

Not the Neo-Acadian orogeny: distinguishing Quaboagian deformation in New England from events in Atlantic Canada

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ABSTRACT

The tectonic evolution of the northern Appalachian orogen is typically organized into orogenic episodes. The Taconic orogeny includes latest Cambrian to Late Ordovician arc-continent collision. Subsequent polarity reversal led to Silurian accretion of Ganderian terranes during Salinian orogenesis. The Acadian orogeny comprises Pridoli to Middle Devonian deformation attributed to accretion of West Avalonia to Laurentia. The term Neo-Acadian was coined by Robinson for Late Devonian to Mississippian shortening in New England, ca. 370–350 Ma, but the Indigenous-derived name Quaboagian was subsequently favoured for this episode.

The “Neoacadian” later became associated with Meguma terrane docking, but clear convergent deformation in the Meguma terrane falls outside the original Neo-Acadian interval. Folding of strata in the Meguma terrane from ca. 409 Ma, concurrent with Acadian deformation, occurred in a different tectonic environment; emplacement of subduction-related plutons followed at mainly ca. 379–372 Ma. The ca. 370–350 Ma interval saw uplift of the Meguma terrane, local plutonism, and deposition of the Horton Group in a basin-and-range setting, whereas the crust beneath the Gulf of St. Lawrence thinned to less than half normal thickness during Maritimes Basin development. These anorogenic transtensional basins were probably connected with Quaboagian shortening in New England via dextral strike-slip. Shortening and inversion resumed after ca. 330 Ma, associated with dextral transpression, docking the Meguma terrane close its present-day position.

The misuse of “Neoacadian orogeny” leads to misconceptions about timing of accretion of the Meguma terrane and about ca. 370–350 Ma tectonics in Atlantic Canada, which involved extension not shortening. We recommend that the term be abandoned in favour of Quaboagian and restricted to convergence in New England. Earlier deformation in the Meguma terrane may be attributed to the Kejimikujic orogeny.

RÉSUMÉ

L'évolution tectonique de l'orogène appalachien septentrional est généralement structurée en épisodes orogéniques. L'orogénèse taconique englobe la collision arc-continent ayant duré de la fin du Cambrien à l'Ordovicien tardif. Une inversion de polarité subséquente a produit l'accrétion silurienne des terranes gandériens au cours de l'orogénèse salinienne. L'orogénèse acadienne inclut les déformations du Pridolien au Dévonien moyen attribuées à l'accrétion de l'Avalonie occidentale à la Laurentie. Le terme « néo-acadien » avait été proposé par Robinson pour désigner un raccourcissement ayant eu lieu en Nouvelle-Angleterre entre le Dévonien tardif et le Mississippien, vers 370 à 350 Ma, mais le qualificatif « quaboagien », découlant d'un nom autochtone, a subséquentement été privilégié pour cet épisode.

Le terme « néo-acadien » a par la suite été associé à l'arrimage du terrane de Meguma, mais la déformation convergente claire dans Meguma se situe hors de l'intervalle néo-acadien initial. Le plissement des strates dans le terrane de Meguma il y a environ 409 Ma, concomitant à la déformation acadienne, s'est déroulé dans un milieu tectonique différent; la mise en place de plutons liés à la subduction a suivi principalement entre 379 et 372 Ma. L'intervalle de 370 à 350 Ma correspond à un soulèvement du terrane de Meguma, à un plutonisme local et au dépôt du groupe de Horton dans un milieu de type « bassin à horsts et dépressions tectoniques », tandis que la croûte sous le golfe du Saint-Laurent s'est amincie à moins de la moitié de son épaisseur normale durant le développement du bassin des Maritimes. Ces bassins transtensionnels anorogéniques étaient probablement reliés au raccourcissement quaboagien qu'un décrochement dextre a causé en Nouvelle-Angleterre. Le raccourcissement

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et l'inversion ont repris après 330 Ma, conjointement avec une transpression dextre, arrimant le terrane de Meguma près de sa position actuelle.

L'usage erroné du terme « orogénèse néo-acadienne » crée des malentendus quant au moment de l'accrétion et à la dynamique tectonique de 370 à 350 Ma au Canada atlantique, lesquelles étaient extensives plutôt que compressives. Il est recommandé d'abandonner le terme au profit de « quaboagien » et de limiter ce dernier à la convergence de la Nouvelle-Angleterre. La déformation antérieure dans le terrane de Meguma peut être attribuée à l'orogénèse de Kejimikujic.

[Traduit par la rédaction]

INTRODUCTION

In this paper we examine the Appalachian orogen of New England and Atlantic Canada (Fig. 1), where multiple orogenic episodes have been recognized. We focus in particular on the *Neo-Acadian* (or *Neoacadian*) orogeny which was defined (Robinson *et al.* 1998) based on mainly geochronologic evidence of convergence and crustal thickening in the Late Devonian to Mississippian New England Appalachian orogen, but which has come to be applied with different meanings elsewhere in the orogen. After a brief review of the varied usage of the term *orogeny*, we outline the main orogenic episodes identified in the Appalachian orogen. We describe the problems and contradictions involved in usages of the terms “Neo-Acadian” and “Neoacadian”, and suggest a kinematic model for the Late Devonian to Mississippian terrane movements which may explain the contrasting processes that occurred in different parts of the orogen during this interval. Finally, we propose alternative nomenclature that recognizes the variety of concurrent processes in different parts of the orogen.

OROGENIC EPISODES IN THE NORTHERN APPALACHIAN OROGEN

Concepts of orogenesis

The term *orogenesis* describes mountain-building processes dominated by shortening of the crust, forming folds, reverse faults, and fabrics in the affected rocks, associated with regional metamorphism and hydrous magmatism due to subduction and/or crustal thickening. The episodic nature of orogenesis has been recognized since the middle 1800s CE, but initially, in a geoscientific community informed by the doctrine of catastrophism (e.g., Cannon 1960) and a Eurocentric perspective, orogenic episodes were assumed to have been global events. This led to the naming of orogenies based on locations in Europe that were assumed to have been simultaneous worldwide. For example, the term “Caledonian orogeny,” named for Scotland, continues to be used (e.g., Mughal *et al.* 2020; Zhang *et al.* 2023; Xu *et al.* 2025; Zhao *et al.* 2025) to describe early Paleozoic shortening events in areas of Asia that were far from Scotland at the time.

Plate tectonics, coupled with advances in geochronology, has revealed that orogenesis has been occurring somewhere

in the tectonic system at most points in geologic time, at least since the Proterozoic Eon. Orogenesis is therefore only episodic when viewed from a local perspective. In addition, because the arcs and continental margins involved in collisions are rarely perfectly parallel, shortening events are typically diachronous along a given plate boundary (van Staal *et al.* 1998). Furthermore, if a plate boundary is sinuous, or the Euler pole of plate rotation is close to the boundary, orogenesis by oblique convergence (transpression) may occur at one point on the plate boundary concurrently with oblique extension (transtension) elsewhere. Thus, although discrete orogenies may be identified by stratigraphic or isotopic time-constraints at one geographic location in an orogenic belt, as these events are traced laterally they may overlap in time, causing an originally clear scheme of timing to become ambiguous and controversial.

To resolve such problems, orogenies are increasingly defined based on tectonic style rather than only by age. For example, in the history of an orogen, it may be possible to recognize an initial arc-continent collision, followed by subduction polarity reversal and a history of subduction and accretion at an active continental margin, perhaps followed by a terminal continent-continent collision. If such episodes can be recognized they provide a basis for a rational naming of orogenic episodes by style, in addition to age.

Numerous orogenic episodes have been identified in the Appalachian orogen. We here review the most frequently identified events. Many of these orogenies have names ending “-ic” or “-ian”. We use predominantly names ending “-ian” for consistency with Robinson *et al.* (1998) and to conform to the majority usage for the Acadian and Neo-Acadian orogenies (for which the form “Acadic” is not used), which are the main topic of this paper.

Cambrian to Silurian deformation episodes

Taconian/Grampian

The Taconian orogeny is named for the Taconic Mountains in New York state (Fig. 1) and adjacent Connecticut, Massachusetts, and Vermont. In its type-area, the Taconic orogeny is Late Ordovician and resulted in the emplacement of thrust sheets (the Taconic allochthons) of deep-water sedimentary and minor igneous rocks above Late Ordovician graptolitic shale and turbiditic sandstone that draped the foundered Laurentian continental margin. However, Taconian orogenesis started much earlier, as the Moretown terrane,

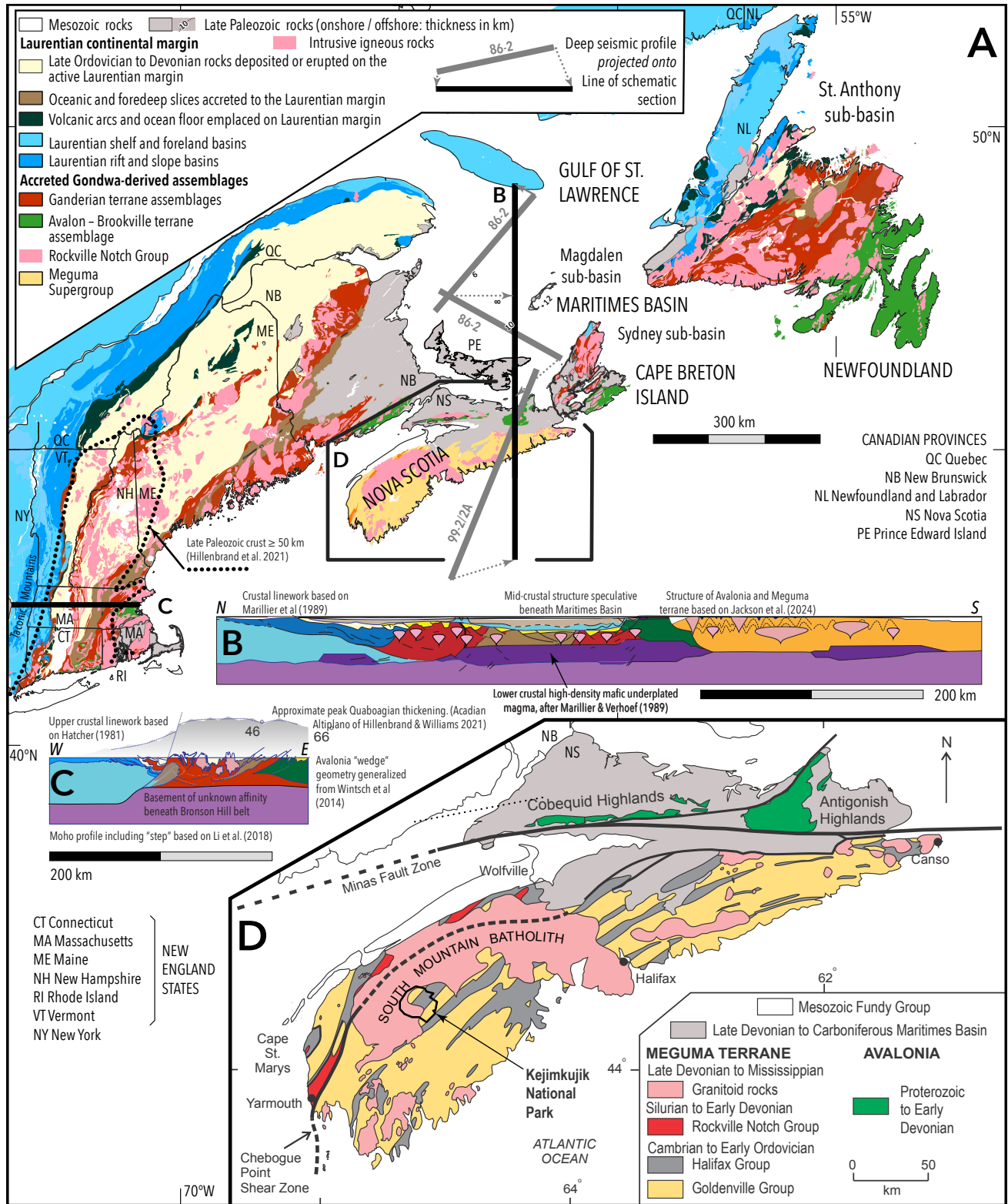


Figure 1. (A) Regional map of the northern Appalachian orogen, after Waldron *et al.* (2022b). Box encloses enlarged map (D) of the Meguma terrane. Cross-sections (black) are shown at double scale but without vertical exaggeration. (B) N–S section through Appalachian orogen of Atlantic Canada showing extreme attenuation of the orogen initiated during the interval 370–350 Ma. Detail projected from interpreted seismic lines 86-1, 86-2 (Marillier and Verhoef 1989; Marillier *et al.* 1989) and 99-2 (Jackson *et al.* 2024). (C) East-west cross-section through Appalachian orogen of New England showing crustal thickness variations (Li *et al.* 2018) and multiphase shortening in the upper crust (Hatcher 1981) produced by shortening in the interval 420–350 Ma (Hillenbrand *et al.* 2021; Hillenbrand and Williams 2021). (D) Summary geological map of mainland Nova Scotia showing principal features of the Meguma terrane.

of Gondwanan provenance has been shown (Macdonald *et al.* 2014), to have arrived above Laurentian marginal rocks as early as 475 Ma, in the Early Ordovician. Traced to the north, Taconian foreland basin strata in the Gaspé belt of Québec are of similar age, but the Moretown terrane is absent, and the colliding entity appears to have been ophiolitic rocks included in a colliding arc system (White and Waldron 2022). In Newfoundland, the Taconian allochthons reached their westernmost position in the Middle Ordovician (Lacombe *et al.* 2020), and Taconian deformation began in the Furongian (late Cambrian) prior to 488 Ma (Waldron and van Staal 2001). Like the allochthons in Québec, colliding arcs emplaced ophiolites onto the margin and do not appear to have involved Gondwana-derived material. In Britain and Ireland, the corresponding deformation event is known as Grampian and has been hypothesized to cover a time-span similar to the Taconian orogeny in Newfoundland. The collided arc–ophiolite system is preserved in the South Mayo Trough of Ireland (Ryan and Dewey 2019 and references therein). Although these events cover a wide time span (>40 Ma) they have a common origin: an arc-continent collision involving the formerly passive margin of Laurentia.

Penobscottian/Monian

More outboard terranes of the Appalachian orogen are also affected by deformation, locally including the emplacement of ophiolites (O'Neill and Blackwood 1989; Colman-Sadd *et al.* 1992), in late Cambrian to early Ordovician time. Such deformation was historically included in the Taconian orogeny (e.g., Viele and Thomas 1989) but clearly occurred near the margin of Gondwana in terranes that were still distant from Laurentia. Accordingly, such deformation is given a different name: *Penobscottian* (e.g., van Staal *et al.* 2009), following Neuman (1967, 1987).

Salinian/Scandian

Boucot (1962) used the term *Salinic disturbance* for an event that resulted in a widespread disconformity in New England in late Silurian time, subsequently widely identified as an orogenic episode in Newfoundland (Dunning *et al.* 1990) and elsewhere (e.g., Wilson and Kamo 2012). We here use *Salinian* (Tremblay and Castonguay 2002; Waldron *et al.* 2022b) for consistency with the other orogenic events in the northern Appalachian orogen.

Salinian deformation is predominantly SE-vergent. Perhaps the most complete record of Salinian deformation is present in New Brunswick where Wilson and others (Wilson and Kamo 2012; Wilson *et al.* 2017) documented a series of unconformities. Van Staal *et al.* (2008) showed that this deformation occurred by underthrusting of Gondwana-derived terranes beneath the Laurentian active margin, starting in the Late Ordovician. Salinian deformation has thus come to be associated with a process (subduction–accretion at the active Laurentian margin) beyond its original definition as a Silurian event. For consistency, Late

Ordovician deformation that followed subduction polarity reversal after the Taconian arc–continent collision (van Staal and Dewey 2023) should logically be regarded as proto-Salinian rather than late Taconian.

Equivalent deformation in Britain that dominates the Southern Uplands of Scotland lacks an orogenic name, but we suggest could be included in the protracted Salinian orogeny. In Scandinavia, however, Silurian subduction culminated in a continent–continent collision between Baltica and Laurentia termed *Scandian*, after which Devonian deformation is characterized by the development of classic pull-apart basins (e.g., Nilsen and McLaughlin 1985) developed in transtension associated with releasing bends on strike-slip faults.

Devonian to early Carboniferous deformation episodes

Dana (1890) and Schuchert (1923) described an Acadian trough or “geosyncline” and identified its demise in a Devonian deformational event that was named the Acadian orogeny by Schuchert (1930). Acadian structures are widely recognized across Québec and Atlantic Canada where deformed Early Devonian rocks are cross-cut by Late Devonian granitoid plutons and/or unconformable Late Devonian to Carboniferous cover. However, the time of Acadian deformation varies across the orogen. Bradley (1983) and Bradley *et al.* (2000) traced the migration of an Acadian foredeep across New England from southeast to northwest from ca. 423 to 382.5 Ma, a time interval spanning the latest Silurian (Pridoli) to approximately the end of the Middle Devonian in recent time scales (Gradstein *et al.* 2012, 2020; Cohen *et al.* 2013, updated 2024).

The rocks that fill the foreland basin can be traced southward through New England (Robinson *et al.* 1998; Bradley *et al.* 2000). Recumbent folds and west-vergent thrusts in central Maine affect latest Silurian strata but are overprinted by upright tight folds that are in turn cross-cut by dated dykes, constraining the folding between ca. 418 and ca. 399 Ma (Tucker *et al.* 2001). Farther south, Early Devonian and older strata are increasingly affected by nappe-forming deformation, both west- and east-vergent (Thompson *et al.* 1968; Eusden and Lyons 1993; Eusden *et al.* 1996; Robinson *et al.* 1998) and Barrovian metamorphism indicating burial to depths of >35 km between ca. 393 and ca. 375 Ma (Armstrong and Tracy 2000; Hillenbrand *et al.* 2023a, 2023b). Devonian plutons were intruded both during and after deformation, showing a range of fabrics in the highly deformed belt. West-vergent nappes (recumbent folds) are in places overprinted by more discrete west-vergent thrust faults (Eusden *et al.* 1996; Robinson *et al.* 1998 and references therein).

In terranes attributed to Avalonia (Fig. 1), along the eastern edge of the orogen, the effects of Acadian deformation are milder, including folding and regional middle Devonian unconformities, but without high-grade metamorphism (Braid and Murphy 2006; Abad *et al.* 2012), suggesting that Avalonia behaved as a relatively rigid block during its accre-

tion. However, the most outboard Meguma terrane shows folding, cleavage development, metamorphism and intrusion of granitoid plutons in the interval 409–374 Ma (van Rooyen *et al.* 2024 and references therein).

In southern New England, granitoid plutons younger than the classic Acadian interval have increasingly been recognized in the complexly deformed folded rocks, leading Robinson (1998) to define a separate orogenic event that he initially named Neo-Acadian, spanning a time interval from Late Devonian (ca. 370 Ma) to early Mississippian (Tournaisian, ca. 350 Ma). Fabric development in a large area of New Hampshire, Massachusetts, and Connecticut affected both stratified rocks and intrusions during this interval, producing east-vergent fold nappes and backfolds of the earlier west-directed Acadian structures (Robinson *et al.* 1998 and references therein). Folds post-dating ca. 399 Ma dykes in Maine are oriented N-S, *en echelon* with respect to the orogen as a whole, and backfolding was associated with dextral transpression in many other areas of New England (e.g., Robinson *et al.* 1998; West *et al.* 2003; Massey *et al.* 2017). Synorogenic crustal thickening that began during the Acadian interval produced an orogenic plateau that was maintained into the Mississippian (Hillenbrand *et al.* 2021; Hillenbrand and Williams 2021)

Robinson apparently became unhappy with the assignment of “Neo-Acadian” to describe these features and proposed the name *Quaboagian*, although this proposal appeared in print only in abstracts and publications of the New England Intercollegiate Geological Conference (NEIGC) (Robinson 2003).

Subsequently, van Staal (2005), in a review of the Appalachian orogen for an encyclopedia, used the term *Neoacadian* (without the hyphen) for the accretion of the Meguma terrane of Nova Scotia, extending Robinson’s Neo-Acadian back in time to 395 Ma (Emsian: late Early Devonian), in order to encompass $^{40}\text{Ar}/^{39}\text{Ar}$ ages for fabric development in the Meguma terrane (Hicks *et al.* 1999). Van Staal *et al.* (2009) further extended the start of the Neoacadian back to 400 Ma, and Nagurney *et al.* (2022) gave a Neoacadian age range from 406–388 Ma, entirely preceding the interval defined by Robinson *et al.* (1998). Some subsequent authors working in New England (Hillenbrand and Williams 2021) have used a definition (400–350 Ma) of the Neoacadian based on that of van Staal (2009), although this approach leads to substantial temporal overlap of *Neoacadian* with the traditional *Acadian*. Others (Hibbard *et al.* 2010) preferred a time-based nomenclature, referring to the Neo-Acadian (Robinson *et al.* 1998) or Quaboagian (Robinson 2003) episode as *Fammennian* deformation.

The tectonic definition of *Neoacadian* to refer to events interpreted as associated with the accretion of the Meguma terrane has been followed by subsequent authors, leading to further increases in its supposed duration. For example, van Staal and Barr (2012) extended the duration of the event to 340 Ma, although metamorphic ages cited by them are as young as 337 Ma (Reynolds *et al.* 2004). This younger date (337 Ma, Viséan or middle Mississippian) was considered

by Piette-Lauzière *et al.* (2024b, 2024a) to mark the end of the *Neoacadian* orogeny.

Later deformation

Alleghanian: Middle Carboniferous to Permian deformation

Convergent deformation in large areas of the southern New England Appalachian orogen continued even later in the Paleozoic Era. For example, Robinson *et al.* (1998) recognized a *Late Pennsylvanian* episode between 300 and 290 Ma (extending into the Cisuralian or early Permian in modern timescales) and a later interval, from 280 to 260 Ma, was identified as *Alleghanian*, coeval with a major orogenic episode recognized in the southern Appalachian orogen. However, outside New England, deformation falls between these supposedly separate events. For example, deformation in the southwestern Meguma terrane and along the Minas fault zone (MFZ) that separates it from Avalonia was focussed in the interval 325–315 Ma (Culshaw and Liesa 1997; Culshaw and Reynolds 1997; Murphy *et al.* 2011; Piper and Pe-Piper 2021), whereas deformation in southern New Brunswick (previously attributed to a “Maritimes Disturbance”) probably occurred between 320 and 310 Ma (Park and Hinds 2020). Most authors (e.g., Murphy and Collins 2008; Hibbard *et al.* 2010; van Staal and Barr 2012) have attributed all the deformation from approximately Serpukhovian to Guadalupian (330–260 Ma) to a single protracted *Alleghanian* orogeny associated with gradual collision of Gondwana and Laurussia to assemble the supercontinent Pangea.

Mesozoic deformation

The initial opening of the Atlantic Ocean resulted in Triassic–Jurassic extension, producing a series of basins, including the Fundy rift, filled by the Triassic–Jurassic Newark Supergroup. In the early stages of rift development, a range of directions between SSW and ESE is possible, but later stages showed SE-directed extension (Withjack *et al.* 1995, 2009). Comparable extension occurred in the Hartford basin (Fig. 1), and farther south in the Newark, Gettysburg, and Culpeper basins, together with additional basins in the southern Appalachian orogen and offshore reviewed by Schlische (1993). Except for the Fundy Basin, which may have undergone extension variously estimated between 10 and 50 km (Withjack *et al.* 2009; Waldron *et al.* 2022b), the amounts of extension implied by the cross-sections of individual basins by Schlische (1993) are less than 10 km. The basins are presumably linked by diffuse transfer zones or minor reactivations of Paleozoic faults, because current geological maps of the Appalachian orogen do not show discrete transfer faults linking the various basins.

Subsequent minor inversion may have affected the Fundy basin (Withjack *et al.* 2009) and other parts of Atlantic Canada during the Cretaceous Period, possibly a result of

differential motion between Newfoundland and Iberia (Piper and Pe-Piper 2025).

Devonian–Carboniferous deformation and the Meguma terrane

To clarify the relationship between the accretion of the Meguma terrane and deformation that has been variously called *Quaboagian*, *Neo-Acadian* or *Neoacadian* in New England, we here review the evolution of the Meguma terrane, as summarized in Figure 2.

The basement of the Meguma terrane is unexposed; the terrane is dominated by a thick succession of Cambrian (or older) to Ordovician mainly turbiditic sedimentary rocks (Meguma Group, now Supergroup) after which the terrane was named and for which sedimentology and provenance suggest deposition in a submarine fan offshore of the West African craton (e.g., Schenk 1973; Waldron and Jensen 1985; Waldron *et al.* 2009). Rocks in the Welsh basin of Britain (Cymru terrane of Pharaoh *et al.* 1989) show similar facies and provenance, suggesting that the two terranes were adjacent on the margin of Gondwana during the Cambrian, defining the domain *Megumia* (Waldron *et al.* 2011). *Megumia* clearly broke up in the Early Ordovician, as the histories of the two terranes diverge (Pothier *et al.* 2015a, 2015b), and the subsequent trajectory of the Meguma terrane is controversial: it may have remained attached to northwest Africa until incorporated in Pangea (e.g., Schenk 1997); it may have remained attached to Avalonia (e.g., Murphy *et al.* 2004); or, it may have travelled as an independent micro-continent (e.g., van Staal and Barr 2012).

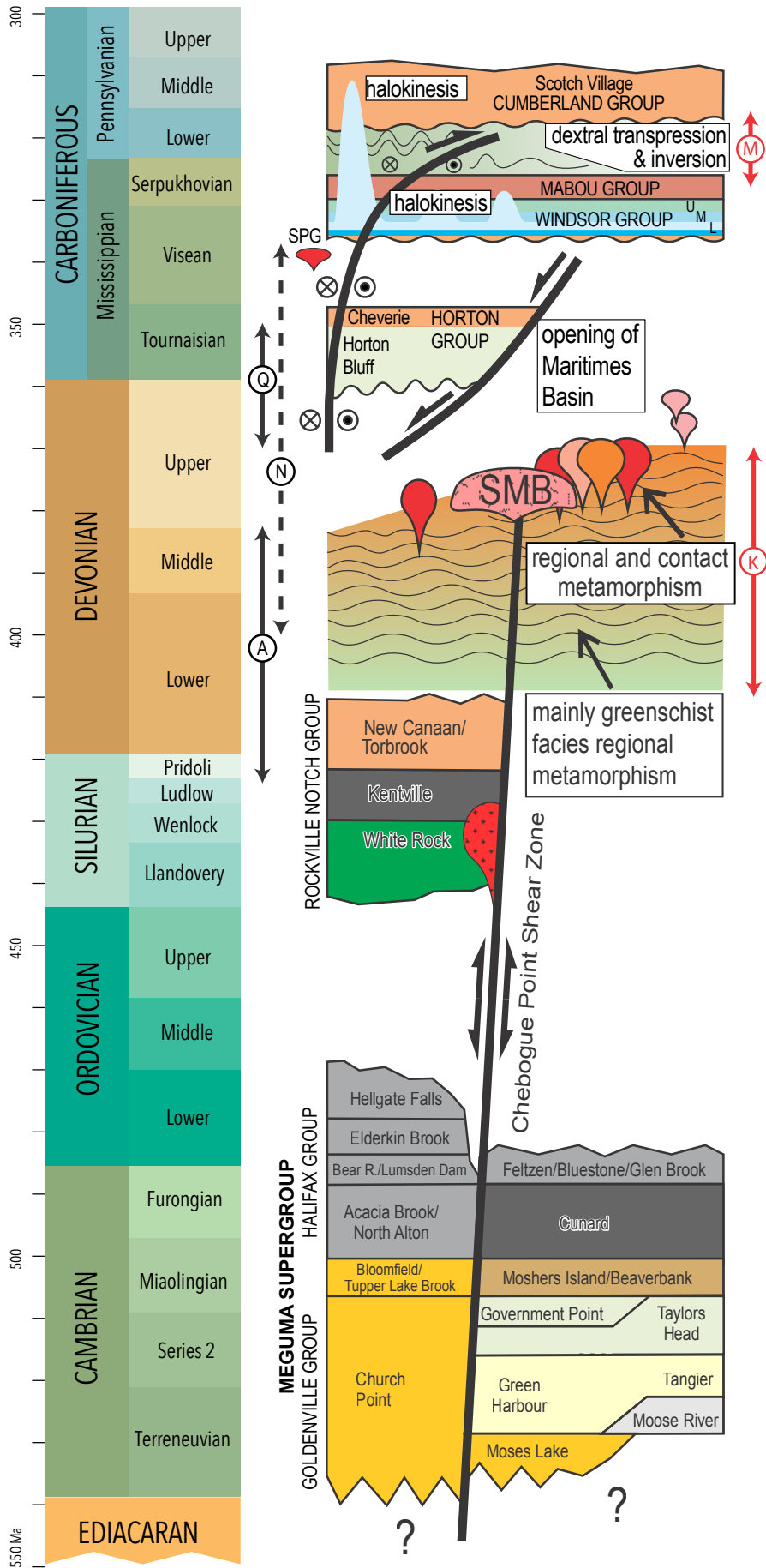
The stratigraphic succession of the Meguma terrane continues above an Ordovician unconformity (Fig. 2). Silurian to lower Emsian strata are assigned to the Rockville Notch Group (White and Barr 2017; White *et al.* 2018). The base Emsian boundary is 407.6 ± 2.6 Ma in recent time scales (Becker *et al.* 2020) but has been the subject of discussion: the base of the conodont zone (*Eocostapolygnathus kitabicus*) used in the 2012 time scale (Becker *et al.* 2012) is most recently (Becker *et al.* 2020) estimated at 410.5 Ma; this is therefore the current maximum possible depositional age of the youngest strata of the Rockville Notch Group. The earliest structures suggesting convergent deformation of the Meguma terrane formed very soon after deposition of the youngest strata of the Rockville Notch Group; bedding-concordant quartz veins that contain gold and sulphides were dated at 409 ± 5 Ma (Morelli *et al.* 2005). The strata and

veins are folded by regional upright folds with axial planar cleavage and saddle-reef veins dated in southern Nova Scotia between 395 and 388 Ma (Hicks *et al.* 1999), although sulphide minerals in saddle reef veins in eastern Nova Scotia are slightly younger at 380 ± 3 Ma (Morelli *et al.* 2005). These ages all pre-date the Neo-Acadian or Quaboagian time interval of Robinson (1998).

Higher-grade metamorphic rocks in southwestern and eastern Nova Scotia display conditions of generally high geothermal gradient with temperatures up to 550–650°C at modest pressures of 0.4–0.5 GPa (Nagurney *et al.* 2022; van Rooyen *et al.* 2024). Van Rooyen *et al.* (2024) obtained Lu–Hf ages from metamorphic garnet of 372 ± 1.4 Ma, indistinguishable from the ages of granitoid plutons in the same area (379–374 Ma Dostal *et al.* 2006; Archibald *et al.* 2018, 2024). Plutons in southwestern Nova Scotia, including the large South Mountain Batholith (Clarke *et al.* 1997, 2025), cross-cut the regional folds (Fig. 1A, 2) but span a somewhat longer interval from 385–370 Ma (summarized by Bickerton *et al.* 2022), although the presence of antecrysts and xenocrysts places some doubt on the older age limit and the offshore Seal Island pluton is younger at 362.8 ± 0.7 Ma (Moran *et al.* 2007).

Deformation and plutonism were followed rapidly by exhumation and deposition (Fig. 2) of clastic sedimentary rocks of the Horton Group (Martel *et al.* 1993; St. Peter and Johnson 2009; Gibling *et al.* 2019), resting with profound angular unconformity across multiple Appalachian terranes (Keppie 1985), and recording the initiation of the Maritimes Basin, a large and complex sedimentary basin that straddled all the tectonic zones of the Appalachian orogen (Gibling *et al.* 2019) between late Famennian (>364 Ma) and early Permian (<290 Ma), based on biostratigraphic and isotopic data (Waldron *et al.* 2017). The earliest dated strata in the Horton Group on the Meguma terrane (Martel and Gibling 1996) belong to the *Retispora lepidophyta* – *Verrucosisorites nitidus* zone, within late Famennian, 361–360 Ma in recent time scales (Becker *et al.* 2020), though possibly extending back to ca. 363.5 Ma based on dates from the Piskahegan Group in New Brunswick (Tucker *et al.* 1998). The Horton Group occupies a series of graben and half-graben (Martel and Gibling 1996; Murphy *et al.* 2011) that extend across Nova Scotia (e.g., Hamblin 1989), New Brunswick (e.g., St. Peter and Johnson 2009), southwestern Newfoundland (Snyder and Waldron 2021), and the Gulf of St. Lawrence (Durling and Marillier 1990, 1993; Pinet *et al.* 2018). Crustal seismic reflection and refraction data (Marillier and Verhoef

Figure 2. (next page) Summary of Paleozoic units and events in the history of the Meguma Terrane. SMB = South Mountain Batholith. SPG = St. Peter's Gabbro. Black arrows show previously used orogenic ranges: (A) Acadian orogenesis (Bradley *et al.* 2000); (N) Aggregated range of “Neoacadian” orogenesis as used in subsequent publications on the geology of Atlantic Canada (van Staal *et al.* 2009; Piette-Lauzière *et al.* 2024b). (Q) Quaboagian or Neo-Acadian orogenesis as defined by Robinson *et al.* (1998; 2003). Red arrows show timing of major deformation in Meguma terrane, potentially relating to its docking with Laurentia: (K) Kejimikujik orogeny as used here; (M) Major strike slip and transpression along the Minas fault zone and in southwest Nova Scotia, here referred to an early phase of the Alleghanian orogeny (Culshaw and Liesa 1997; Culshaw and Reynolds 1997; Murphy *et al.* 2011; Pe-Piper *et al.* 2018).



1989; Marillier *et al.* 1989; Jackson *et al.* 2024) indicate extreme thinning of the crust beneath the central Maritimes Basin, the Magdalen sub-basin (Fig. 1B). At least 12 km of upper crust is occupied by the fill of the Maritimes Basin, and a similar thickness of lower crust is believed to be occupied by underplated mafic magmatic rock. The thickness of the Acadian orogen was therefore reduced to approximately one third of typical continental crustal thickness. Although the thickness of Maritimes Basin strata on the Meguma terrane is significantly less (~3 km, Waldron *et al.* 2010), the Horton Group was clearly deposited in a basin-and-range environment (e.g., Gibling *et al.* 2019) that reflects crustal thinning across the entire region, attributed by Hibbard and Waldron (2009) to transtension at a releasing bend on a broadly orogen-parallel strike-slip fault. The geochemistry of contemporary (358–355 Ma; Dunning *et al.* 2002) volcanic rocks (Fountain Lake Group) and related plutons in the Cobequid Highlands, immediately north of the Meguma terrane, are chemically consistent with eruption emplacement in a within-plate extensional setting (Dunning *et al.* 2002; Pe-Piper *et al.* 2018).

Deposition of the Horton Group (Fig. 2) in predominantly lacustrine environments with occasional marine incursions (Martel and Gibling 1996; Gibling *et al.* 2019) continued until the Ivorian spore zone of *Spelaotriletes pretiosus* var. *pretiosus* (late Tournaisian, Ivorian substage) at approximately 350 Ma (Waldron *et al.* 2017). Thereafter, a hiatus of uncertain duration preceded the deposition of the mainly Viséan Windsor Group, consisting of carbonate, evaporite and clastic sedimentary rocks deposited in a much less faulted environment. In contrast to the Horton Group, many units can be correlated long distances within the Maritimes Basin. Considerable discussion, summarized by Waldron *et al.* (2017), has surrounded the age of the basal Windsor Group limestone, the Macumber Formation, with proposed ages ranging from late Chadian (ca. 345 Ma) to early Asbian (ca. 336 Ma), but recent dating of the Boyd Creek Tuff in New Brunswick, within basal Windsor Group strata, at 336.9 ± 2 Ma (Park *et al.* 2024) supports the youngest of these proposals and suggests a hiatus of up to 13 Myr between the Horton Group and the overlying Windsor Group (Fig. 2). Ages of fabrics in the Horton Group 15–50 km north of the Meguma terrane in the Lochaber area fall within this gap (Reynolds *et al.* 2004), as does intrusion of the within-plate St. Peter's Gabbro (339 ± 1 Ma) in Cape Breton Island (Barr *et al.* 1994), metamorphism of mafic gneiss (343–335 Ma) in the Minas fault zone (Gibbons *et al.* 1996), and deposition of the Sussex Group in southern New Brunswick (St. Peter and Johnson 2009), suggesting that Maritimes Basin deposition was interrupted by transcurrent deformation and uplift at this time.

Sedimentation continued from the episodically marine, evaporitic Windsor Group into the conformably overlying nonmarine Mabou Group (Fig. 2), although both were strongly affected by halokinesis which probably began soon after deposition of thick lower Windsor salt (Waldron *et al.* 2022a). Both groups were deformed after deposition of the

youngest Mabou Group rocks on the Meguma terrane, in the Arnsbergian stage of the Serpukhovian, after ca. 328 Ma (Belt 1965; Allen *et al.* 2013). This deformation inverted the basins generated in the Late Devonian to Tournaisian extension, probably in transpression associated with substantial dextral strike-slip motion that occurred on the Minas fault zone (MFZ) that forms the northern boundary of the Meguma terrane (Waldron *et al.* 2010; Murphy *et al.* 2011; Piper and Pe-Piper 2021). Inversion affected areas far to the north of the Meguma terrane, beneath the Gulf of St. Lawrence (Pinet *et al.* 2012). In southwestern Nova Scotia at this time, D₂ shear-zone, fabric and fold development overprinted the older, Devonian D₁ structures, between 325 and 315 Ma (Culshaw and Liesa 1997; Culshaw and Reynolds 1997). White micas both north and south of the MFZ were reset (Murphy and Collins 2008). This interval of Mississippian–Pennsylvanian deformation is generally interpreted to record the westward (dextral) translation of the Meguma terrane, roughly parallel to the MFZ, into a position close to its present-day location. The amount of westward translation is poorly constrained, although Waldron *et al.* (2015) argued for over 150 km of dextral motion, on the basis of the width and high strains associated with the MFZ, and the disparate facies of Horton and Fountain Lake groups that are juxtaposed. Warsame *et al.* (2021) interpreted that the Meguma terrane underwent approximately 24° of counter-clockwise rotation after the Carboniferous acquisition of remanent magnetization at ca. 320 Ma. They attributed this deformation to further convergence of the Meguma terrane with Avalonia during dextral motion along the MFZ in the later part of the Alleghanian orogeny, but could not discount a rotational component related to the Mesozoic opening of the Fundy graben.

Later Carboniferous deformation also affected areas of Nova Scotia to the north of the Meguma terrane. For example, Waldron *et al.* (2013) documented structures in the Cumberland sub-basin consistent with northward thrusting of the Cobequid Highlands around 310 Ma.

Subsequently, certain Paleozoic structures were reactivated in transtension during Mesozoic rifting associated with the opening of the Atlantic Ocean. The MFZ underwent sinistral-normal oblique slip, down-dropping the southern hanging wall (Meguma terrane) and allowing subsidence of the Fundy half-graben. Minor later shortening has been suggested based on structures in the Lower Cretaceous Chaswood Formation (Stea and Pullan 2001; Piper *et al.* 2005; Piper and Pe-Piper 2025) although most Chaswood Formation occurrences are localized over Mississippian evaporites, which were likely mobile in the Mesozoic.

DISCUSSION

Contrasting tectonic histories

Southern New England and Maritime Canada record Taconian and Salinian orogenic histories that are broadly

comparable. This similarity includes the onset of Devonian orogenesis, as sedimentary strata below the Acadian unconformity identified by Schuchert (1930) are mainly conformable into the earliest Emsian ($<407.6 \pm 2.6$ Ma) across the entire region, which was subjected to tectonic shortening during the Middle Devonian. The tectonic driver of this shortening is unclear, though most interpreters have attributed the Acadian orogeny to collision of West Avalonia with the composite Laurentian margin (e.g., van Staal and Barr 2012). Continuing volcanic and intrusive activity (Bradley 1983; Dunning *et al.* 1990; Barr *et al.* 2002; Wilson and Kamo 2012; Wilson *et al.* 2017), together with episodic unconformities (Wilson and Kamo 2012; Wilson *et al.* 2017), suggest that most Ganderian terranes in the northern Appalachian orogen lay in an arc or backarc situation throughout the Silurian. An arc-backarc system, termed the coastal igneous belt (CIB) by Waldron *et al.* (2022b) extended from Maine through southern New Brunswick and western Cape Breton Island to southwestern Newfoundland. However, Acadian deformation in New England (Robinson *et al.* 1998), New Brunswick (Massonne *et al.* 2018), and Cape Breton Island (Plint and Jamieson 1989) was accompanied by Barrovian metamorphism, suggesting that by middle Devonian the composite Laurentian margin was being over-ridden. Bradley (1983) suggested that Acadian deformation resulted from closure of a two-sided subduction system similar to the modern Philippine plate, whereas Waldron *et al.* (2022b) suggested that collapse of the CIB backarc basin led to a change in subduction polarity.

Regardless of the tectonic cause of Acadian deformation, the eastern edge of the Acadian orogen is marked by a boundary that can be traced through the northern Appalachian orogen, separating deformed and metamorphosed Silurian arc successions to the northwest from Avalonian and locally Ganderian successions to the southeast that lack Silurian igneous rocks, and remained sufficiently unmetamorphosed that they still contain classic fossiliferous Cambrian and Ordovician successions. This boundary, from the Lake Char fault in southern New England, through the Kennebecasis fault in New Brunswick, through the Eastern Highlands shear zone in Cape Breton Island, and into the Dover–Hermitage Bay fault in Newfoundland, is here interpreted as an Acadian suture of middle Devonian age, despite the absence of recognizable ophiolites (cf. Piette-Lauzière *et al.* 2024b, 2024a, who place the suture differently in New Brunswick and Cape Breton Island).

The deformation history of the Meguma terrane, which lies to the south of West Avalonia, initially resembles that of the New England Acadian orogen. A sedimentary succession extending into early Emsian was deformed, starting around 409 Ma with the formation of bed-parallel veins indicating vertical extension, and folds with regional steep cleavage indicating horizontal SE–NW shortening. However, despite the similarity in age, significant differences are apparent between rocks north and south of West Avalonia. The Silurian succession in the Meguma terrane displays only within-plate volcanic rocks (MacDonald *et al.* 2002;

White and Barr 2017; White *et al.* 2018) in contrast to the arc-related CIB. Metamorphism in the Meguma terrane occurred under conditions of higher geothermal gradient (van Rooyen *et al.* 2024 and references therein), producing andalusite and sillimanite rather than kyanite. Folds are regionally upright and cross-cut by large S-type granitoid plutons produced by melting of wet Meguma terrane sedimentary rocks and their basement (Bickerton *et al.* 2022; van Rooyen *et al.* 2024). Most interpreters (e.g., Keen *et al.* 1991) have suggested that the Meguma terrane was thrust over West Avalonia during the Devonian, but recent interpretations of geophysical data (Jackson *et al.* 2024) limit the overthrusting to a few kilometres.

In New England, convergence following Acadian (middle Devonian) deformation clearly continued into the Late Devonian and Early Mississippian (Tournaisian), building a thick Quaboagian/Neoacadian orogen (Fig. 1C) supporting an orogenic plateau (Hillenbrand *et al.* 2021; Hillenbrand and Williams 2021). This plateau continued to the northeast as far as approximately the New Hampshire–Maine border, beyond which the orogen shows little evidence of crustal thickening after the Middle Devonian.

In contrast, the region southeast of the Acadian orogen in Atlantic Canada, including the Meguma terrane, shows no evidence of Quaboagian/Neoacadian thickening. Instead, crustal thinning from late Famennian (ca. 364 Ma) produced basins within which predominantly non-marine clastic sedimentation continued until ca. 350 Ma (late Tournaisian). Localized shortening affected parts of West Avalonia between 340 and 337 Ma (Reynolds *et al.* 2004) but on the Meguma terrane itself the Horton–Windsor contact is a subtle disconformity (Waldron *et al.* 2010), suggesting that it was caused by simple uplift and subsidence, without basin-bounding faults. Atlantic Canada continued to subside and accumulate sediment until the earliest Pennsylvanian, when convergent deformation characterized as early Alleghanian (Culshaw and Liesa 1997; Culshaw and Reynolds 1997) affected the southwestern Meguma terrane accompanied by dextral strike slip along the MFZ and inversion of Mississippian basins (Murphy *et al.* 2011; Piper and Piper 2021).

Nomenclature

The term *Neo-Acadian* was initially proposed (Robinson *et al.* 1998) to describe an episode of crustal shortening, metamorphism, and magmatism in southern New England between 370 and 350 Ma of unknown tectonic cause. A cause (collision of the Meguma terrane) was proposed (van Staal 2005) and subsequent authors used this interpreted tectonic environment as the defining characteristic of their *Neoacadian* orogeny. However, the history of the Meguma terrane shows that it underwent extension, not shortening, during the Neo-Acadian orogeny as originally defined. It experienced shortening both before (409–370 Ma) and after (340–337?, 325–315 Ma) the Neo-Acadian orogeny as defined by Robinson (1998), which led to later interpretations

that dramatically extended the duration of Neocadian back to 406 Ma and forward to 337 Ma. However, even this extended definition does not include the docking of the Meguma terrane close to its present relative position at ca. 320 Ma (Fig. 3). The continued use of the term Neocadian invites New England geologists to mistakenly infer that the Meguma terrane underwent shortening and/or docking between 370 and 350 Ma, and to mistakenly interpret Acadian (409–385 Ma) basins in New England as products of the docking of the Meguma terrane, rather than West Avalonia, a much more likely driver.

We therefore suggest that the terms *Neo-Acadian* and *Neoacadian* should be abandoned. Robinson himself (2003) provided an unambiguous alternative—*Quaboagian*—for Late Devonian to Early Mississippian shortening in southern New England. In Figure 3 we show how this Quaboagian shortening can be linked kinematically, via dextral strike-slip motion parallel to the Norumbega and Belleisle faults, with basin formation during transtension at a releasing bend in Atlantic Canada, rather than any regional orogenic event.

Early shortening in the Meguma terrane occurred between 409 and 385 Ma, within the Acadian time interval (Robinson *et al.* 1998) but in a contrasting environment of higher temperature and lower pressure than the classic Acadian. Although the location of the Meguma terrane during the Acadian orogeny is unknown, it is reasonable to suppose that it may have been separated from the Acadian orogen by West Avalonia, as it is at the present day. As neither “Acadian” nor “Neocadian” can be applied to this orogenic event, a new term is warranted; Barr *et al.* (2022a, 2022b) and van

Rooyen *et al.* (2024) suggested *Kejimkujik orogeny*, an Indigenous name for a lake and National Park in southwestern Nova Scotia (Fig. 1D) which includes rocks of both the Meguma Supergroup and the South Mountain Batholith.

CONCLUSIONS

The term *Neo-Acadian* was initially proposed (Robinson *et al.* 1998) to describe an episode of crustal shortening, metamorphism, and magmatism in southern New England between 370 and 350 Ma of unknown tectonic cause. The term *Neoacadian* was subsequently used to describe collision of the Meguma terrane with Laurentia. However, the Meguma terrane underwent extension during the 370–350 Ma Neo-Acadian interval as originally defined; convergent deformation affected the terrane both before and after this extensional event. Its initial Early Devonian shortening probably occurred outside the Acadian orogen and may have had a different tectonic cause. In the absence of a clear link with the Acadian orogen we refer to this episode as the *Kejimkujik orogeny*.

The terms *Neo-Acadian* and *Neoacadian* have become ambiguous, confusing, and invite misinterpretations of regional geology. Convergent deformation in southern New England is best attributed to the *Quaboagian orogeny*, the preferred term of Robinson (2003), and can be related to transtension in Atlantic Canada via a strike-slip zone sub-parallel to the orogen. A suitable pole of rotation can explain both Quaboagian convergence and Maritimes Basin opening.

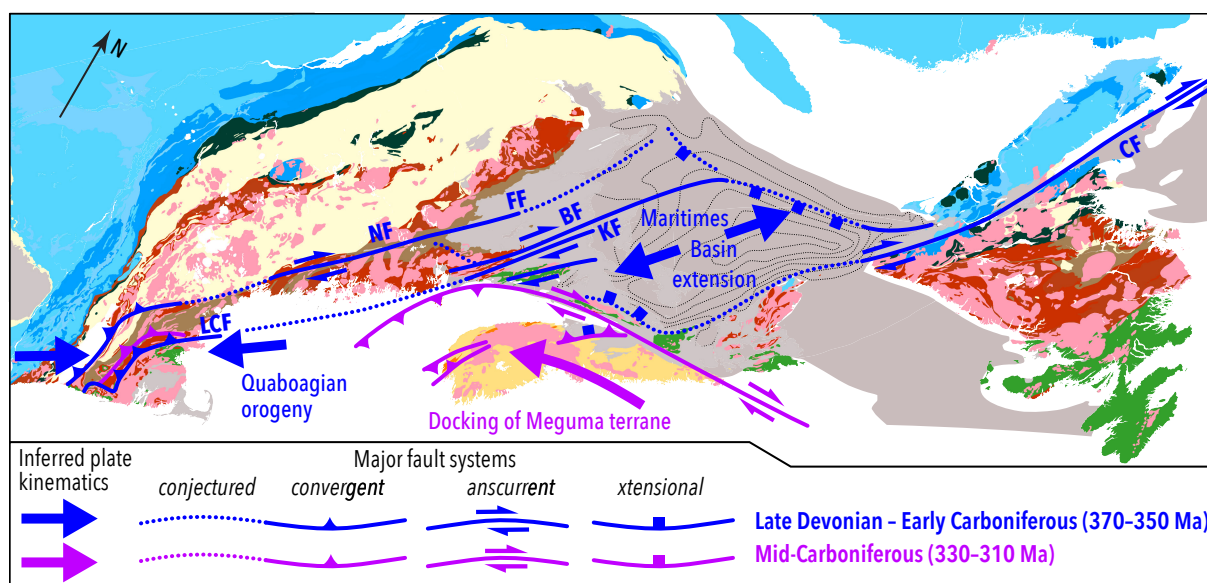


Figure 3. Tectonic model (modified from Hibbard and Waldron 2009; Waldron *et al.* 2015, 2022b) showing inferred linkage of Maritimes Basin extension to Quaboagian shortening via dextral strike-slip faults and shear zones (blue), and subsequent middle Carboniferous final docking of the Meguma terrane (Magenta). BF = Belleisle fault; CF = Cabot fault; FF = Fredericton fault; KF = Kennebecasis fault; LCF = Lake Char Fault. NF = Norumbega fault. Colours as Figure 1A.

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