A newly identified Gondwanan terrane in the northern Appalachian Mountains: Implications for the Taconic orogeny and closure of the Iapetus Ocean

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ABSTRACT

The Taconic and Salinic orogenies in the northern Appalachian Mountains record the closure of the Iapetus Ocean, which separated peri-Laurentian and peri-Gondwanan terranes in the early Paleozoic. The Taconic orogeny in New England is commonly depicted as an Ordovician collision between the peri-Laurentian Shelburne Falls arc and the Laurentian margin, followed by Silurian accretion of peri-Gondwanan terranes during the Salinic orogeny. New U-Pb zircon geochronology demonstrates that the Shelburne Falls arc was instead constructed on a Gondwanan-derived terrane preserved in the Moretown Formation, which we refer to here as the Moretown terrane. Metasedimentary rocks of the Moretown Formation were deposited after 514 Ma and contain abundant ca. 535–650 Ma detrital zircon that suggest a Gondwanan source. The Moretown Formation is bound to the west by the peri-Laurentian Rowe belt, which contains detrital zircon in early Paleozoic metasedimentary rocks that is indistinguishable in age from zircon in Laurentian margin rift-drift successions. These data reveal that the principal Iapetan suture in New England is between the Rowe belt and Moretown terrane, more than 50 km farther west than previously suspected. The Moretown terrane is structurally below and west of volcanic and metasedimentary rocks of the Hawley Formation, which contains Laurentian-derived detrital zircon, providing a link between peri-Laurentian and peri-Gondwanan terranes. The Moretown terrane and Hawley Formation were intruded by 475 Ma plutons during peak activity in the Shelburne Falls arc. We propose that the peri-Laurentian Rowe belt was subducted under the Moretown terrane just prior to 475 Ma, when the trench gap was narrow enough to deliver Laurentian detritus to the Hawley Formation. Interaction between peri-Laurentian and peri-Gondwanan terranes by 475 Ma is 20 m.y. earlier than documented elsewhere and accounts for structural relationships, Early Ordovician metamorphism and deformation, and the subsequent closure of the peri-Laurentian Taconic seaway. In this scenario, a rifted-arc system on the Gondwanan margin resulted in the formation of multiple terranes, including the Moretown, that independently crossed and closed the Iapetus Ocean in piecemeal fashion.

INTRODUCTION

The Iapetus Ocean formed during the Ediacaran to Cambrian breakup of Rodinia, and closed during the Ordovician with the progressive accretion of Laurentian- and Gondwanan-derived terranes on the Laurentian margin (e.g., van Staal and Barr, 2012). This history is recorded in tectonic elements of the northern Appalachian orogen (Fig. 1) that were juxtaposed and deformed through multiple phases of Paleozoic orogeny. The most fundamental Appalachian structure, the Iapetan suture, separates peri-Laurentian from peri-Gondwanan tectonic elements, yet it is poorly documented throughout the orogen; its location has only been confidently defined in Newfoundland.

Based on stratigraphy, paleontology, geochemistry, and geochronology, Williams et al. (1988) divided the Dunnage zone of Newfoundland into the peri-Laurentian Notre Dame and peri-Gondwanan Exploits subzones, and referred to the boundary between the two as the Red Indian Line (Fig. 1), which is interpreted as the main Iapetan suture. To the west of the Red Indian Line, the Notre Dame subzone consists of hyperextended Laurentian crustal fragments, such as the Rattling Brook allochthon and Dashwoods terrane (van Staal et al., 2013). To the east, the Exploits

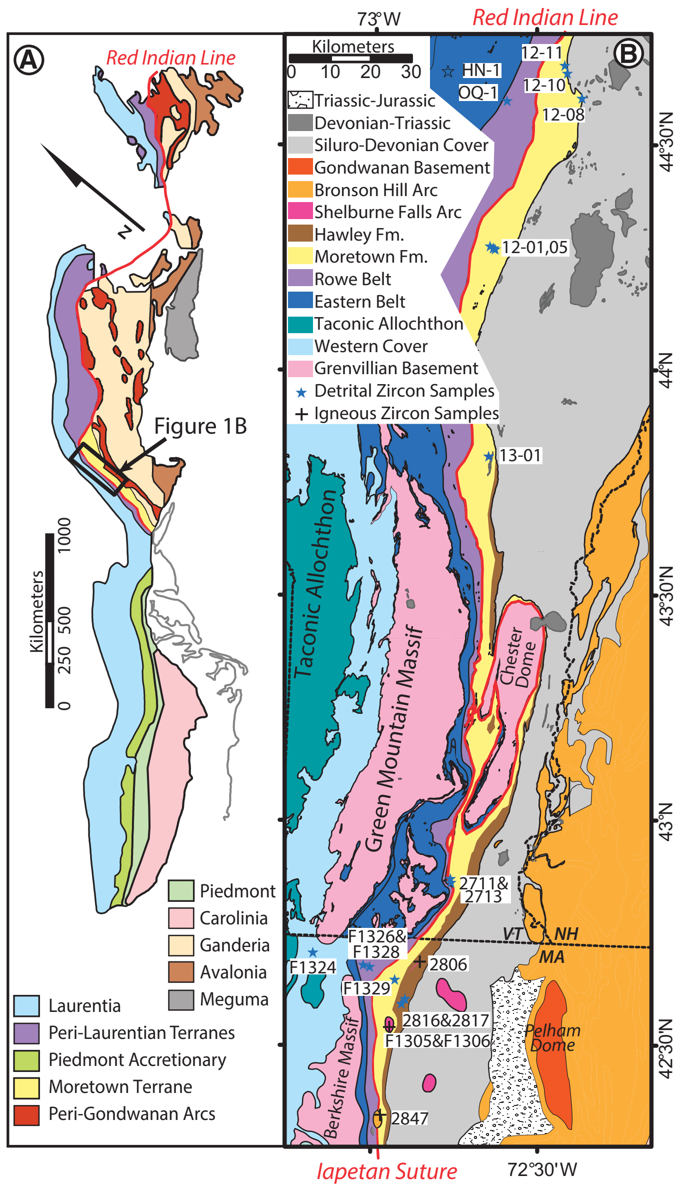

Figure 1. A: Tectonic map of the Appalachian Mountains (modified from Hibbard et al., 2006). B: Simplified geological map with locations of dated samples (modified from Ratcliffe et al., 2011).

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subzone consists of Cambrian to Ordovician peri-Gondwanan arc and backarc terranes of Ganderia (Zagorevski et al., 2010). Van Staal et al. (1998) correlated the Red Indian Line in Newfoundland to the Boil Mountain line in western Maine, west of the Bronson Hill arc, which was shown by Tucker and Robinson (1990) to be built on Neoproterozoic Gondwanan basement exposed in the Pelham dome (Fig. 1). Karabinos and Gromet (1993) suggested that the Moretown and Hawley Formations, just west of the Pelham dome, had a Laurentian provenance and the Shelburne Falls arc was a peri-Laurentian arc (Karabinos et al., 1998), which implied that the Red Indian Line was under Silurian–Devonian cover sequences between the Shelburne Falls arc and the Pelham dome. However, these inferences were based on scant geochronology and ambiguous isotope geochemistry, and the location of the main Iapetan suture in New England has remained enigmatic (Dorais et al., 2012).

We use detrital zircon geochronology to delineate the Iapetan suture by constraining the provenance of early Paleozoic metasedimentary units exposed between the Laurentian margin and Gondwanan basement exposed in the Pelham dome (Fig. 1). We then constrain the timing and nature of the accretion of peri-Laurentian and peri-Gondwanan tectonic elements by dating intrusions within these units. Our data demand important changes in the interpretation of the early Paleozoic orogenic history of the New England Appalachian Mountains, and highlight similarities and contrasts with the well-documented history in the Canadian Appalachians.

TACONIC TECTONOSTRATIGRAPHIC UNITS IN NEW ENGLAND

In New England, west of Grenvillian basement of the Green Mountain (Karabinos and Aleinikoff, 1990) and Berkshire massifs, an Ediacaran–Ordovician rift-drift succession of the Laurentian margin (western cover sequence of Karabinos, 1988; Fig. 1) is overthrust by the Taconic allochthon (Rowley and Kidd, 1981). To the east are allochthonous Ediacaran–Ordovician successions, referred to here as the Eastern and Rowe belts, which include metasedimentary rocks and greenstone and/or amphibolite. The Taconic allochthon likely restores to the Eastern belt, west of the Rowe belt (Stanley and Ratcliffe, 1985; Karabinos, 1988). Ultramafic lenses are common in the Rowe belt near its eastern contact with the Moretown Formation, suggestive of an ocean transition zone, and potentially equivalent to the Birchy Complex in Newfoundland (van Staal et al., 2013).

The Moretown Formation was interpreted as a Laurentian forearc deposit of the west-facing Shelburne Falls arc (e.g., Stanley and Ratcliffe, 1985; Karabinos et al., 1998). It consists of "pinstripe" granofels and quartz-rich phyllite with amphibolite (Ratcliffe et al., 2011), and was intruded by the 502 ± 4 Ma Newfane tonalite (Aleinikoff et al., 2011; Ratcliffe et al., 1998). Structurally above and east of the Moretown Formation, the Hawley Formation was also depicted as a forearc to the Shelburne Falls arc based on boninitic geochemical characteristics of its mafic units (Kim and Jacobi, 1996). The eastern margin of the Hawley Formation is structurally below Silurian–Devonian cover sequences, which also overlie domes of the Shelburne Falls and Bronson Hill arcs (Fig. 1).

GEOCHRONOLOGY

We report laser ablation–inductively coupled plasma–mass spectrometry detrital zircon U-Pb dates from Paleozoic metasedimentary rocks in New England (Fig. 2). Three intrusions and some of the youngest detrital grains were dated with chemical abrasion–thermal ionization mass spectrometry (CA-TIMS) (Fig. 3). Sample locations are shown in Figure 1, and the GSA Data Repository[1] contains analytical methods, data tables, plots, and cathodoluminescence images of zircon.

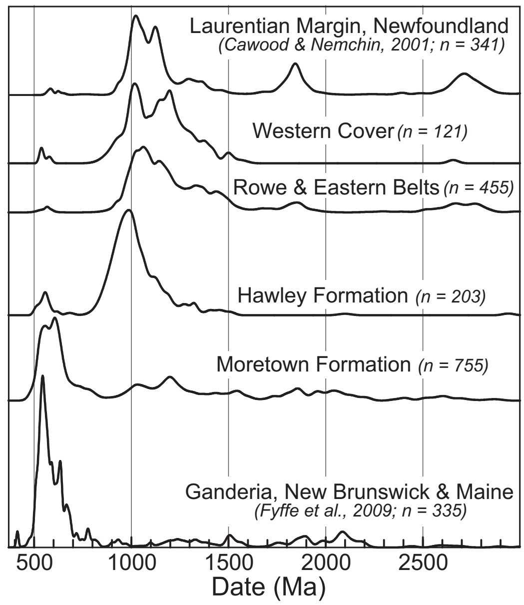

Figure 2. Detrital zircon normalized probability density plots of samples from map units in Figure 1, compared to previously reported data from the Laurentian margin and Ganderia.

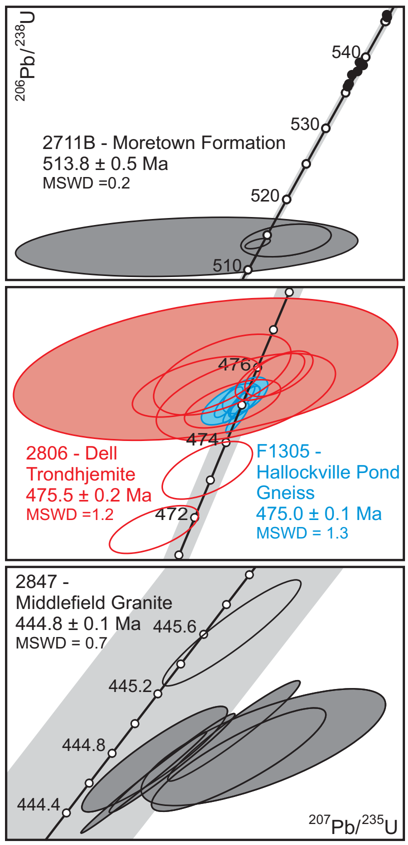

Figure 3. Concordia plots from single grains and fragments of zircon analyzed by chemical abrasion–thermal ionization mass spectrometry. Error ellipses and weighted mean errors are at 2σ. Analyses used in calculation of weighted mean date are shown by filled ellipses. MSWD—mean square of weighted deviates.

The western cover sequence, Eastern belt, and Rowe belt have detrital zircon age spectra characteristic of Grenville-derived rift-related sedimentary rocks in the north-central Appalachian Mountains (Cawood and Nemchin, 2001); broad humps between 950 and 1500 Ma, prominent peaks at ca. 1000 and 1200 Ma, and secondary peaks at ca. 550, 1850, and 2700 Ma (Fig. 2). In striking contrast, the Moretown Formation has prominent peaks between 520 and 650 Ma, a minor ca. 1200 peak, and rare

[1]GSA Data Repository item 2014189, geochronological methods, data tables, plots of CA-TIMS dates, CL images of samples dated by CA-TIMS, and probability distribution plots of individual samples, is available online at www.geosociety.org/pubs/ft2014.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

Paleoproterozoic and Archean grains. The combination of abundant Cambrian and Ediacaran zircon, which is rare on the Laurentian margin, and sparse Paleoproterozoic zircon is characteristic of sediment derived from peri-Gondwanan terranes (e.g., Fyffe et al., 2009; Ryan-Davis, 2013). A maximum age constraint on the Moretown Formation is provided by one whole grain and two fragments of another grain that yielded a CA-TIMS weighted mean date of 513.8 ± 0.5 Ma (Fig. 3).

The Hawley Formation has a sharp peak between 950 and 1000 Ma, with secondary peaks at ca. 550 and 1200 (Fig. 2). The absence of 600–700 Ma zircon is inconsistent with a peri-Gondwanan source, but the narrowness of the peaks and rarity of pre–1200 Ma zircon is also unlike the Laurentian rift-drift succession. The sharp peak between 950 and 1000 Ma is most easily attributable to the ca. 960 Ma Stamford Granite Gneiss and Bull Hill Gneiss (Karabinos and Aleinikoff, 1990), which are located <30 km from the present position of the samples, in the Green Mountain massif (Fig. 1).

The Moretown Formation was intruded by the Hallockville Pond gneiss (Fig. 1, F1305) that yielded a CA-TIMS weighted mean date of 475.0 ± 0.1 Ma (Fig. 3). The Hawley Formation was intruded by the Dell trondhjemite (Fig. 1, 2806) that yielded a weighted mean CA-TIMS date of 475.5 ± 0.4 Ma (Fig. 3). These dates are indistinguishable from ages of 475 ± 1.4 Ma from the Shelburne Falls dome, 473 ± 2.0 Ma from the Goshen dome, and 471 ± 4 Ma from the Barnard Volcanic Member of the Missisquoi Formation (Karabinos et al., 1998). Small, isolated intrusive bodies dated between 502 and 486 Ma have been identified in the Shelburne Falls arc (Aleinikoff et al., 2011), but the most common age of large plutons is 475 Ma, suggesting that a significant part of the arc was built at this time.

The western contact of the Moretown Formation with the Rowe belt is stitched by the Middlefield Granite (Fig. 1, 2847) that yielded a CA-TIMS weighted mean date of 444.8 ± 0.1 Ma (Fig. 3). The Moretown Formation contains two deformation fabrics that postdate intrusion of the 475 Ma Hallockville Pond gneiss and predate intrusion of the 445 Ma Middlefield Granite (Karabinos and Williamson, 1994).

DISCUSSION

The new detrital zircon data demonstrate that the Moretown Formation is a peri-Gondwanan terrane, which we refer to as the Moretown terrane, and its western contact with the Rowe belt marks the principal Iapetan suture. In the context of the tectonic model for the closure of the Iapetus developed in Newfoundland (e.g., van Staal and Barr, 2012), the Moretown terrane could be interpreted as the leading edge of Ganderia that was thrust under the Laurentian margin during the Salinic orogeny. However, this tectonic model creates several problems in New England, particularly with respect to interpretation of the Hawley Formation, which is structurally above and to the east of the Moretown terrane. If the Hawley Formation represents a thin relict of a peri-Laurentian terrane equivalent to the Notre Dame subzone in Newfoundland, its position would require that it was originally thrust eastward above the Moretown terrane as a fragment of an east-facing arc, and then later carried westward above the Rowe belt, all prior to the intrusion of the Middlefield Granite at 445 Ma. Instead, the geochronological data presented here agree with geochemical correlations of Kim and Jacobi (1996), which suggest that igneous rocks in the Moretown and Hawley Formations are related to magmatism in the west-facing Shelburne Falls arc (Karabinos et al., 1998). If the Moretown terrane was part of the leading edge of Ganderia and did not arrive on the margin of Laurentia until ca. 455 Ma (e.g., van Staal and Barr, 2012), then at 475 Ma, the Hawley and Moretown Formations would have been on opposite sides of the Iapetus Ocean and it would be a coincidence that magmatic rocks in both formations have indistinguishable ages and geochemical characteristics. Furthermore, Ganderia records the ca. 486–478 Ma Penobscot orogeny, and magmatism in the Penobscot and Victoria arcs occurred in two pulses, at ca. 513–486 and 473–453 Ma, with a regional volcanic hiatus from 485 to 473 Ma (Zagorevski et al., 2010). In contrast, the Moretown terrane was deformed between 475 and 445 Ma and the Shelburne Falls arc grew rapidly at 475 Ma.

Alternatively, extension of the active Gondwanan margin resulted in formation of multiple Ganderia-like terranes, including Carolinia in the southern Appalachians (Fig. 1), with overlapping but distinct geological histories (Hibbard et al., 2005; Zagorevski et al., 2010). In this scenario, the Moretown terrane split from the Ganderian rifted arc system during the Cambrian and crossed the Iapetus Ocean independently. Shelburne Falls arc magmatism may have started as early as 502 Ma on the Moretown terrane above an east-dipping subduction zone, but peak igneous activity occurred at 475 Ma. We suggest that the Rowe belt, and possibly portions of the Eastern belt and allochthonous Grenville basement, constituted hyperextended peri-Laurentian continental fragments, analogous to the Rattling Brook allochthon and Dashwoods terrane in Newfoundland (van Staal et al., 2013), that were subducted under the Moretown terrane just prior to the 475 Ma magmatic flareup in the Shelburne Falls arc. At that time, the trench had either already closed along strike, or was narrow and shallow enough to deliver Laurentian detritus to the Hawley Formation, which we suggest is a linking sedimentary-volcanic unit between peri-Laurentian and peri-Gondwanan terranes (Fig. 4). Analogs for the Hawley Formation can be found in the Australia-Indonesia arc collision in East Java, where subducted Gondwanan-derived fragments provided zircon to overlap assemblages on the Eurasian plate (Smyth et al., 2007). In this model, the 505–473 Ma ^{40}Ar-^{39}Ar metamorphic cooling dates from amphiboles in mafic schists of the Rowe belt (Castonguay et al., 2012; Laird et al., 1984) record subduction and accretion between the hyperextended peri-Laurentian crustal fragments, culminating with the initial closure of the Iapetus Ocean and accretion of the Moretown terrane onto the Rowe belt. However, at this time, the Taconic seaway separated these amalgamated terranes from the Laurentian margin. Metamorphic ^{40}Ar-^{39}Ar cooling dates between 471 and 460 Ma were reported in both the Laurentian rift-drift succession and the Rowe belt (Castonguay et al., 2012; Laird et al., 1984) and are coincident with ^{40}Ar-^{39}Ar white mica dates of 463 ± 5 Ma in Que-

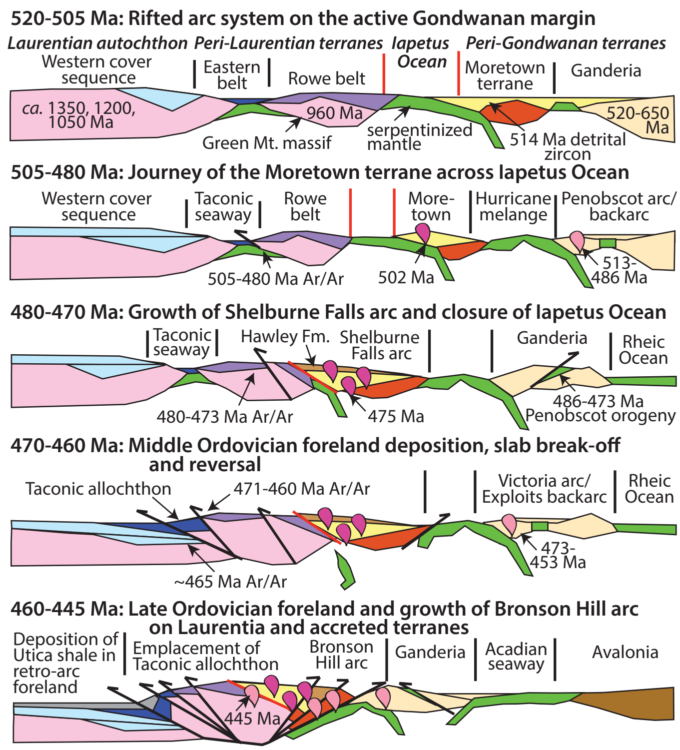

Figure 4. Simplified model for the tectonic evolution of the Taconic orogeny and closure of the Iapetus Ocean. Horizontal distances are not to scale. Details are described in text.

bec (Whitehead et al., 1996). These dates are interpreted to represent the closure of the Taconic seaway with the obduction of the previously united peri-Gondwanan and peri-Laurentian terranes onto the Laurentian margin, and are similar to the end date of the passive margin inferred from foreland deposits in the Table Head and Goose Tickle Groups of Newfoundland (Waldron and van Staal, 2001), which can be correlated with the Middle Ordovician Chazy Group of Vermont. We suggest that Late Ordovician flysch deposits on the Taconic allochthon (Rowley and Kidd, 1981) and Laurentian autochthon are not peripheral foreland deposits, but instead formed in a composite retroarc foreland basin after slab reversal (Fig. 4).

CONCLUSION

We show that the main Iapetan suture is between the Gondwanan Moretown Formation and the Laurentian Rowe belt, and thereby extend the Red Indian Line from Canada south through New England (Fig. 1). We propose that a Cambrian rifted-arc system of the active Gondwanan margin resulted in formation of multiple Ganderia-like terranes, including the Moretown terrane, which independently crossed the Iapetus and collided with peri-Laurentian fragments at ca. 475 Ma. This model is consistent with evidence for an east-dipping subduction zone in the Shelburne Falls arc, and it accounts for Early Ordovician metamorphism and deformation, closure of peri-Laurentian seaways, the distribution of Laurentian and Gondwanan detrital zircon, and the structural relationship between the Moretown and Hawley formations.

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REFERENCES CITED

Aleinikoff, J.N., Ratcliffe, N.M., and Walsh, G.J., 2011, Provisional zircon and monazite uranium-lead geochronology for selected rocks in Vermont: U.S. Geological Survey Open-File Report 2011–1309, p. 1–46.

Castonguay, S., Kim, J., Thompson, P.J., Gale, M.H., Joyce, N., Laird, J., and Doolan, B.L., 2012, Timing of tectonometamorphism across the Green Mountain anticlinorium, northern Vermont Appalachians: ^{40}Ar/^{39}Ar data and correlations with southern Quebec: Geological Society of America Bulletin, v. 124, p. 352–367, doi:10.1130/B30487.1.

Cawood, P., and Nemchin, A.A., 2001, Source regions for Laurentian margin sediments: constraints from U/Pb dating of detrital zircon in the Newfoundland Appalachians: Geological Society of America Bulletin, v. 113, p. 1234–1246, doi:10.1130/0016-7606(2001)113<1234:PDOTEL>2.0.CO;2.

Dorais, M., Atkinson, M., Kim, J., West, D.P., and Kirby, G.A., 2012, Where is the Iapetus suture in northern New England? A study of the Ammonoosuc Volcanics, Bronson Hill terrane, New Hampshire: Canadian Journal of Earth Sciences, v. 49, p. 189–205, doi:10.1139/e10-108.

Fyffe, L.R., Barr, S.M., Johnson, S.C., McLeod, M.J., McNicoll, V.J., Valverde-Vaquero, P., van Staal, C.R., and White, C.E., 2009, Detrital zircon ages from Neoproterozoic and early Paleozoic conglomerate and sandstone units of New Brunswick and coastal Maine: Implications for the tectonic evolution of Ganderia: Atlantic Geology, v. 45, p. 110–144, doi:10.4138/atlgeol.2009.006.

Hibbard, J.P., Miller, B.V., Tracy, R.J., and Carter, B.T., 2005, The Appalachian peri-Gondwanan realm; A palaeogeographic perspective from the south, *in* Vaughan, A.P.M, et al., eds., Terrane processes at the margins of Gondwana: Geological Society of London Special Publication 246, p. 97–111, doi:10.1144/GSL.SP.2005.246.01.03.

Hibbard, J.P., van Staal, C.R., Rankin, D.W., and Williams, H., 2006, Lithotectonic map of the Appalachian Orogen: Geological Survey of Canada Map 2096A, 2 sheets, scale 1:1,500,000.

Karabinos, P., 1988, Tectonic significance of basement-cover relationships in the Green Mountain massif, Vermont: Journal of Geology, v. 96, p. 445–454, doi:10.1086/629239.

Karabinos, P., and Aleinikoff, J.N., 1990, Evidence for a major middle Proterozoic post-Grenvillian igneous event in western New England: American Journal of Science, v. 290, p. 959–974, doi:10.2475/ajs.290.8.959.

Karabinos, P., and Gromet, P.L., 1993, Application of single-grain zircon evaporation analyses to detrital grain studies and age discrimination of igneous suites: Geochimica et Cosmochimica Acta, v. 57, p. 4257–4267, doi:10.1016/0016-7037(93)90321-M.

Karabinos, P., and Williamson, B.F., 1994, Constraints on the timing of Taconian and Acadian deformation in western Massachusetts: Northeastern Geology, v. 16, p. 1–8.

Karabinos, P., Samson, S.D., Hepburn, C.J., and Stoll, H.M., 1998, Taconian orogeny in the New England Appalachians: Collision between Laurentia and the Shelburne Falls arc: Geology, v. 26, p. 215–218, doi:10.1130/0091-7613(1998)026<0215:TOITNE>2.3.CO;2.

Kim, J., and Jacobi, R.D., 1996, Geochemistry and tectonic implications of Hawley Formation meta-igneous units, northwestern Massachusetts: American Journal of Science, v. 296, p. 1126–1174, doi:10.2475/ajs.296.10.1126.

Laird, J., Lanphere, M.A., and Albee, A. L., 1984, Distribution of Ordovician and Devonian metamorphism in mafic and pelitic schists from northern Vermont: American Journal of Science, v. 284, p. 376–413, doi:10.2475/ajs.284.4-5.376.

Ratcliffe, N.M., Hames, W.E., and Stanley, R.S., 1998, Interpretation of ages of arc magmatism, metamorphism, and collisional tectonics in the Taconian orogen of western New England: American Journal of Science, v. 298, p. 791–797, doi:10.2475/ajs.298.9.791.

Ratcliffe, N.M., Stanley, R.S., Gale, M.H., Thompson, P.J., and Walsh, G.J., 2011, Bedrock geologic map of Vermont: U.S. Geological Survey Scientific Investigations Map 3184, scale 1:100,000.

Rowley, D.B., and Kidd, W.S.F., 1981, Stratigraphic relationships and detrital composition of the medial Ordovician flysch of western New England: Implications for the tectonic evolution of the Taconic orogeny: Journal of Geology, v. 89, p. 199–218, doi:10.1086/628580.

Ryan-Davis, J., 2013, Origins of the Moretown Formation, northern Vermont: A detrital zircon study [B.A. thesis]: Middlebury, Vermont, Middlebury College, 74 p.

Smyth, H.R., Hamilton, P.J., Hall, R., and Kinny, P.D., 2007, The deep crust beneath island arcs: Inherited zircons reveal a Gondwana crustal fragment beneath East Java, Indonesia: Earth and Planetary Science Letters, v. 258, p. 269–282, doi:10.1016/j.epsl.2007.03.044.

Stanley, R., and Ratcliffe, N., 1985, Tectonic synthesis of the Taconian orogeny in western New England: Geological Society of America Bulletin, v. 96, p. 1227–1250, doi:10.1130/0016-7606(1985)96<1227:TSOTTO>2.0.CO;2.

Tucker, R.D., and Robinson, P., 1990, Age and setting of the Bronson Hill magmatic arc: A re-evaluation based on U-Pb zircon ages in southern New England: Geological Society of America Bulletin, v. 102, p. 1404–1419, doi:10.1130/0016-7606(1990)102<1404:AASOTB>2.3.CO;2.

van Staal, C.R., and Barr, S.M., 2012, Lithospheric architecture and tectonic evolution of the Canadian Appalachians and associated Atlantic margin, *in* Percival, J.A., et al., eds., Tectonic styles in Canada: The LITHOPROBE perspective: Geological Association of Canada Special Paper 49, p. 55.

van Staal, C.R., Dewey, J.F., Mac Niocaill, C., and McKerrow, W.S., 1998, The Cambrian–Silurian tectonic evolution of the northern Appalachians and British Caledonides: History of a complex, west and southwest Pacific-type segment of Iapetus, *in* Blundell, D.J., and Scott, A.C., eds., Lyell: the past is the key to the present: Geological Society of London Special Publication 143, p. 197–242, doi:10.1144/GSL.SP.1998.143.01.17.

van Staal, C.R., Chew, D.M., Zagorevski, A., McNicoll, V.J., Hibbard, J.P., Skulski, T., Castonguay, S., Escayola, M.P., and Sylvester, P.J., 2013, Evidence of late Ediacaran hyperextension of the Laurentian Iapetan margin in the Birchy Complex, Baie Vert Peninsula, northwest Newfoundland: Implications for the opening of the Iapetus, formation of peri-Laurentian microcontinents and Taconic-Grampian orogenesis: Geoscience Canada, v. 40, p. 94–117, doi:10.12789/geocanj.2013.40.006.

Whitehead, J., Reynolds, P.H., and Spray, J.G., 1996, ^{40}Ar/^{39}Ar age constraints on Taconian and Acadian events in the Quebec Appalachians: Geology, v. 24, p. 359–362, doi:10.1130/0091-7613(1996)024<0359:AAACOT>2.3.CO;2.

Williams, H., Coleman-Sadd, S.P., and Swinden, H.S., 1988, Tectonic-stratigraphic divisions of central Newfoundland, *in* Current research, Part B: Eastern and Atlantic Canada: Geological Survey of Canada Paper 88–1B, p. 91–98.

Zagorevski, A., van Staal, C.R., Rogers, N., McNicoll, V.J., Dunning, G.R., and Pollock, J.C., 2010, Middle Cambrian to Ordovician arc-backarc development on the leading edge of Ganderia, Newfoundland Appalachians, *in* Tollo, R.P., et al., eds., From Rondinia to Pangea: The lithotectonic record of the Appalachian region: Geological Society of America Memoir 206, p. 367–396, doi:10.1130/2010.1206(16).

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