and (S_4) for the Devonian Acadian event (D_4 of *Tremblay and Pinet* [1994]).

4.1.1. Preobduction Structures

[13] Our mapping has revealed the presence in the AHM of numerous subvertically dipping, N-S to 20° striking faults, spaced ~1 km apart on average [*Schroetter et al.*, 2004]. In the plutonic part of the crust, the faults are manifested as sheared or mylonitic dunites and synmagmatic breccias, and commonly correspond to along-strike breaks in lithology. The fault breccias are cut by undeformed, 10-m scale, websteritic to lherzolitic intrusions, demonstrating the premagmatic to synmagmatic nature of the faulting. Assuming that rhythmic cumulate layering was

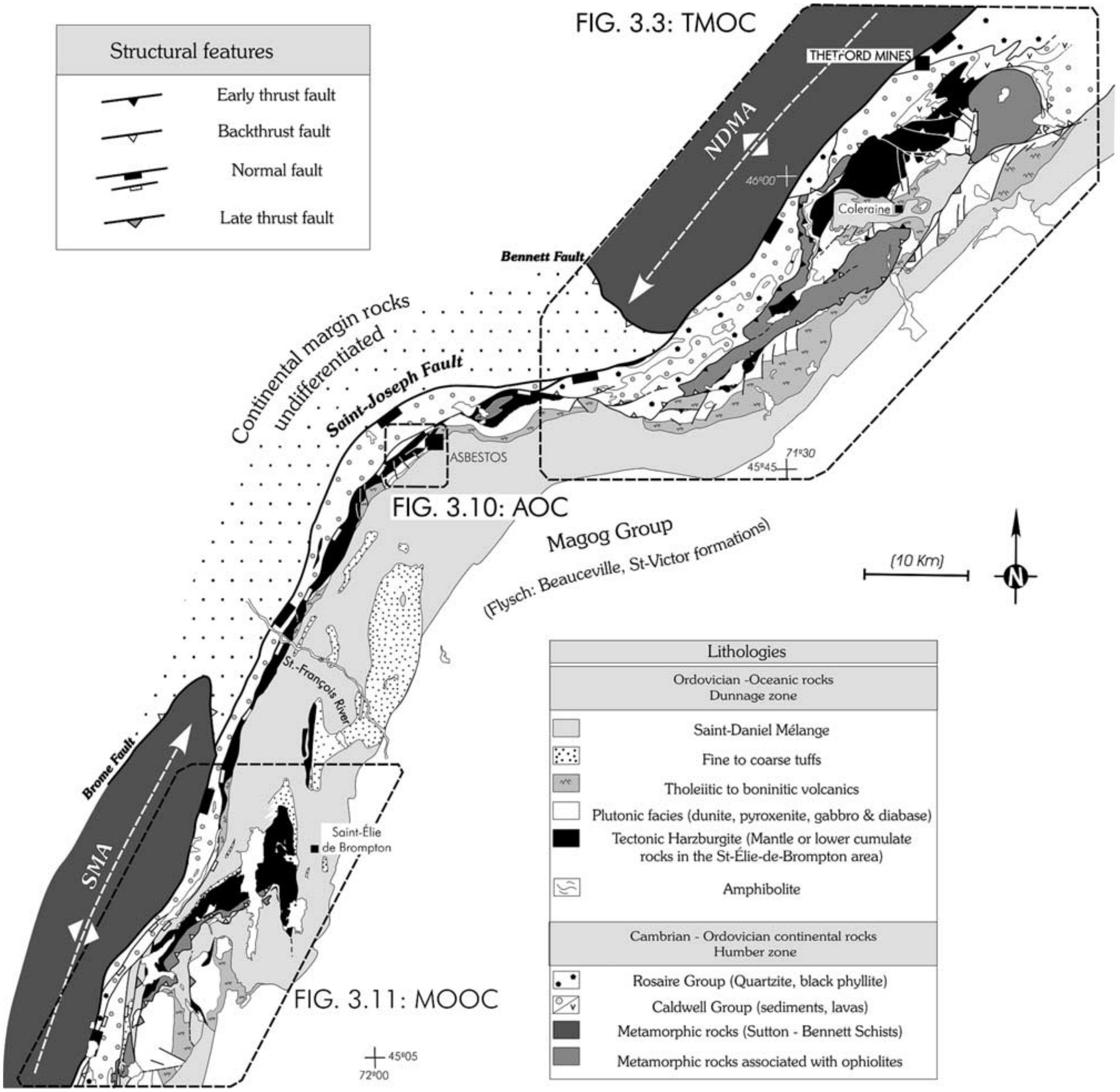


Figure 2. Geological map of the southern Québec ophiolitic belt, based on this study and complemented by mapping data compiled from *Beulac* [1982], *Brassard and Tremblay* [1999], *Brodeur and Marquis* [1995], *Cooke* [1938, 1950], *Hébert* [1980, 1983], *Huot* [1997], *Lamarche* [1973], *Lavoie* [1989], *Marquis* [1989], *Pinet* [1995], *Riordon* [1954], *Rodrigue* [1979], *St-Julien* [1963], and *Avramtchev et al.* [1989]. See Figure 1 for location. Other symbols as in Figure 1.

originally paleohorizontal, then kinematic analysis implies that these were originally normal faults separating a series of tilted blocks. Swarms of N-S striking dykes are oriented parallel to the major faults and locally constitute a sheeted complex. In the upper part of the crust, the faults correspond to marked lateral changes in the thickness and facies assemblages seen in supracrustal rocks, are locally marked by prominent subvolcanic breccias, and have upwardly decreasing throws, which together suggest that they are growth faults. The base of the volcano-sedimentary sequence is a major erosional surface in many places, which can penetrate down to Dunitic Zone rocks. We have interpreted the prominent lateral thickness variations in oceanic lavas and sediments as the consequence of extensional, preobduction, faulting. The evidence for coeval extension and magmatism, and the presence of a sheeted dyke complex, imply that the TMOC formed by seafloor spreading [*Schroetter et al.*, 2004]. The dominance of a boninitic signature in cumulate and volcanic rocks suggests that spreading occurred in a subduction zone environment,

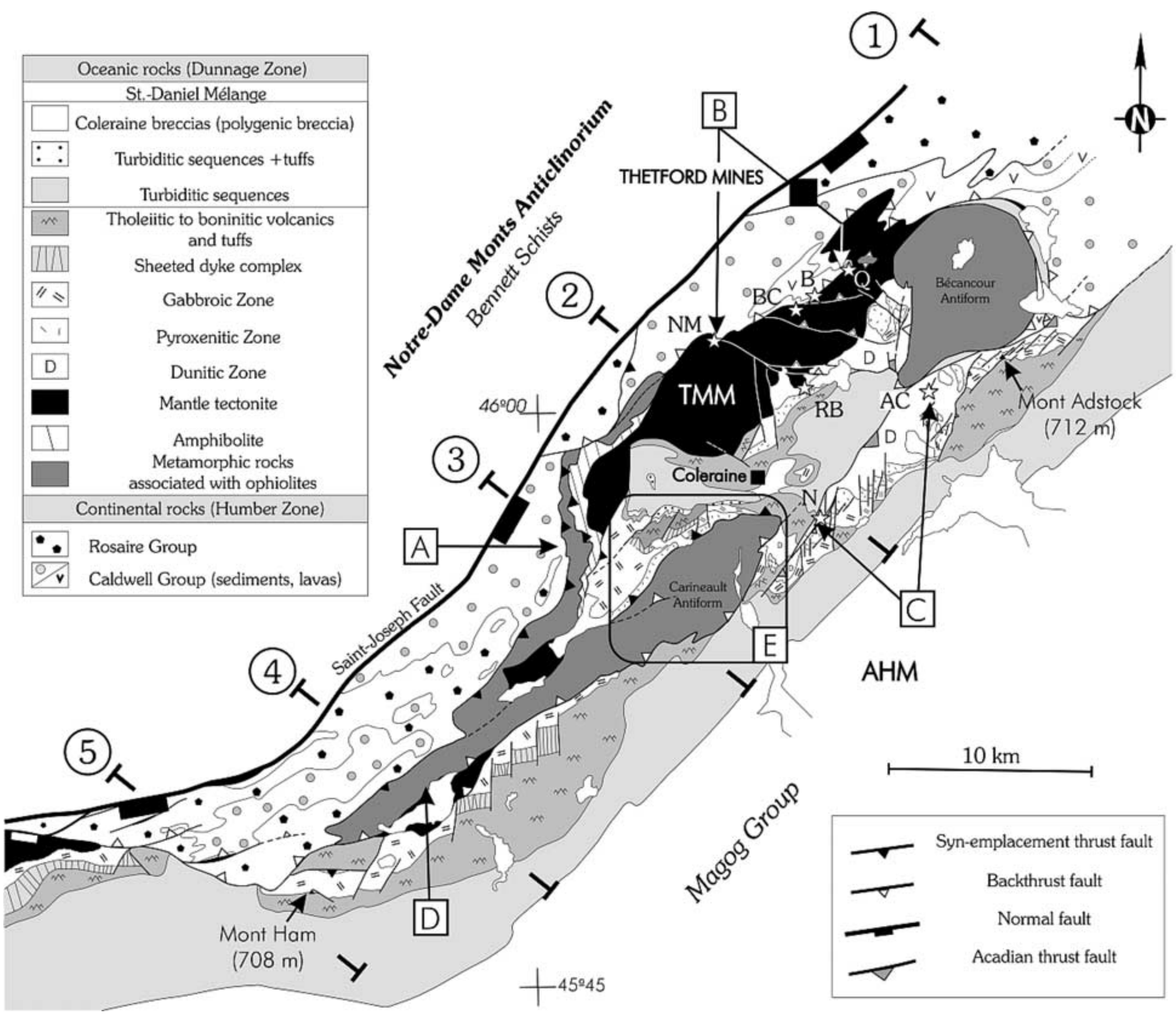


Figure 3. Geological map of the Thetford Mines Ophiolite Complex showing the location of key outcrops and sites mapped during this study. Abbreviations are as follows: TMM, Thetford Mines massif; AHM, Adstock-Ham massif; RB, Reed-Bélanger mine; N, Nadeau mine; NM, Normandie mine; B, Beaver mine; AC, American Chrome mine. Letters in squares refer to detailed field sketches or photographs described in this study. Numbered circles refer to the location of structural profiles shown in Figure 7. See Figure 2 for location.

possibly in a forearc setting [*Bédard et al.*, 2001; *Bédard and Kim*, 2002].

4.1.2. Obduction-Related Structures

[14] Structures that can be strictly assigned to obduction processes are only locally developed in the TMOC. An obduction-related metamorphic sole up to 1 km thick separates the base of the mantle sequence from Laurentian margin metasediments (Figure 3). Planar fabrics in the metamorphic sole are subparallel to the contact with the overlying ophiolite, and dip moderately to steeply toward the east or the southeast (Figure 3 Box A, and Figure 5a). The dominant fabric in the sole is a metamorphic foliation (S_n) axial-planar to isoclinal folds and is defined by the preferred orientation of hornblende and epidote [*Feininger*, 1981; *Clague et al.*, 1981; *Whitehead et al.*, 1995]. High-strain zones related to obduction are only locally developed in the overlying mantle rocks. In contrast, obduction-related deformation and metamorphism extend for a considerable distance into the Laurentian margin rocks (~2.5 km), with NW verging isoclinal folds (P1) becoming progressively more open (Figure 5a (east) to Figure 5c (west)) away from the contact with the ophiolite.

[15] Metamorphic assemblages in the sole are, from the top down: (1) brown hornblende + epidote ± garnet ± clinopyroxene, for rocks in the upper amphibolite facies; (2) green hornblende ± quartz + epidote ± garnet, for rocks in the lower amphibolite facies; and (3) chlorite + albite + quartz + muscovite ± garnet, for rocks in the greenschist facies. Metamorphic temperatures are 850°–780°C near the contact with the harzburgite tectonite, and decrease to 580°–500°C at the base of the sole. Metamorphic pressures range from 7 to 5 kbars [*Feininger*, 1981; *Clague et al.*,

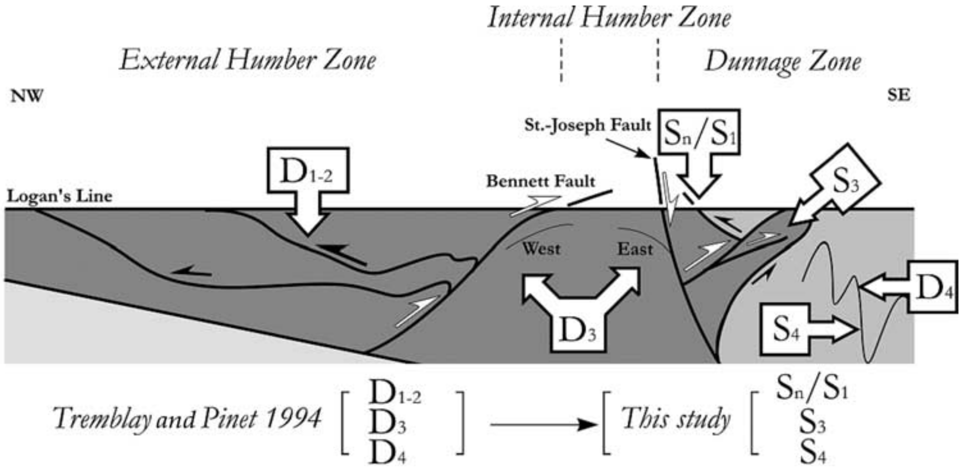


Figure 4. Schematic illustration of the nomenclature used to describe the different deformational events of the area. See text for discussion.

1981]. The data indicate an inverse thermal gradient of 40°C/km [*Feininger*, 1981]. Amphibolitic rocks from the sole yield $^{40}Ar/^{39}Ar$ ages of 477 ± 5 Ma [*Whitehead et al.*, 1995], whereas the underlying metasediments (i.e., Carineault and Bécancour Anticlines, Star in Box E in Figure 3) yield muscovite $^{40}Ar/^{39}Ar$ ages ranging from 469 to 460 Ma [*Whitehead et al.*, 1995; *Castonguay et al.*, 2001]. These ages have been interpreted to record intraoceanic detachment (i.e., the amphibolite sole), which culminated with the emplacement of the oceanic lithosphere onto the continental margin [*Pinet and Tremblay*, 1995a; *Tremblay and Castonguay*, 2002]. The $^{40}Ar/^{39}Ar$ ages difference (~15 to 17 m.y.) between amphibolitic metamorphism in the dynamo-thermal sole (477 Ma on amphibole) and the underlying quartz-muscovite schists (462–460 Ma on muscovite) of the Carineault and Bécancour antiforms could be due to differences in the Ar blocking temperatures for amphibole (~500°C) and muscovite (~350°C).

4.1.3. Postobduction Structures

[16] Two postobduction deformational events are recognized in the Thetford Mines ophiolite: (1) a SE verging folding/backthrusting event previously recognized in the metamorphosed continental rocks of the internal Humber zone by *Tremblay and Pinet* [1994] and (2) an Acadian folding/thrust-faulting event which forms the dominant regional fabric in the Dunnage Zone of southern Québec [*Tremblay and St-Julien*, 1990; *Tremblay*, 1992].

[17] 1. Backthrusting structures and fabrics (folds and faults) are well exposed (Figure 3, Box B, NM and Q) along the northwestern margin of the TMOC. Our observations show that the greenschist-grade metasediments of the continental margin were thrust over the ophiolite along a major fault, referred to here as the $\varphi 1$ fault (Figure 6a). The $\varphi 1$ fault trends NNE and dips approximately 50° toward the WNW. Slickensides, striations and other shear lineations are essentially downdip, and C/S fabrics clearly indicate a west-over-east sense of shear (Figure 6b). In the Normandie mine (NM, Figure 3), the metamorphic foliation (S_n) of metasedimentary rocks in the hanging wall of the backthrust fault is folded (Figures 6c and 6d), and the overprinting axial-planar fabric is a poorly developed fracture cleavage (S_3). Similar structures and relationships are found in other quarries along this contact (e.g., Q, Figures 3b, 3c, 6e, and 6f); and are also well developed locally within the mantle section [*Laurent et al.*, 1984; *Clague et al.*, 1985; *Whitehead et al.*, 2000]. Within the metamorphic sole, a crenulation cleavage (S_3) trends east-west and dips moderately (~60°) to the north (Figures 5a and 5b). This (S_3) fabric overprints the metamorphic foliation (S_n), but contrasts both in trend and dip with the Acadian (S_4) cleavage (see below).

[18] The $\varphi 1$ backthrust fault is considered the major backthrust structure of the area and is responsible for a large recumbent fold documented by *St-Julien* [1987] in the continental rocks of the margin to the north of the TMOC (see structural profile 1 in Figure 7). Structurally, the Thetford Mines massif occupies the hinge zone of a SE verging syncline that is located in the footwall and genetically related to the $\varphi 1$ backthrust fault, which has overturned the SE facing pseudostratigraphy of the Thetford Mines massif (Figure 3 and structural profile 2 in Figure 7). Structural relationships between (S_3) and (S_n) are also consistent with the presence of SE verging overturned folds (Figures 5a and 5b).

[19] However, the $\varphi 1$ backthrust fault cannot explain the structural relationships between the TMOC and a series of tectonic windows (Carineault and Bécancour antiforms), which form NE trending domes of metamorphosed continental margin sediments (Figure 3). Mapping in the Carineault antiform (Figure 3, Box E) shows that rocks composing the anticline are affected by three tectonic fabrics (Figure 8a). The earliest tectonic fabric (S_n), as previously noted, is a metamorphic foliation defined by alternating quartz-rich and mica-rich metasediments. When the bedding and primary sedimentary structures are preserved (Figure 8a), we refer to this foliation as (S_n). Where metamorphic foliations dominate, we call this fabric (S_1). North of Lac Nicolet (Figure 3, Box D, and Figure 8b), near the contact with the ophiolite, the

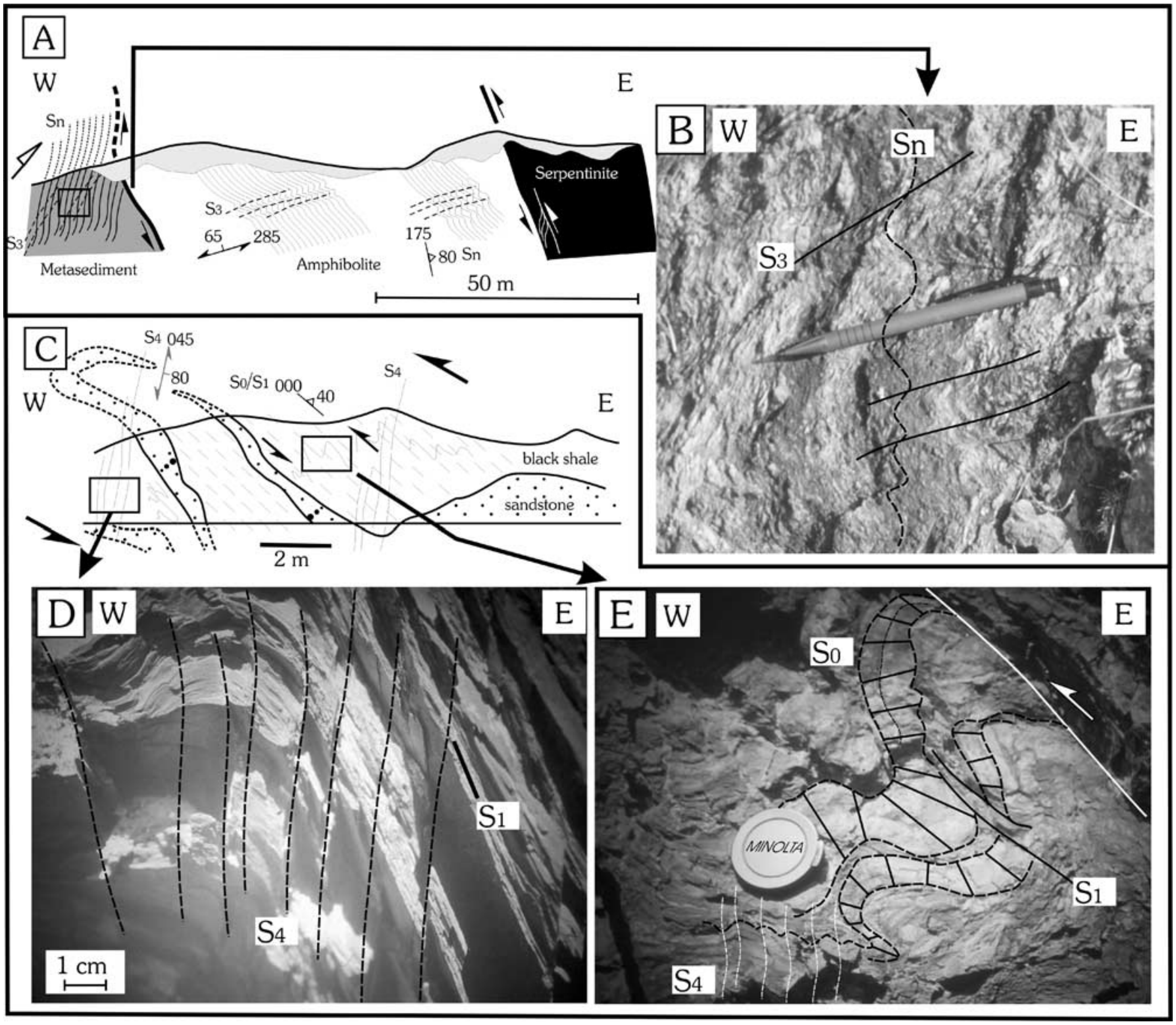


Figure 5. Field sketches and photographs illustrating the variety of fabrics and structures in the vicinity of the contact between the ophiolites and the underlying sedimentary rocks. Location A in Figure 3. (a) Field sketch of the contact ophiolite margin at the amphibolitic sole; (b) photograph showing overprinting relations between the main obduction fabric [Sn] and the backfold fabric [S_3] in metasedimentary rocks. The pencil is 15 cm long; (c) field sketch of an isoclinal, synobduction fold overprinted by an Acadian fold with [S_4] as an axial-planar fabric; (d) photograph showing [S_4] overprinting the [S_1] obduction fabric [S_1] in low-grade sedimentary rocks (Caldwell-type); (e) photograph showing a NW verging obduction fold [S_1] overprinted by the subvertical [S_4] Acadian cleavage. Camera lens is 6 cm.

metamorphic foliation (S_n) in metasedimentary rocks of the Carineault Antiform is overprinted by a poorly developed N-S to NE-SW trending (S_3) fracture cleavage (Figure 8a) axial planar to folds that trend approximately NS in this area (Figure 8b). C/S fabrics developed at the southern boundary of the anticline are consistent with the presence of a SE verging backthrust fault ($\varphi 2$ fault), as was suggested by *Beulac* [1982], and which we believe transported the metasedimentary rocks of the Carineault anticline toward the south over the ophiolitic rocks of the AHM (profiles 3 and 4 in Figure 7). The (S_n)/(S_1) and (S_3) fabrics are overprinted by a late, NS to NNE trending, open fold with axial-planar cleavage (S_4) that we correlate to the Acadian orogeny (D_4 of *Tremblay and Pinet* [1994]) and which is more fully described below.

[20] 2. Acadian folding/reverse faulting is a major deformational event that is characterized by subvertical folds trending NE-SW, with an axial-planar cleavage (S_4) that is developed on a regional scale, and which progressively decreases in intensity from SE to NW [*St-Julien and Hubert*, 1975; *Labbé and St-Julien*, 1989; *Tremblay and St-Julien*, 1990; *Tremblay and Pinet*, 1994].

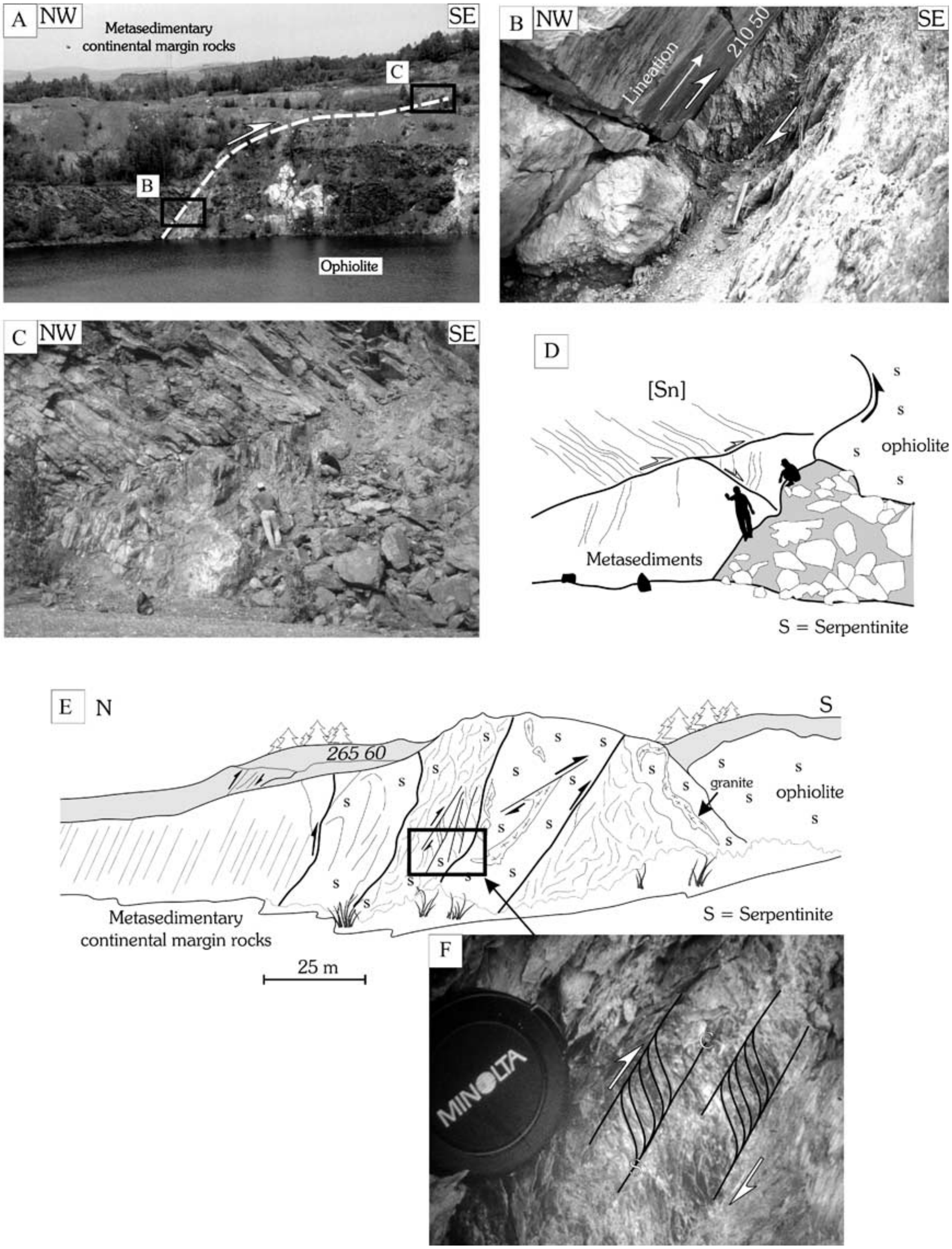


Figure 6. Photographs and field sketches illustrating the backthrusting deformational event in the Normandie mine and other quarries of the Thetford Mines area. See Figure 3 for location (location B and sites NM and Q). (a) View of northern wall of the Normandie mine showing the trace of the backthrust fault. (b) Close-up view of the backthrust fault and the contact between continental metasedimentary rocks (top left) and ophiolitic rocks (bottom right). Note the steeply plunging fault striations. Hammer for scale. (c and d) Close-up view and field sketch of the backfold affecting a syn-[S_n] contact (obduction?) between the ophiolite and the margin. See Figure 6a photograph for location. (e and f) Field sketch and photographs showing well-developed, SE verging C-S fabrics developed in serpentinites of the TMOC in a quarry south of Thetford Mines. Camera lens for scale.

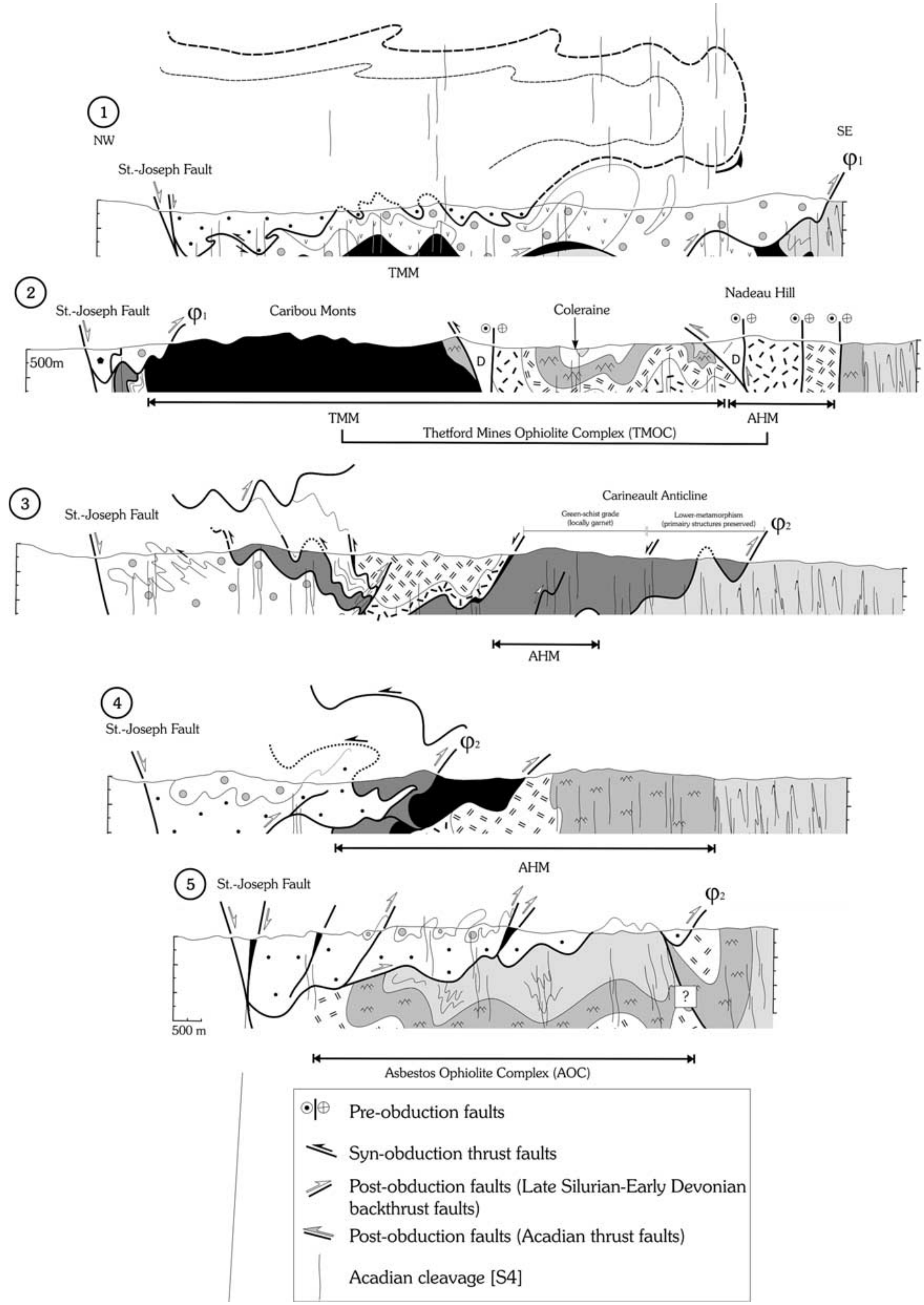
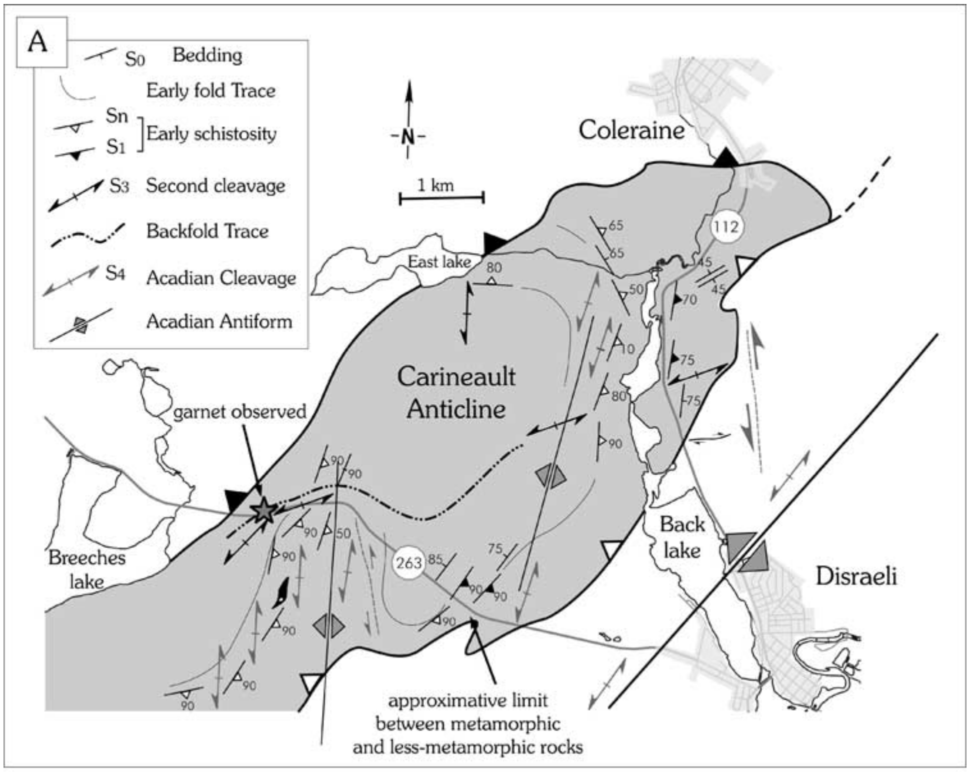


Figure 7. NW-SE trending structural profiles of the Thetford Mines Ophiolite. See Figure 3 for location. Same symbols as in Figure 3. See text for discussion.



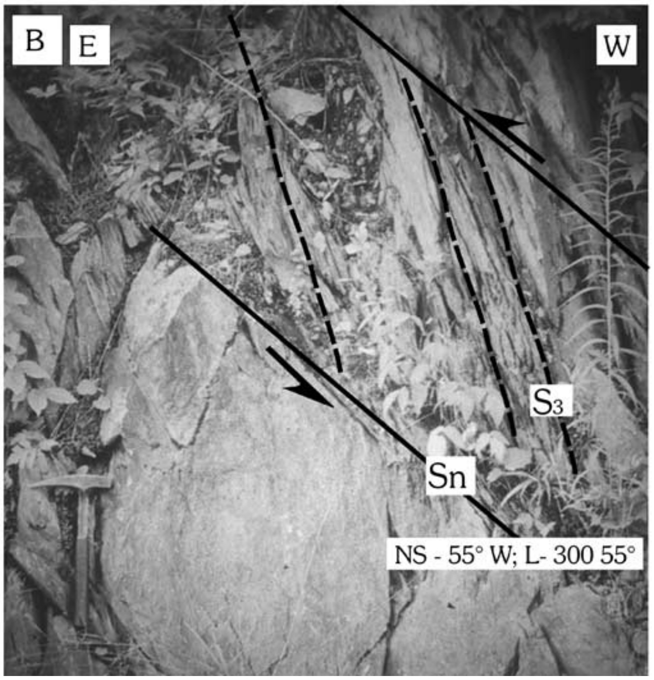


Figure 8. (a) Detailed map of the Carineault antiform showing the distribution and the orientation of structural fabrics and associated folds. Location E in Figure 3. (b) Photograph of an east verging backfold showing the thrusting of (top) metasedimentary rocks onto (bottom) ophiolite rocks. Hammer for scale. Location D in Figure 3.

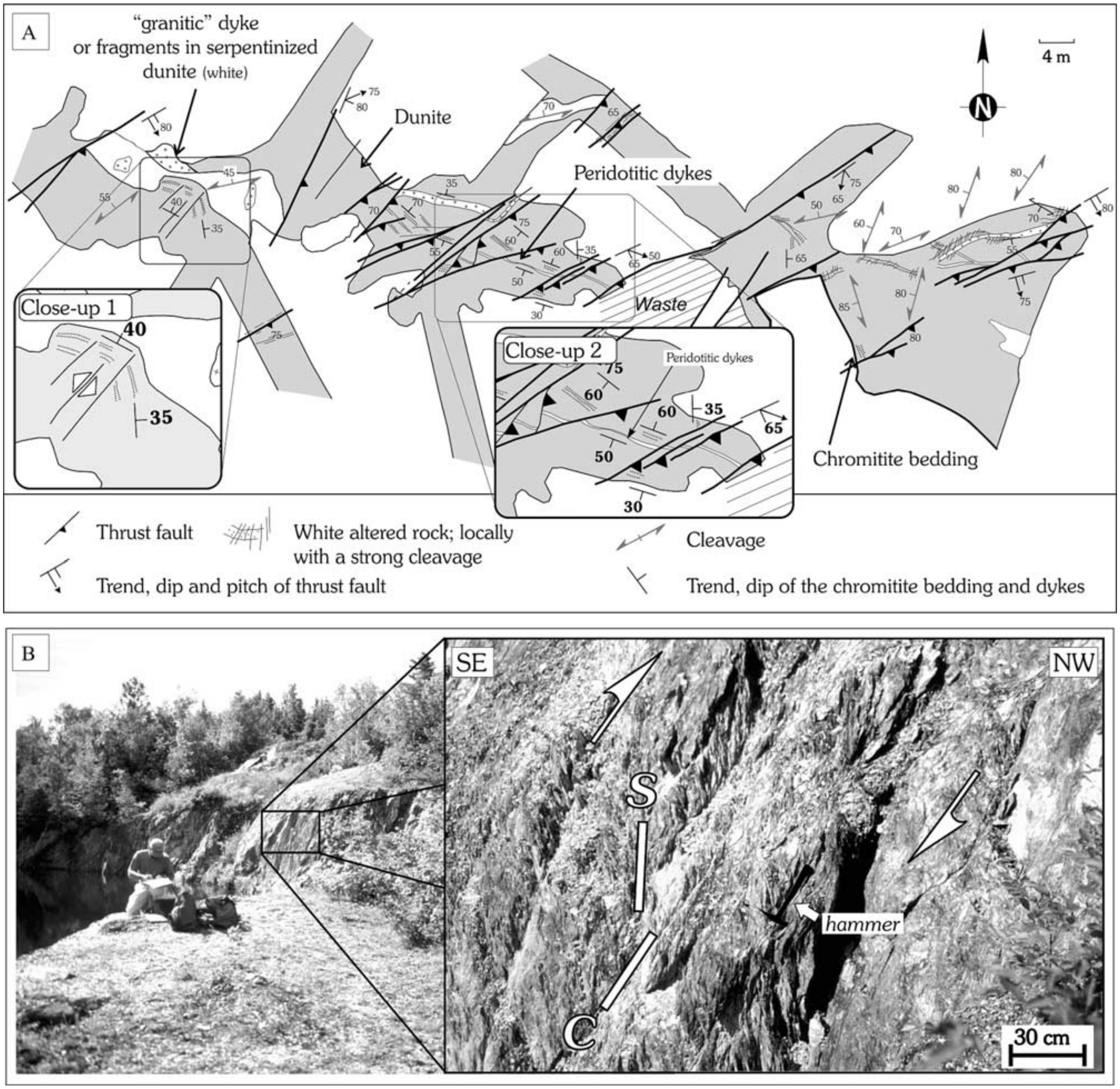


Figure 9. (a) Detailed map of the American Chrome mine showing late (Acadian) NE trending, SE dipping reverse faults crosscutting the dunitic zone of the AHM massif. See Figure 3 for location. (b) Exposure of an Acadian reverse fault in the Nadeau mine with C/S fabrics indicating NW verging faulting. See Figure 3 (location C) for location.

[21] These D_4 (Acadian) folds are superposed onto, and have locally reactivated the earlier fabrics of the TMOC (Figures 5d and 8a) and the continental margin rocks. The obduction-related metamorphic foliation in the sole, for example, is affected by subvertical, NE trending open folds (S_4) [*Clague et al.*, 1981] that have been attributed to an Acadian deformational overprint [*Whitehead et al.*, 1995]. To the west of the sole, crosscutting relationships between the bedding (S_0), the dominant schistosity (S_1), and the Acadian fabric (S_4) are locally well-exposed, and clearly show that (S_0) and (S_1) were overprinted by late Acadian folds characterized by a subvertical, NE trending axial-planar cleavage (Figures 5c, 5d, and 5e). Figure 9b shows another example of reverse faulting in a quarry known as the Nadeau mine. The reverse fault there is much better developed than the one described above, and is marked by sheared serpentinites with C/S fabrics indicating east-over-west motion (Figure 9b). In terms of regional structures, these reverse faults and related folds are responsible for the north-westward juxtaposition of the AHM onto the TMM and its cover rocks of the Saint-Daniel Mélange (Figure 3); and for the development of folds in rocks of the Saint-

Daniel Mélange and the overlying Magog Group. Structural relations between the Carineault and Bécancour antiforms and the ophiolite (e.g., Figure 3 Boxes D and E, and Figure 8a), suggest that the doubly plunging domal antiforms result from the mutual interference of the Devonian and Silurian folding events.

4.1.4. Summary and Correlation of Structures

[22] The Thetford Mines Ophiolite Complex (TMOC) preserves evidence for three major deformational events that can be correlated with those documented in the internal Humber zone of southern Québec. These various structures are illustrated by 5 structural profiles covering most of the TMOC (Figure 7), and which will also facilitate structural correlations along-strike with other massifs in the southern Québec ophiolitic belt. The first recognizable event is a set of north striking, paleonormal, synmagmatic faults that dissect the ophiolitic pseudostratigraphy into a series of tilted, partly eroded blocks on a kilometer scale. The D_1 episode (marked by $(S_n)/(S_1)$) is related to intraoceanic detachment of the ophiolite and its emplacement onto the Laurentian margin. D_1 is manifested as a discontinuous tectonometamorphic sole of amphibolite- and greenschist-grade metamorphic rocks, and is correlated with the $D_{1\text{-}2}$ event of *Tremblay and Pinet* [1994]. The lack of penetrative obduction-related deformation in ophiolitic units and the localization of strain in the metamorphic sole suggest to us that obduction probably occurred along a ductile detachment fault. Such structures can accommodate displacements of hundreds of kilometers, as has been documented in other ophiolites [e.g., *Nicolas*, 1989]. The D_2 deformational event (marked by (S_3) fabrics) is characterized by SE verging (hinterland-directed) thrusting and associated recumbent folding and corresponds to the D_3 deformation of *Tremblay and Pinet* [1994], which has been dated at circa 430–415 Ma by *Castonguay et al.* [2001]. In the TMOC, this event is responsible for major faults and folds that affected all stratigraphic units and overturned the ophiolite. Our interpretation of the regional deformation related to D_2 is that the TMOC occupies a major backfold in the footwall of a backthrust fault ($\varphi 1$ fault in Figure 7). Finally, the D_3 event of the TMOC (underlined by (S_4)) is attributed to the Acadian orogeny. It is essentially characterized by the NW verging folding and reverse faulting and corresponds to the D_4 event of *Tremblay and Pinet* [1994]. Its major effect in the TMOC has been (1) the formation of type 3 (dome and basin) interference patterns with antiformal culminations corresponding to the Carineault and Bécancour antiforms (Figures 3 and 7), and (2) a series of NW directed reverse faults that juxtaposed the lower crust of the Adstock-Ham massif against the Thetford Mines massif supracrustal sequence and the overlying Saint-Daniel Mélange.

4.2. Comparison With the Asbestos and Mont Orford Ophiolite Complexes

[23] Figure 2 presents a geological compilation map, which includes our new observations, and which shows the geographical distribution of ophiolitic rocks of southern Québec. In the following, we will discuss the geology of these rocks and propose some lithological and structural correlations.

4.2.1. Asbestos Ophiolite Complex (AOC)

[24] The AOC is located approximately 20 km to the southwest of the TMOC. It preserves a thinner (2000–2500 m) but very similar ophiolitic sequence, consisting of harzburgitic mantle, overlain by ultramafic-to-mafic cumulates (dunite, pyroxenite, and gabbro), and capped by diabasic and volcanic rocks [*Hébert*, 1980]. The ophiolitic lavas are overlain by fine-grained volcaniclastic rocks and flow breccias, and then by the phyllites of the Saint-Daniel Mélange. N-S trending faults chop up the crustal stratigraphy and as for the TMOC, they are interpreted to represent preobduction paleonormal faults. The contact between the AOC and the internal Humber zone to the west, defining the BBL [see *Williams and St-Julien*, 1982], can be observed in the Jeffrey mine (Figure 10). In the Jeffrey mine, the synobduction event is restricted to an amphibolitic thrust slice in a major fault at the contact between the Humber zone and the ophiolite. Here, the continental margin rocks consist of black and rusty schists that record three generations of fabrics (Figure 10a). At the contact between the margin rocks and the AOC, there is a ~50-m-wide fault zone that shows well-developed C/S fabrics, indicating down-to-the-east normal faulting (Figure 10c). This contact (and hence the BBL) is therefore interpreted to be a major normal fault, which can be correlated with the Saint-Joseph fault of the Thetford Mines area. Together, these structures constitute the Saint-Joseph-BBL normal fault system [*Tremblay and Castonguay*, 2002], which is attributed to the relaxation phase of the Late Silurian-Lower Devonian SE verging deformation [*Tremblay and Castonguay*, 2002]. Finally, in the hanging wall of the Saint-Joseph-BBL fault system, the serpentinized peridotites of the AOC are affected by SE dipping reverse faults, attributed to the Acadian deformation event.

[25] The AOC and the TMOC are very similar. As for the TMOC, the AOC occupies the hinge zone of a backfold located in the footwall of a major backthrust ($\varphi 2$ fault in Figure 7), which was developed at a lower structural level than the $\varphi 1$ fault of the Thetford Mines area. Because both ophiolites have a similar stratigraphy, are coeval, show similar preobduction structures, and occupy similar structural positions in relation to backthrusts, we suggest that they were originally connected.

[26] To the east and south of the AOC, the dominant structures are NNE to NE trending Acadian folds with a subvertical axial-planar cleavage. These folds define a series of antiforms and synforms that dominate the geological map pattern of this region, with ophiolitic rocks occurring locally as antiformal culminations peeping up through the Saint-Daniel Mélange (Figures 2 and 11). Ophiolitic plutonic rocks occur in the vicinity of the Saint-François River, and consist of dunitic peridotites, gabbros, volcanic and volcaniclastic rocks that can be correlated with those of the AOC (Figure 2). This sequence of ophiolitic rocks extends almost continuously southward toward Saint-Élie-de-Brompton (Figure 2) where it merges into the Lac Montjoie ophiolitic mélange (Figure 2 [*Lamothe*, 1978]), previously

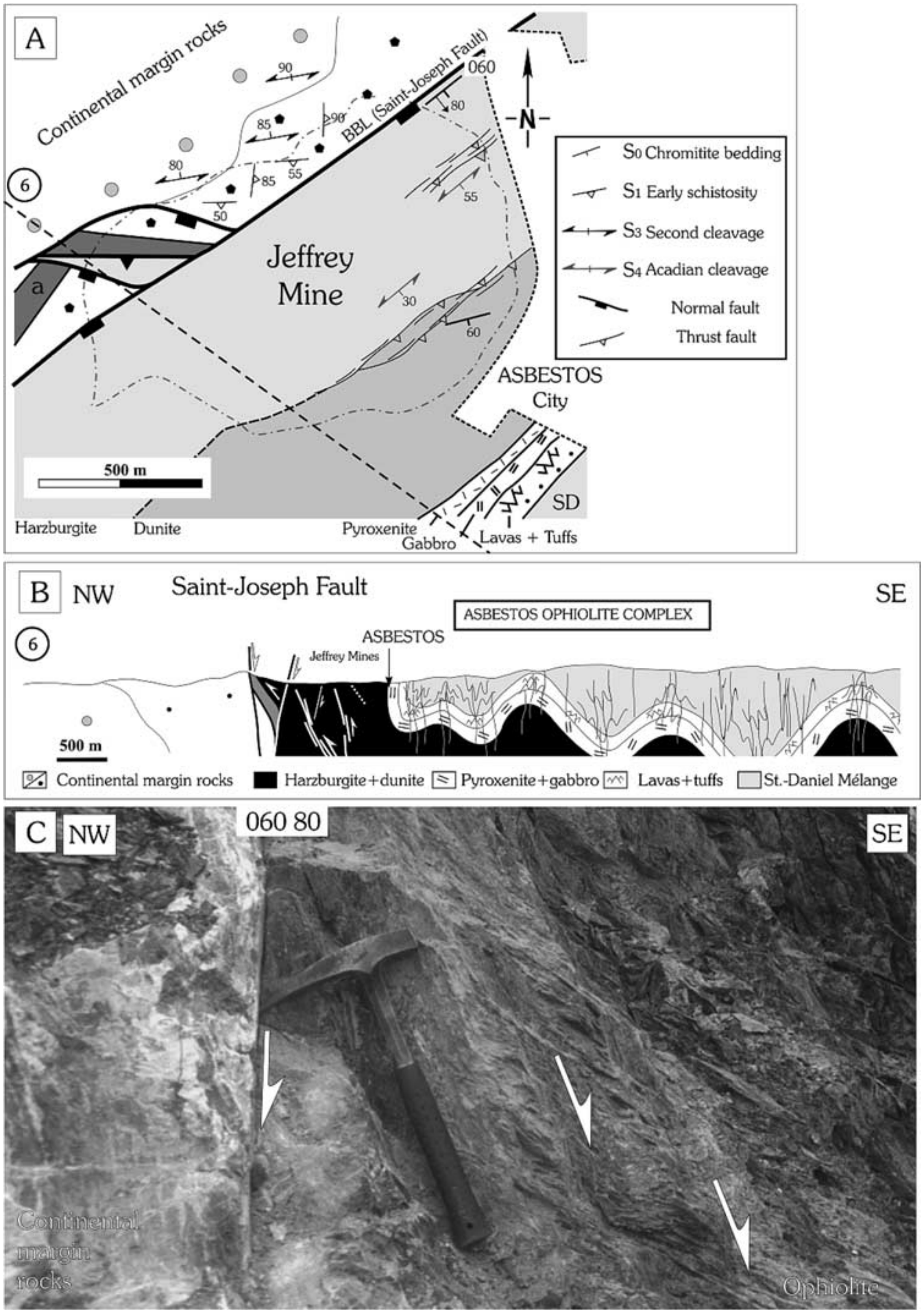


Figure 10. (a) Geological map of the Jeffrey mine in the Asbestos area. (b) Structural profile of the Asbestos Ophiolite in the Jeffrey mine. See the map of Figure 10a for location. (c) Photograph of C-S fabrics showing normal-sense shearing at the contact between the continental margin and the Ophiolite in the Jeffrey mine. Vertical view toward the north. See text for discussion.

described as a serpentinite diapir. Our fieldwork suggests rather that Lac Montjoie is part of an ophiolitic sequence (mantle? and lower crustal peridotites with orthopyroxenite dykes) that is underlain, perhaps tectonically, by metamorphic rocks of continental affinity to the south (Figure 11). These rocks are overlain by AOC-type mafic lavas and tuffs, and by the Saint-Daniel Mélange, with the whole sequence defining a northward-plunging anticline (Figures 2 and 11). The continuity of lithologies and exposures suggest to us that the AOC crops out discontinuously between Asbestos itself and Saint-Élie-de-Brompton (Figures 2 and 11). Given the previously discussed resemblance between the TMOC and the AOC, this implies that the ophiolitic rocks of this large area (over 100 km of strike length) may

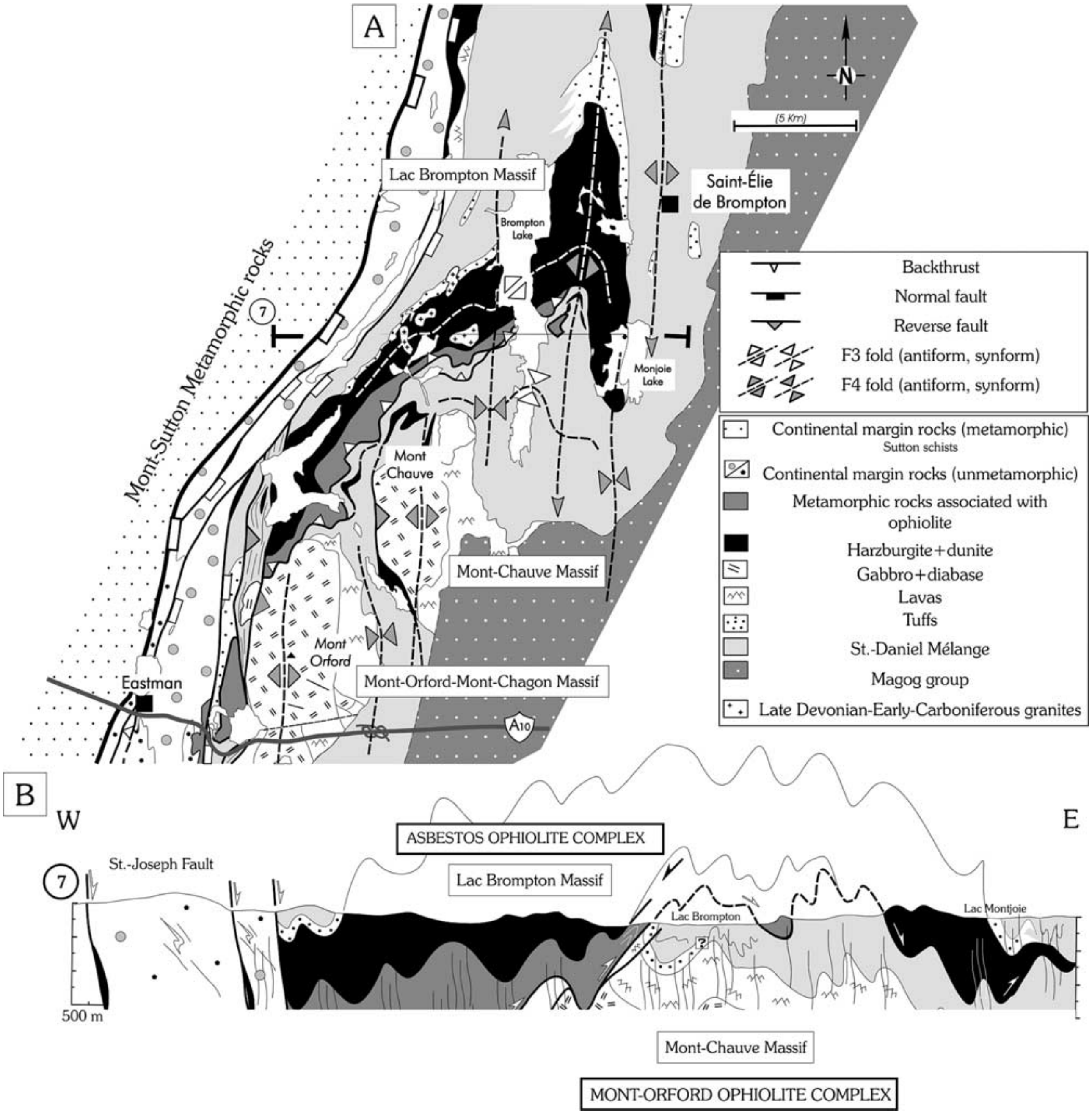


Figure 11. (a) Geological map of the Mont Orford Ophiolitic Complex and of the southern part of the Asbestos Ophiolitic Complex. See Figure 2 for location. (b) Structural profile of the area. See Figure 11a for location.

originally have formed a single panel of obducted oceanic lithosphere.

4.2.2. Mont Orford Ophiolite Complex (MOOC)

[27] South of Saint-Élie-de-Brompton, the ophiolitic sequence of the Mont Orford Ophiolite Complex (MOOC) is dominated by gabbros, overlain by basalts and various types of volcaniclastic rocks that form two principal masses, the Mont Chauve and the Mont Orford-Chagnon massifs (Figures 2 and 11 [*Rodrigue*, 1979; *Laurent and Hébert*, 1989; *Huot et al.*, 2002]). The tectonostratigraphic link between the AOC and the MOOC can be inferred from structural relationships shown by the ophiolitic rocks in the Saint-Élie-de-Brompton area (Figure 2) where the southern extremity of the AOC is separated from the MOOC by an extensive metamorphic unit of micaschists and albite-chlorite laminated greenschist (Figure 11). As it is the case in the Thetford Mines area, these metamorphic rocks are characterized by three generations of fabrics, documented by *St-Julien* [1961, 1963, 1970] and *Lamothe* [1978]. The youngest structures are NE trending open to tight folds and

are clearly related to the Acadian orogeny [*Tremblay*, 1992]. The pre-Acadian deformation is more difficult to interpret, but both the MOOC and the overlying Saint-Daniel Mélange are structurally overlain by (1) the metamorphic rocks unit mentioned above, and (2) ophiolitic rocks that we correlate with the AOC; the structural juxtaposition occurring along a northwest dipping fault zone (the $\varphi3$ fault of Figure 11b) which is folded by a north-plunging Acadian antiform in the Brompton Lake area (Figure 11a). The metamorphic fabric (S_n) in the micaschist and greenschist facies rocks is crosscut by a NW to north dipping crenulation cleavage that can be genetically related to the $\varphi3$ fault zone. We therefore interpret the metamorphic foliation of the metamorphic rocks as correlative to the (S_n) schistosity of the subophiolitic metamorphic rocks of the TMOC; whereas the superposed, pre-Acadian, NW dipping $\varphi3$ fault zone and fabrics are attributed to the SE verging deformational event that has been documented in the Thetford Mines area. Such an interpretation can account for the respective structural positions of the AOC and the MOOC, since the AOC would have been thrust along the $\varphi3$ fault over the MOOC during the SE verging deformational event, with both ophiolites being folded during the Acadian orogeny (Figure 11).

5. Tectonic Implications for the Southern Québec Ophiolitic Belt

[28] In contrast to the Laurentian margin, there are few obvious obduction-related structures (in the sense of Taconian) in the southern Québec ophiolitic belt and in the overlying sedimentary rocks of the Dunnage zone. In contrast, the Silurian to Early Devonian backthrusting (SE verging) deformational event and the superimposed Middle Devonian Acadian folding event, both represent major orogenic phases that largely control the map pattern of the ophiolitic belt. However, the backthrusting deformational event does not occur everywhere in the Dunnage zone. A large part of the Magog Group and the entire Ascot Complex (Figure 1) are devoid of such structures, which appear to be restricted to areas adjacent to the Laurentian margin. To illustrate this, as well as the stratigraphic and structural relationships among the different units of the Dunnage zone and the overlying Silurian-Devonian rocks of southern Québec, two regional structural profiles are shown in Figure 12 (see Figure 1 for location). With the exception of the preobduction structures, each of these tectonic episodes has been documented in metamorphic sequences of the internal Humber zone, albeit at higher metamorphic grades [*Tremblay and Pinet*, 1994; *Tremblay and Castonguay*, 2002; *Castonguay and Tremblay*, 2003].

5.1. Kinematic Model for the Southern Québec Ophiolitic Belt: A Single Obduction Event?

[29] On the basis of our stratigraphical and structural analysis of the southern Québec ophiolitic belt, complemented by published petrological data [*Laurent*, 1975; *Laurent et al.*, 1979; *Hébert*, 1980, 1983; *Beulac*, 1982; *Oshin and Crocket*, 1986; *Laurent and Hébert*, 1989; *Harnois and Morency*, 1989; *Olive et al.*, 1997; *Hébert and Bédard*, 2000; *Huot et al.*, 2002], we present a schematic palinspastic reconstruction of the obducted oceanic terranes in Figure 13. As proposed by *Pinet and Tremblay* [1995a, 1995b], the southern Québec ophiolites are represented as segments of oceanic crust and mantle formed in a broadly suprasubduction zone setting. Our investigation of the preobduction structures in the TMOC [*Schroetter et al.*, 2004] shows that this oceanic lithosphere was partly dismembered by synoceanic, synmagmatic extension, which we believe occurred in a forearc environment [*Hébert and Bédard*, 2000].

[30] Hitherto, the different massifs composing the southern Québec ophiolitic belt were interpreted to represent unrelated oceanic terranes assembled in a subduction complex (i.e., the Saint-Daniel Mélange [*Tremblay*, 1992; *Cousineau and St-Julien*, 1992; *Tremblay et al.*, 1995]. However, all of the southern Québec ophiolites occur above detachment faults, locally marked by dynamo-thermal metamorphism, and are stratigraphically overlain by sedimentary deposits of the Saint-Daniel Mélange. This common structural and stratigraphic context leads us to suggest that the different ophiolitic massifs may represent fragments of a single, composite, oceanic slab, partly dismembered by preobduction, synobduction, and postobduction deformation events. Although the extent of Acadian tightening is difficult to quantify in the southern Québec Appalachians, our structural analysis permits a schematic reconstruction of the oceanic segment of the orogen (Figure 13), with the position of each major backthrust faults ($\varphi1$, $\varphi2$, $\varphi3$) outlined. In this reconstruction, the TMOC (the structurally highest synform) represents the westernmost segment of the oceanic slab, whereas the MOOC (the structurally lowest panel) represents its easternmost segment.

[31] Obduction of oceanic lithosphere onto the Laurentian margin (Figure 14a) has been associated with the development of a dynamothermal metamorphic aureole in the subcreted Laurentian and peri-Laurentian volcanic and sedimentary rocks [*Feininger*, 1981; *Clague et al.*, 1981]. Since these metamorphic rocks yield pressures of 5–7 kb (and possibly higher), this suggests that Laurentian margin rocks were subducted down to at least 20 km depth. Radiometric ages from the dynamothermal sole amphibolites are 477 Ma [*Whitehead et al.*, 1995], while metamorphism of the sedimentary rocks occurred at 469–460 Ma [*Whitehead et al.*, 1995; *Castonguay et al.*, 2001]. Two-mica granites with high Sr-isotopic signatures emplaced within ophiolitic mantle rocks yield U-Pb zircon ages of 469 ± 4 and 470 +5/−4 Ma [*Whitehead et al.*, 2000], suggesting that the thermal anomaly associated with juxtaposition of the young, still-hot oceanic mantle against Laurentian margin sediments and shear heating, were sufficient to induce anatexis.

[32] There are two observations that suggest that the exhumation of the ophiolites and metamorphosed continental margin rocks proceeded very quickly after ophiolite emplacement: (1) metamorphic rock fragments of continental affinity occur in supraophiolitic conglomerates in the

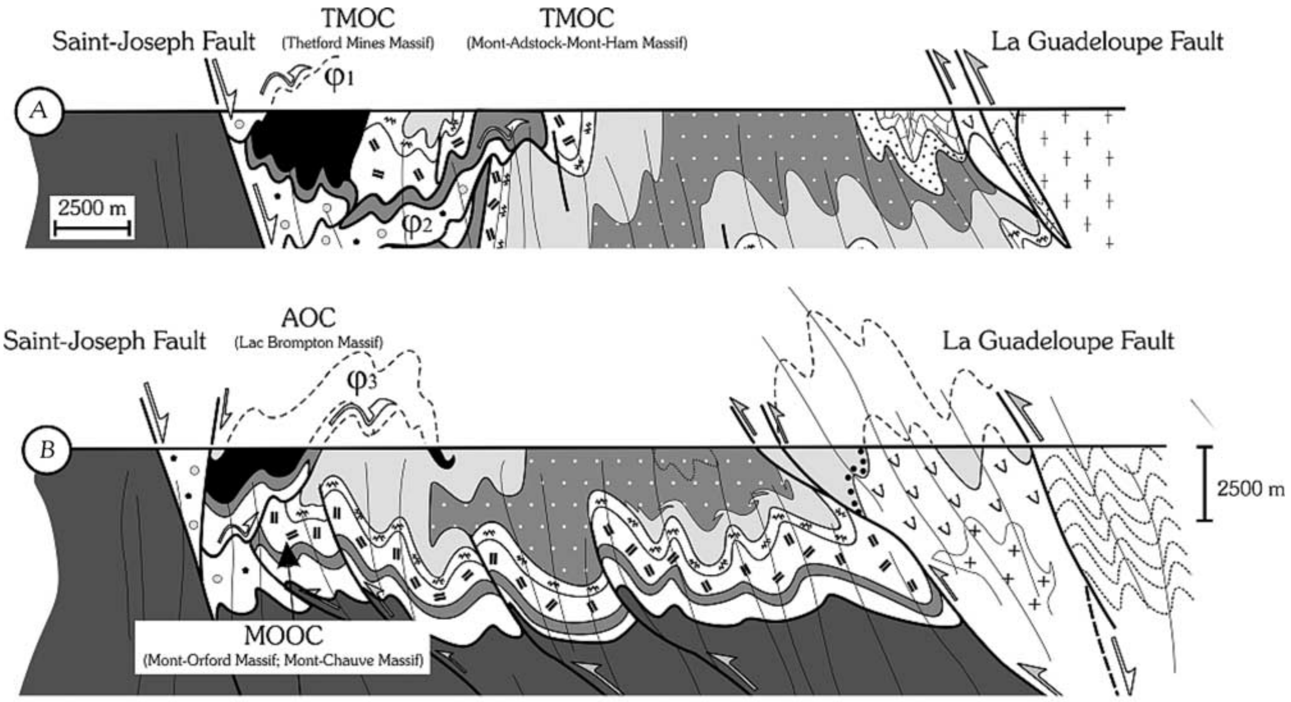


Figure 12. Regional-scale structural profiles across the Dunnage of southern Québec in (1) Thetford Mines and (2) Mont Orford areas. See text for discussion and Figure 1 for location. Same symbols as Figure 2.

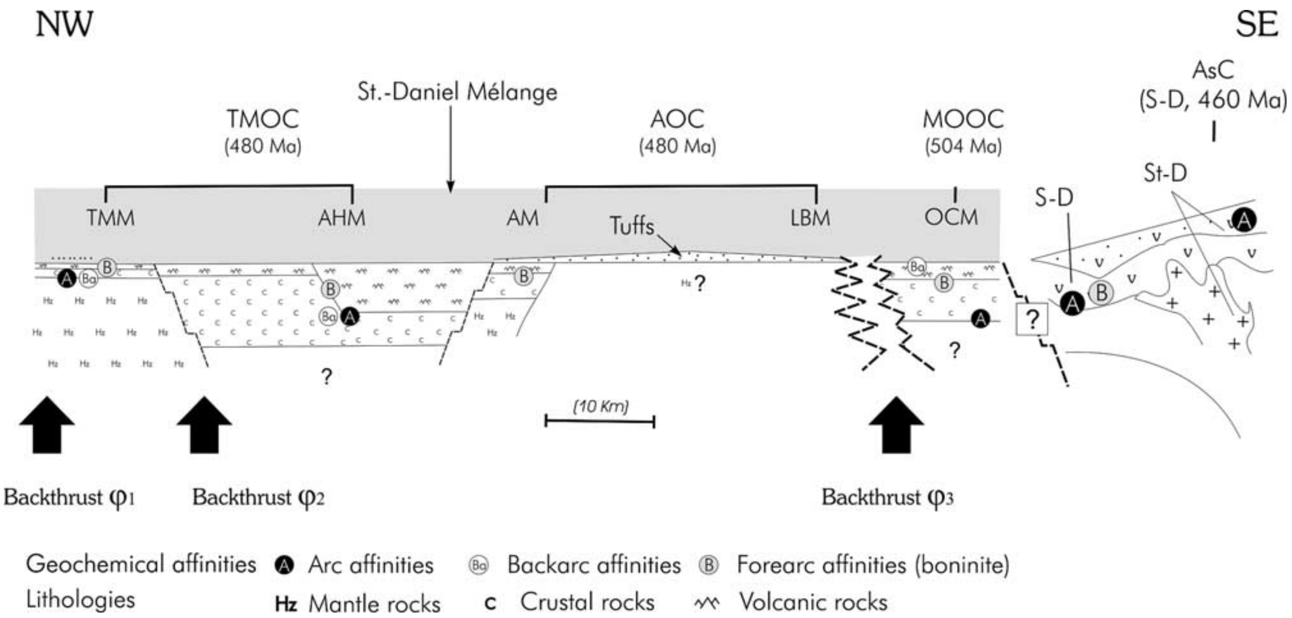


Figure 13. Schematic palinspastic reconstruction of the southern Québec ophiolitic belt, illustrating the inferred position of major backthrust faults (φ1 to φ3), and the thickness variations of the oceanic crustal and supracrustal sequences. See text for discussion. Abbreviations are as follows: AM, Asbestos massif; LBM, Lac Brompton massif; OCM, Orford-Chauve massif; ASC; Ascot Complex. Other abbreviations as in Figures 2 and 3.

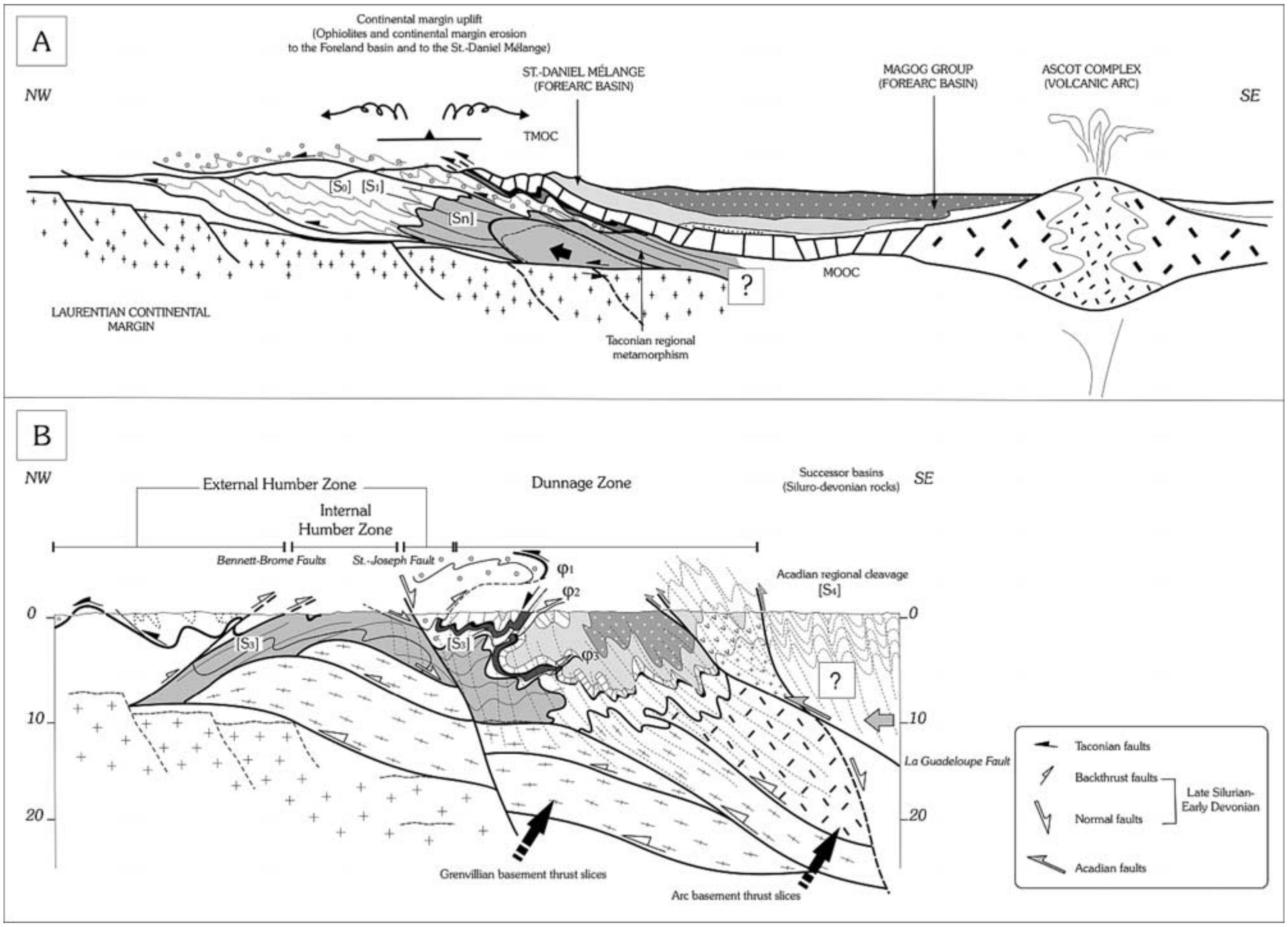


Figure 14. (a) Kinematic model for the main stage of the Taconian orogeny in the southern Québec Appalachians. (b) Post-Acadian interpretative cross section of the southern Québec Appalachians.

Saint-Daniel mélange (i.e., the Coleraine breccia of *Hébert* [1981] or the Coleraine Group of *Riordon* [1954]; cf. *Schroetter et al.* [2002, 2004, submitted manuscript, 2004]), and (2) there is detrital chromite in Middle Ordovician flysch of the Magog Group, attesting to the erosion of ultramafic rocks [*St-Julien and Hubert*, 1975; *Pinet and Tremblay*, 1995a]. These observations imply that the obducted ophiolite and the underlying Laurentian margin rocks were being exposed and eroded soon after emplacement. In northern New England, *Laird and Albee* [1981] describe a HP/LT metamorphic event during the Taconian orogeny, which must be the metamorphic expression of the synconvergence exhumation of the Laurentian margin. The age of this metamorphic event is, however, poorly constrained by ^{40}Ar/^{39}Ar dating varying from 505 ± 2 Ma to 468 ± 8 Ma [*Laird et al.*, 1984].

[33] Although the TMOC/AOC massifs were obducted by 477–460 Ma, and were being actively eroded soon afterward, the common and widespread occurrence of felsic pyroclastic rocks at the base and within the Saint-Daniel Mélange (Figure 2, this study, and *Schroetter et al.* [2004, submitted manuscript, 2004] and in the potentially correlative Magog Group [*Cousineau*, 1988; *Cousineau and St-Julien*, 1994], suggest that island-arc volcanism was active during and after obduction of the TMOC/AOC. The collision of such an arc (possibly preserved in the Ascot Complex in southern Québec) with the Laurentian margin and the accreted ophiolites, could perhaps account for the transition from regional deformation essentially dominated by obduction-related and thin-skinned tectonics to a tectonic style dominated by thick-skinned basement tectonics, and have induced the formation of SE verging backthrusts and backfolds in the metamorphic rocks of the internal Humber zone and the adjacent ophiolites. This hypothesis is similar to one of the scenarios proposed by *Castonguay et al.* [1997] and *Castonguay and Tremblay* [2003] (Figure 14b).

5.2. An Obduction Followed by an Arc-Collision?

[34] The tectonic scenario depicted here (Figure 14b) for the southern Québec Dunnage Zone resembles a Taiwan-type geodynamic evolution [*Pelletier and Stéphan*, 1986], which is characterized by obduction-related stacking of continental and oceanic crustal nappes verging toward the Chinese margin, followed by hinterland-verging folds and shear zones/faults. In southern Québec, the increase in elevation of the developing Taconian Orogen

that resulted from collision between Laurentia and the Ascot arc may have caused the development of a gravitational instability in the orogenic prism, an event that would correspond to the late-Silurian/early-Devonian exhumation and retrogression in the internal Humber Zone rocks and normal faulting along the Saint-Joseph-BBL fault system. This event would eventually have led to the formation of the Silurian-Devonian successor basins to the SE [*Tremblay and Castonguay*, 2002; *Castonguay and Tremblay*, 2003].

6. Conclusion

[35] Detailed mapping and tectonic analysis of the Thetford Mines Ophiolite Complex (TMOC), and comparison with other major ophiolites of the southern Québec Appalachians show that the westernmost ophiolitic rocks exhibit a structural evolution that is almost identical to that of the Laurentian continental margin. Our data allow fabrics in the TMOC to be classified as preobduction, synobduction, and postobduction deformational events. The different generations of structures identified in the metamorphic rocks of the internal Humber Zone (D_{1-2} to D_4 of *Tremblay and Pinet* [1994]) are also seen in the Dunnage Zone. However, the backthrust (SE directed) deformation recorded in the oceanic domain corresponds to the upper structural levels and lower metamorphic grade than in the continental margin rocks, as a result of normal faulting along the Saint-Joseph-BBL faults system in Late Silurian-Early Devonian times.

[36] The structural synthesis of the southern Québec ophiolitic belt suggest that the ophiolites were accreted to the margin as a single, large slab of supra-subduction oceanic lithosphere. We conclude that these ophiolites should not be considered as genetically unrelated tectonic slices incorporated into a subduction complex (i.e., the Saint-Daniel Mélange), but that they form a coherent segment, although structurally complex and partially dismembered, which extends laterally for over a hundred kilometers of strike, and that has experienced at least two episodes of intense deformation after obduction.

[37] **Acknowledgments.** This study represents a part of the first author's Ph.D. thesis done at the University of Québec (INRS Eau, Terre et Environnement). The first author wants to thank his two supervisors Alain Tremblay and Jean H. Bédard. Thanks are due to Philippe Pagé, Sébastien Castonguay, and Nicolas Pinet for numerous discussions; to Pierre Cousineau for volcanological and sedimentological insights, and to Brian Wernicke for insightful and enlightening reviews. This project has been supported by the Geological Survey of Canada, by Canadian National Science and Engineering Research Council grant ESS 233685-99, by a Diversification de l'Exploration Minérale au Québec grant provided by Valorisation-Recherche Québec (project 2201-133), and by Ressources Allican Inc.

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