Five Preliminary Hypotheses for New Mapping in the Windsor-Kennetcook Basin, Central Nova Scotia

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Introduction

The Avalon and Meguma terranes, and Gondwana, accreted to the eastern margin of Laurentia during the mid- to late-Paleozoic, leading to the amalgamation of the supercontinent Pangea (Murphy et al., 2009; Bilardello and Kodama, 2010). In the Meguma Terrane, two distinct phases of continental convergence are recorded. The Neoacadian orogeny was active ca. 406-370 Ma and produced: (1) predominantly upright folding in the Paleozoic Goldenville, Halifax and Rockville Notch groups (D_1), (2) peak regional metamorphism ca. 406-388 Ma, and (3) intrusion of Devonian plutons ca. 385-370 Ma, which truncate D_1 folds and regional metamorphic isograds (Culshaw and Lee, 2006; White, 2009). The Alleghenian orogeny, also called the “Maritimes Disturbance” (Poole, 1967) or Maritimes fold-and-thrust belt (MFTB), appears to have been active from ca. 320 Ma through to the Permian and produced: (1) thrust imbrication and recumbent folding (D_2), and (2) a second phase of mostly upright folding (D_3) (Gibling et al., 2008; Waldron et al., 2010). Maritimes Basin strata were deposited ca. 360-280 Ma in mainland Nova Scotia, and thus both precede and overlap the timing of Alleghenian deformation (Gibling et al., 2008). Neoacadian and Alleghenian orogenies appear to have evolved within dextral-transpressional strain regimes (Waldron et al., 2007; Waldron et al., 2010).

In the Mesozoic (ca. 200 Ma), rifting between the Laurentian margin and Nova Scotia opened the Bay of Fundy (D_4) and rifting between Nova Scotia and Europe/Africa opened the Atlantic Ocean (Olsen and Schlische, 1990). Fundy rifting appears to have evolved within a sinistral-transtensional strain regime (Withjack et al., 1995). The Minas Fault System, defining the present boundary between the Avalon and Meguma Terranes (Murphy et al., 2011), appears to have been progressively and variously exploited during the Neoacadian and Alleghenian orogenies, and Fundy/Atlantic rifting. The detailed evolution of the Minas Fault System is an area of active research (Murphy et al., 2011). Detailed reviews of the Avalon and Meguma Terranes (Keppie and Krogh, 2000; Murphy et al., 2004; Waldron et al., 2009), the Neoacadian orogeny (Culshaw and Lee, 2006), Maritimes Basin stratigraphy and Alleghenian deformation (Gibling et al., 2008), Fundy rifting (Withjack et al., 1995), and the Minas Fault System as a whole (Murphy et al., 2011) are available elsewhere. The purpose of this report is to describe the mapping project currently underway at NSDNR to resolve the elements of the above tectonic evolution as they are expressed in the Windsor-Kennetcook Basin of central Nova Scotia. This basin, or sub-basin, represents a critical gap in current knowledge of the Maritimes Basin and its synchronous-subsequent modification by the Alleghenian orogey.

A Gap in Knowledge

Figure 1 shows the boundaries for previous regional maps of bedrock geology prepared by NSDNR in sub-basins of the Maritimes Basin in mainland Nova Scotia (grey). Notably, the Stellarton and Windsor-Truro areas have not been mapped by NSDNR. Although the Geological Survey of Canada has prepared a map of the Stellarton Area within recent decades, maps for the Windsor to Truro area have not been prepared by either survey for more than half a century. Figure 1 shows where new mapping underway at NSDNR has targeted this area.

Keppie, D.F., 2011: *in* Mineral Resources Branch, Report of Activities 2010; Nova Scotia Department of Natural Resources, Report ME 2011-1, p. 63-69.

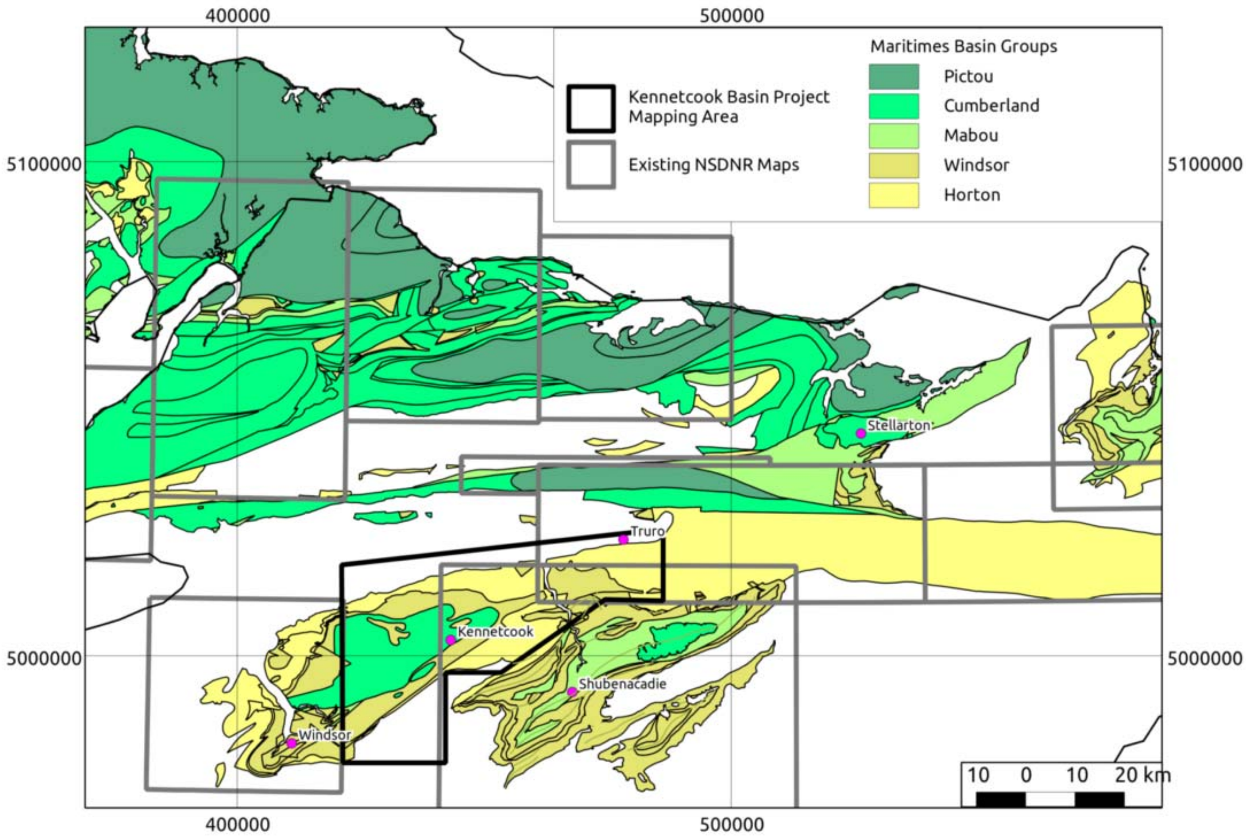

Figure 1. Map of New Brunswick and Nova Scotia showing stratigraphy of the Maritimes Basin and outline of existing detailed maps of mainland Nova Scotia from NSDNR.

Hypothesis 1: Polyphase Interference Pattern for Folds in the Goldenville, Halifax and Rockville Notch Groups

One of the more striking features of Devono-Carboniferous stratigraphy in the Windsor-Kennetcook and Shubenacadie basins, also called the Minas Basin when grouped together, is illustrated in Figures 2 and 3. Using known boundaries for the Goldenville, Halifax and Rockville Notch groups, and their distinctive aeromagnetic signature (King, 2006; Fig. 2), it is possible to sketch a rough approximation for the ca. 10-20 km wavelength anticlinoriums and synclinoriums exposed in the Windsor-Kennetcook Basin basement. These folds are generally attributed to Neoacadian D_1 deformation (Culshaw and Lee, 2006). It is striking, however, that hinge traces of anticlinoriums and synclinoriums exposed in Devono-Carboniferous strata of the Windsor-Kennetcook and Shubenacadie basins, and thus of Alleghenian age or younger, are sub-parallel to the basement folds (Fig. 3). This could indicate that folds in the Goldenville, Halifax and Rockville Notch groups have been tightened or refolded during Alleghenian deformation, and thus deformation due to the combined effects of D_1 and D_3. If so, this could imply two things: (1) that the two different wavelengths of fold previously identified in the Goldenville, Halifax and Rockville Notch groups (Culshaw and Lee, 2006) formed at different times, and (2) that the subtle dome-and-basin map pattern expressed by the Goldenville, Halifax and Rockville Notch groups may be a result of polyphase interference, and not simply due to hinge-parallel fold growth (Keppie et al., 2002). Thus, the hypothesis proposed here for testing is that some deformation expressed in the Goldenville, Halifax and Rockville Notch groups occurred during the late Carboniferous and/or early

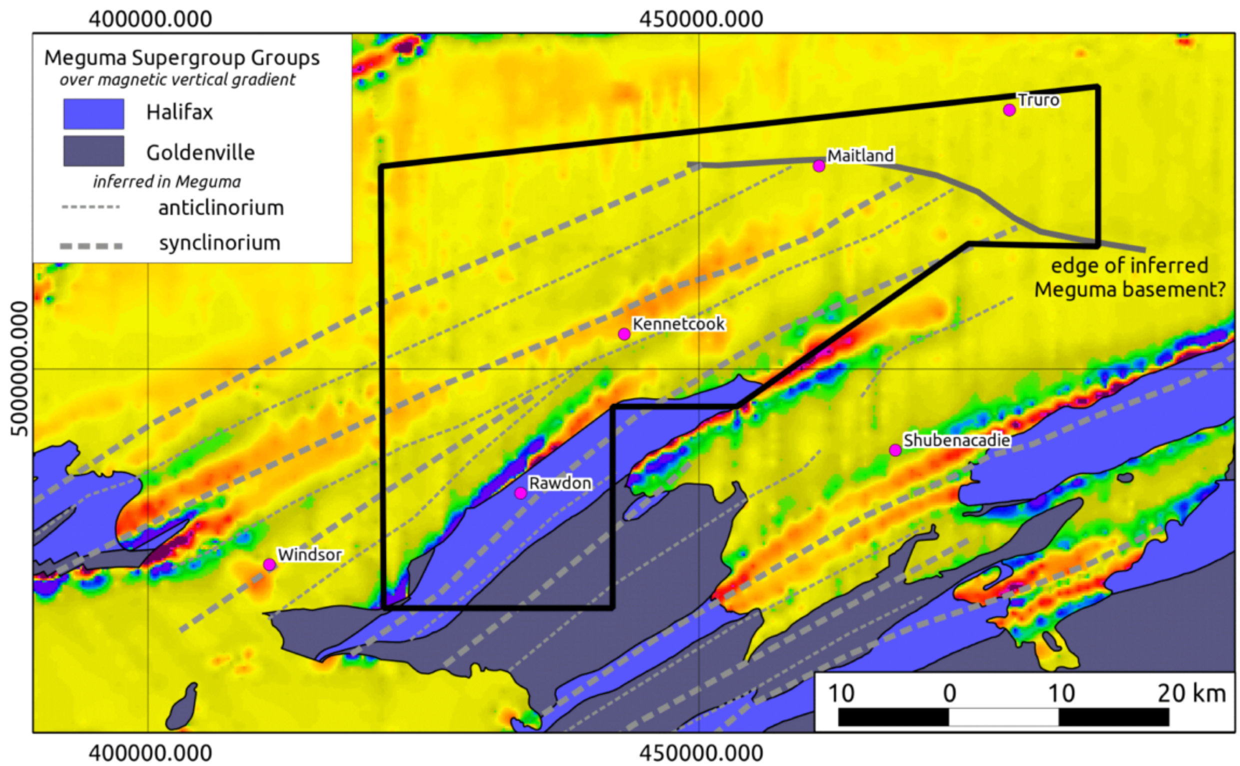

Figure 2. Map of the project area showing inferred anticlinoriums and synclinoriums in the Goldenville, Halifax and Rockville Notch groups beneath and adjacent to the Windsor-Kennetcook Basin.

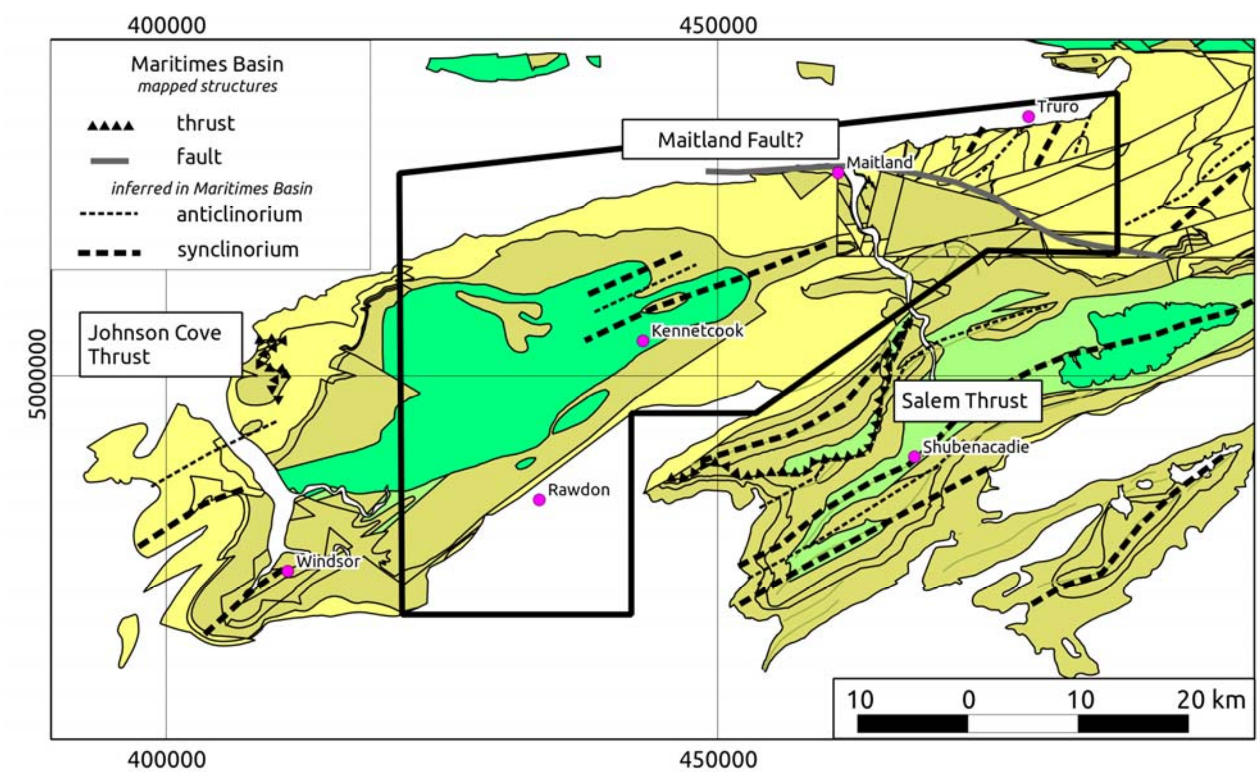

Figure 3. Map of the project area showing hinge traces of inferred anticlinoriums and synclinoriums in the Maritimes Basin stratigraphy of the Windsor-Kennetcook and Shubenacadie sub-basins. Stratigraphy as in Fig.1. Inferred traces for Johnson Cove Thrust and Salem Thrust are also shown.

Permian. Note also that the present exposure of the Windsor-Kennetcook and Shubenacadie basins within regional synclinoriums implies the present basin geometry may not be primary, or that primary basin geometry has been enhanced by D_3 folding.

Hypothesis 2: Boundary Fault Between the Windsor-Kennetcook and Saint Marys Basins

The aeromagnetic signature of the Goldenville, Halifax and Rockville Notch groups is sufficiently strong that basement structure can be interpreted beneath the Windsor-Kennetcook and Shubenacadie basins. Moving east, this signature gets weaker, indicating increasing sediment thicknesses within the Devono-Cariboniferous strata (Fig. 2). Notwithstanding this, however, there is little to no evidence of a basement signature extending east past Maitland, for example, in the north. This could be because Devono-Cariboniferous thicknessess are sufficiently great to completely obscure the basement signature. Alternatively, there may be a fault or shear zone contact extending through this area (Fig. 2). Evidence supporting the presence of a fault or shear zone lineament include an apparent offset in inferred hinge traces of Alleghenian folds, and the presence of linear boundaries in previous maps for the area. Thus, the hypothesis proposed here for testing is that a fault or shear zone, dubbed here the Maitland Fault (Fig. 3), may extend NW from the southern margin of the St. Marys Basin to form the eastern boundary of the Windsor-Kennetcook Basin.

Hypothesis 3: Polyphase Interference Pattern for Folds in the Horton, Windsor, Mabou and Cumberland Groups

Recently, Waldren et al. (2010) re-interpreted surface outcrops from coastal sections, and seismic sections from petroleum exploration, and identified the Johnson Cove Thrust (Fig. 3) near Cheverie and a main Kennetcook Thrust in the sub-surface. Thrust faults, collectively referred to as the Kennetcook Thrust System, may help to explain stratigraphic duplication within the Cheverie Well core (Waldron et al., 2010), and may include the Salem Thrust (Fig. 3) previously identified in the Shubenacadie Basin (Giles and Boehner, 2006). The Kennetcook Thrust System is a new identification of a regional component of Alleghenian deformation in the Maritimes Basin (Waldron et al., 2010; Murphy et al., 2011), and is constrained by age data to be complete by ca. 315 Ma (Waldron et al., 2007; Waldron et al., 2010). For mapping purposes, the key result is the recognition that recumbant folding may accompany D_2 thrusting. When refolded by the D_3 upright folds, a Type 3 fold inteference pattern is predicted (Twiss and Moores, 2006). This leads to synformal anticlines and antiformal synclines such as those reported in the Shubenacadie Basin (Giles and Boehner, 2006; Waldron et al., 2010). Thus, the hypothesis proposed here for testing is that Type 3 fold interference may constitute part of the map pattern in the Windsor-Kennetcook Basin.

Hypothesis 4: There Exists a Kennetcook River Fault

A 20 m digital elevation model (DEM) is publically available for Nova Scotia. For the Windsor-Kennetcook Basin, a prominent W-E lineament is followed by the Kennetcook River across the Windsor-Kennetcook Basin (Fig. 4). The hypothesis proposed here for testing is that this ineament represents the trace of a fault, dubbed here the Kennetcook River Fault.

Hypothesis 5: Northwest-trending Lineaments Prominent in a 20 m Digital Elevation Model Represent Faults Formed and/or Modified by Fundy Rifting

The 20 m DEM also indicates the presence of a ubiquitous set of NW-trending lineaments at 0.1-1.0 km spacing (Fig. 4). These lineaments appear to control the location of lakes and rivers and appear to crosscut Goldenville, Halifax and Rockville Notch group strata as well. Within the Windsor-Kennetcook Basin, these faults curve from NNW to NW as one approaches the Minas Fault System.

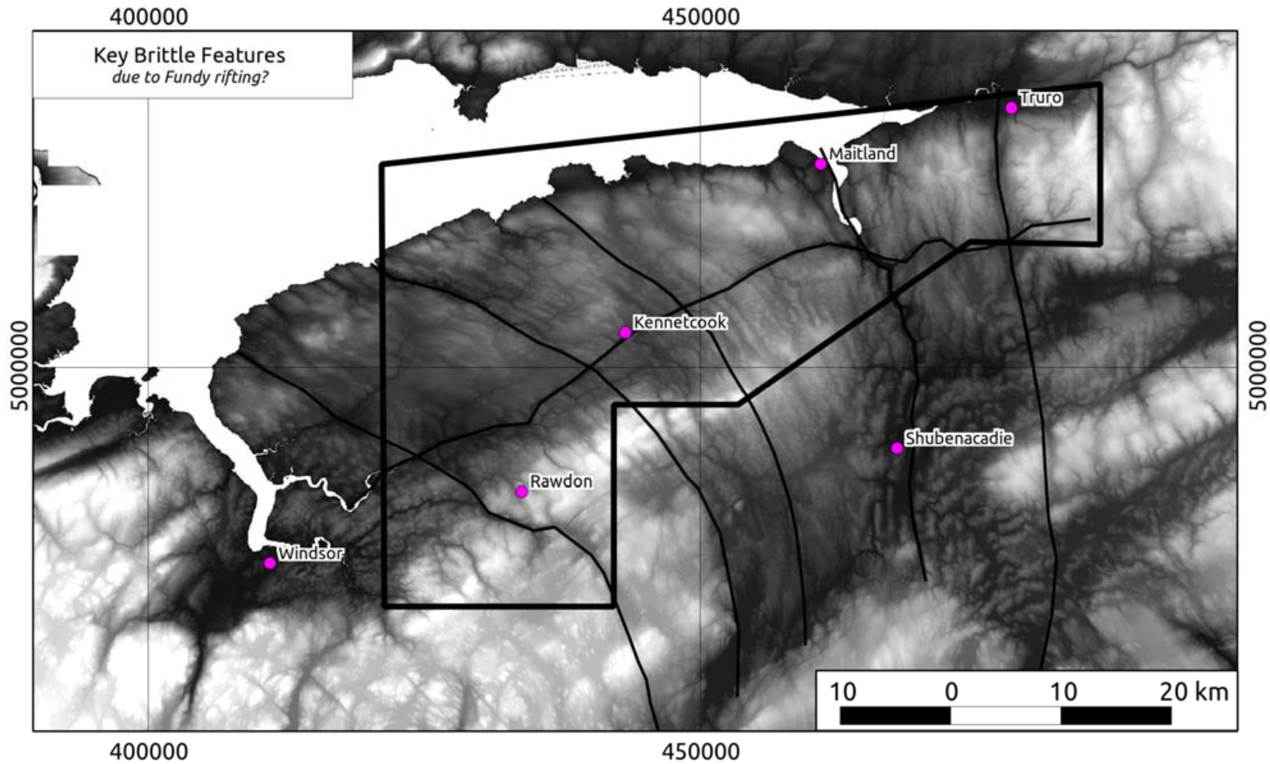

Figure 4. Map of the project area showing 20 m Nova Scotia Digital Elevation Model data. Note the linear trend of the Kennetcook River, which may indicate the presence of a fault. Note also the NW-SE lineaments (a selected few are drawn) that curve to the west as they approach the Bay of Fundy coast. This sense of curvature would be consistent with sinistral drag, possibly related to Fundy rifting.

This change in lineament trend is consistent with drag folding related to sinistral, strike-slip shear on the Minas Fault System during Fundy rifting (D_4), or alternately, with the deflection of later faults away from a major rheological contact. The hypothesis proposed here for testing is that this lineament set represents faults formed and/or modified during sinistral shearing on the Minas Fault System during Fundy rifting. This apparent fault system could represent important fluid pathways for hydrocarbons and mineralizing fluids and have significant economic importance (Mills et al., 2003). Inferred fault locations will be validated with mapping.

Conclusions

Preliminary analysis of the Windsor-Kennetcook sub-basin of the Maritimes Basin has identified five hypotheses for testing: (1) folds in the Goldenville, Halifax, and Rockville Notch groups may reflect a Type 0 interference pattern related to phases of upright folding in both the Neoacadian and Alleghenian orogenies, (2) folds in the Horton, Windsor, Mabou and Cumberland groups may reflect a Type 3 interference pattern where thrust-related recumbant folds have been refolded by later upright folding, (3) the boundary between the Windsor-Kennetcook and Saint Marys basins may be a fault or shear zone, dubbed here the Maitland Fault, (4) the Kennetcook River may follow a W-E fault, dubbed here the Kennetcook River Fault, and (5) a set of NW-trending lineaments within the Windsor-Kennetcook Basin may represent a fault set formed and/or modified during sinistral-tensional Fundy rifting. Investigating these hypotheses will help to guide new mapping efforts within the Windsor-Kennetcook Basin. For reference, Figure 5 summarizes the main stages of deformation described above and their possible timing and expression in Maritimes Basin strata and its basement.

Age (Ma)	Lithology	Setting	Deformation	Structures	Tectonics
200	Fundy	Intrusion & Deposition	Transtension (Sinisitral) "Fundy–Atlantic rifting"	NW–SE extension W–E sinistral faults sinistral drag on N–S faults	Ocean opening "Bay of Fundy" "Atlantic"
220					
240					
260		Erosion			Supercontinent "Pangea"
280					
	Pictou				
300			Transpression (Dextral?) "Maritime fold–and–thrust belt (MFTB)"	NW–SE thrusting SW–NE axial recumbant folds SW–NE upright/horizontal folds *Type 3 interference?	Ocean closing "Rheic?"
	Cumberland				
320	Mabou				
	Windsor	Deposition			
340					Initiation of ocean closing? "Maritimes Basin?"
	Horton				
360		Erosion			
	Devonian Plutons	Intrusion			
380	Peak Metamorphism Meguma Supergroup		Transpression (Dextral?) "Neoacadian orogeny"	SW–NE upright/horizontal folds *Type 0 interference? (after MFTB)	Ocean Closing "Southern Iapetus?"
400					

Figure 5. Summary of main events affecting the evolution of the eastern margin of Laurentia between ca. 400 and 280 Ma**.**

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