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IAPETAN RIFT–PASSIVE MARGIN TRANSITION IN NE LAURENTIA AND EUSTATIC CONTROL ON CONTINENTAL SLOPE OXYGENATION, TACONIC SLATE COLORS, AND EARLY PALEOZOIC CLIMATE

By

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INTRODUCTION

This excursion along the eastern margin of the New York Promontory was prepared for the combined meeting of the New England Intercollegiate Geological Conference and the New York State Geological Association (October 2018). Parts of this guide have been modified from reports by EL and MW and are so indicated. There are two purposes of the trip:

(1) The oldest rocks of the Taconic allochthon (originally deposited on the east Laurentian margin of the Iapetus Ocean and at least 75 km east of its present location) and coeval shelf margin rocks in the Green Mountain anticlinorium (not seen on this trip) indicate a surprisingly late persistence or rejuvenation of Iapetan rifting. Although Iapetan rifting began in the later Ediacaran, the oldest record of sedimentary rocks deposited on the middle Proterozoic basement of the Grenvillian orogen in NE Laurentia is late Early Cambrian, with immature sandstone (arkose) deposition continuing well into the Middle Cambrian in the eastern Ottawa-Bonnechere aulacogen (Landing et al., 2009, In press; Figure 1).

(2) The second purpose of this trip emphasizes the relationship of major eustatic changes to macroscale alternations in oxygenation on the east Laurentian continental slope as exhibited in the Lower Paleozoic of the Taconic allochthon. One take away from the trip is that formation-level, type 1 depositional sequences on the Cambrian–Ordovician shelf of eastern Laurentia are reflected by macroscale color alternations on the continental slope. Major eustatic rises and marine onlap of the cratons led to an increase in global insolation as reflective subaerial continental regions areas were inundated by shallow marine seas. These epeiric seas served as a heat sink, warmed the World Ocean, increased a key greenhouse gas (water vapor), all of which led to global temperature rise. Additional effects of high global temperatures include a decrease in storminess with decreased latitudinal temperature gradient as well as major intervals of deposition of organic-rich muds on the continental slope. Increased organic-rich mudstone deposition followed on the slope from the greater thickness and intensity of the mid-water low oxygen zone and in shallow shelf water with decreased oxygen solubility. Thus, high eustatic levels and consequent high global temperatures correlate with carbon sequestration and are the backdrop of the fossil fuel industries. This temperature increase is unrelated to changes in pCO_2 or other greenhouse gasses, and is termed "global hyperwarming" (Landing, 2002, 2007, 2012). "Global hyperwarming" is also pertinent to global climate in the near future with accelerated global warming with eustatic rise due to the melting of ice on land in the high mountains, Greenland and other North Atlantic islands, and Antarctica. (modified from Landing et al., 2007, p. 25)

GEOLOGICAL CONTEXT

The route of this field trip helps emphasize the wealth of geologic history and geologic provinces that are displayed by the bedrock of eastern New York and eastern North America (Figure 1). The trip originates in Lake George village in middle Proterozoic basement of the southern Adirondacks (deformed and metamorphosed ca. 1.1 Ga in the Grenvillian orogeny) and ends in the Late Ordovician overthrust belt of the Taconic allochthon. This ca.

40 km W–E transect is comparable in geologic content to an excursion beginning in the Proterozoic of the Black Hills massif of South Dakota and ending in the Roberts Mountain allochthon in central Nevada.

By this analogy, the route (see geologic map in Fisher, 1984) passes out of the Proterozoic Adirondack basement south of Lake George; crosses the nearly flat-lying (albeit block-faulted) Laurentian Cambrian–Ordovician shelf of southern Warren and western Washington counties; then crosses N- and NE-trending faults that uplift the Proterozoic–Lower Paleozoic in the Whitehall area into a ridge comparable to the Rocky Mountain front range. The narrow belt of autochthonous Cambrian–Ordovician shelf sedimentary rocks just east of Whitehall and the Champlain Canal is comparable in position to the Paleozoics of the Great Basin. These Cambrian–Ordovician shelf rocks are thrusted upon themselves on a fault comparable to the Champlain thrust in the Whitehall area has an analog in the Sevier belt of central Utah. Finally, the transport of slope and rise facies of the Taconic allochthon onto Laurentia in the Late Ordovician–Early Silurian is analogous to the history and facies of the Devonian–Carboniferous Antler orogen of central Nevada–Idaho (Figure 2). (modified from Landing, 2002, p. B6-2, B6-3).

A more detailed geological history should note that the east Laurentian Early Paleozoic margin had re-entrants and promontories formed by the later Ediacaran break-up of Rodinia. Either this break up took place along a series of triple junctions with the opening of the Iapetus Ocean or along a series of rift segments offset by transform faults (see review in Webster and Landing, 2016, p. 195, 196). By either explanation, the fragmented NE Laurentian margin has the Newfoundland and New York promontories, Quebec Reentrant, and the Pennsylvania Reentrant (Figure 1).

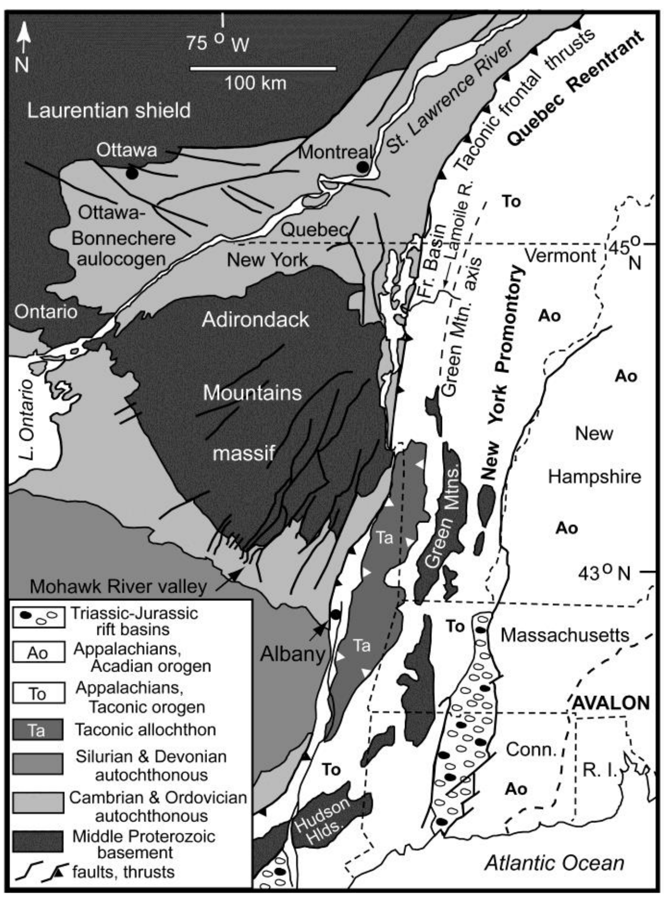

Figure 1. Geology of eastern New York and adjacent New England, Quebec, and Ontario. Figure emphasizes Ediacaran–earliest Cambrian rif features [active arms of Quebec Reentrant and New York Promontory and Ottawa–Bonnechere aulacogen failed arm] and from Mesozoic rifting that opened the Atlantic Ocean ["Trend of New York Bight" defined by SW- and E-trending active arms. North-trending failed arm formed Newark and Hartford basins]. Cretaceous coastal plain deposits of Long Island not shown. Modified from Hayman and Kidd (2002, fig. 1).

The rift–drift transition was late Early Cambrian (Landing, 2007, 2012; Landing et al., 2009, In press, Submitted), and is seen by a change from rift to shallow-marine sedimentary rocks in the Pinnacle Formation in NW Vermont (Cherichetti et al., 1998). Coeval feldspathic turbitites (Rensselaer and Bomoseen formations) are rift-related units further south (Figures 1, 2), where the rift–drift transition is marked by a change from the feldspathic sandstones of the Bomoseen into a muddy slope and rise. Coeval carbonates and siliciclastics were deposited on the slowly subsiding shelf. The passive margin ended with the Taconic orogeny and transport of slope–rise, trench-fill, and arc successions onto east Laurentia as the Taconian allochthons (Stop 5). This thrusting was accompanied by minor mafic volcanism, of which the Stark's Knob mélange block near Schuylerville village provided the first evidence of volcanism on a subducting plate (Landing et al., 2003B). The outer (northern or western) allochthon slices (Figure 2) are weakly metamorphosed and have a coherent stratigraphy and the only fossils in the overthrusts (e.g., Zen, 1972). These features preserve and allow regional correlation of macroscale alternations in slope mudstones (modified from Landing, 2002, p. B6-2).

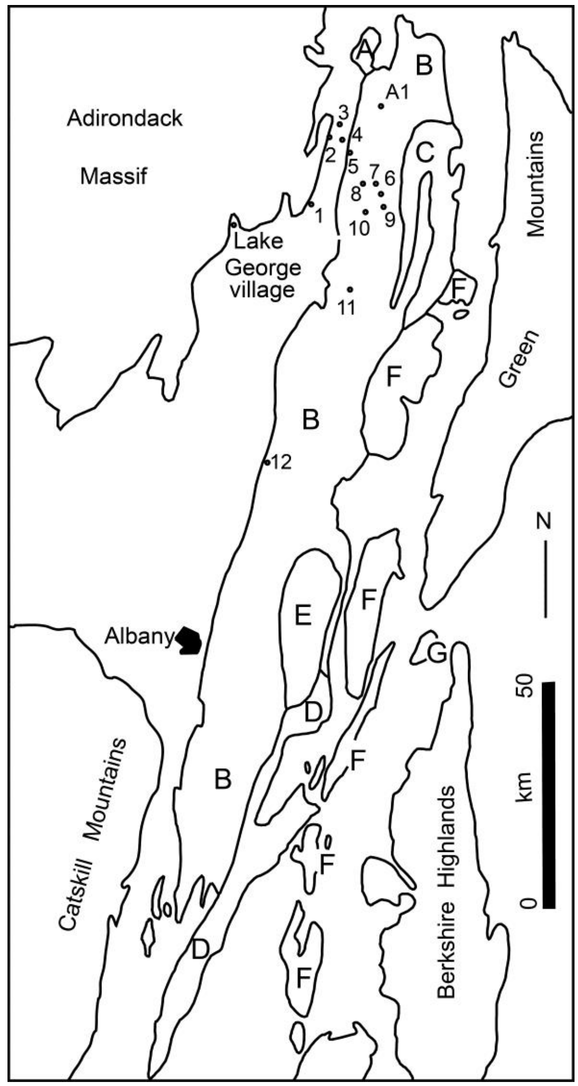

Figure 2— Generalized map showing Stops 1–12 and suggested Stop A1 at West Castleton (Appendix 1). Map shows succession of slices in the Taconic allochthon: A, Sunset Lake; B, Giddings Brook; C, Bird Mountain; D, Chatham; E, Rensselaer Plateau; F, Dorset Mountain–Everett; G, Greylock. Modified from Zen (1967).

MACRO- AND MESOSCALE COLOR ALTERNATIONS IN THE TACONIC SUCCESSION

Siliciclastic mudstone colors in many rock successions, as well as the slates in the Taconian allochthons from New Jersey to western Newfoundland, are a proxy for changes in sea level, in climate, and in relative oxygenation of the mid-water mass on the continental slope. Macroscale alternations of black and green-dominated siliceous mudstones in the Cambrian–Ordovician in the external slices of the Taconian allochthons of New York and Québec (Figure 3; Stops 9, 12) reflect paleo-oceanographic changes. These macroscale alternations are 0.5–10.0 m-thick intervals of black mudstone, commonly pyritic and with thin- to locally thick-bedded limestone, that can be correlated between the Taconian overthrusts from eastern Pennsylvania to western Newfoundland. In addition, biostratigraphic study of fossils from the black mudstone alternations also allows each black mudstone to be correlated with a formation-scale depositional sequence on the Laurentian platform (Landing et al., 1992; Landing 2002, 2012, 2013A, 2013B; Figure 3). Thus, the black mudstones of the Schaghticoke dysoxic/anoxic interval on the Taconian slope (Stop 12) can be confidently correlated with the Tribes Hill Formation on the east Laurentian shelf.

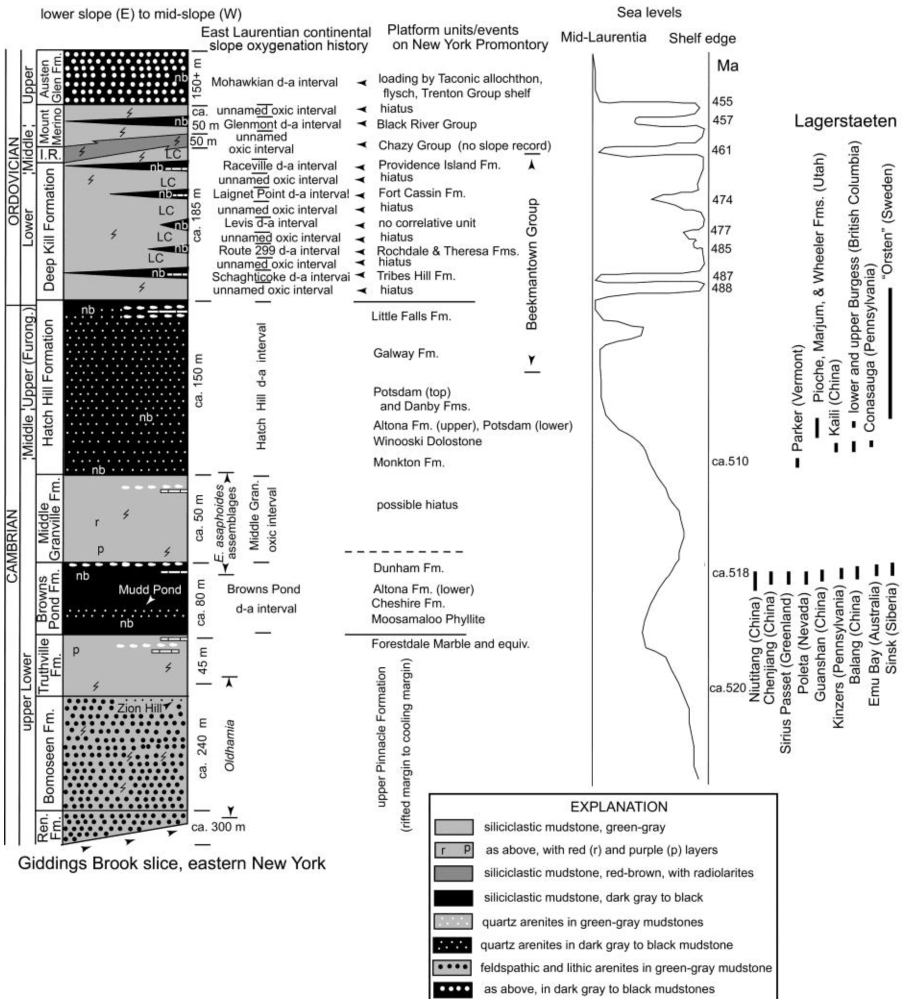

Figure 3. Stratigraphy of Giddings Brook slice, eastern New York–adjacent Vermont. Figure shows relationship of d/a black mudstones (Browns Pond and Hatch Hill formations and in Deep Kill Formation) and oxic slope facies to Laurentian shelf and global developments. After Landing (2012, fig. 1). "Ren." = Rensselaer Formation, which in the Giddings Brook slice is interbedded with the Bomoseen; d-a = dysoxic/anoxic; Gran., Granville. See stratigraphic nomenclature (Appendix 2)

Black organic-rich mud in the macroscale alternations was deposited on the upper and middle continental slope under a more intense and thicker dysaerobic to anoxic (d/a) slope water mass (Stops 6–10, 12). These d/a masses developed with sea-level rise, resultant climate amelioration (very warm "global hyperwarming" intervals), reduced oceanic circulation, and reduced srorminess with a decrease in latitudinal temperature gradients. Green (and purple and red) mud deposition reflect improved mid-water oxygenation, climate minima (icehouse/cool intervals), increased deep-water circulation; often have abundant sediment-surface and deep, probing traces; and very significantly, replace black mudstones in deeper waters of the lower continental slope (Landing and Benus, 1985; James and Stevens, 1986; James et al., 1988; Landing et al., 1992, 2002, 2007; Landing, 2007, 2012; Stop 6; Figure 4).

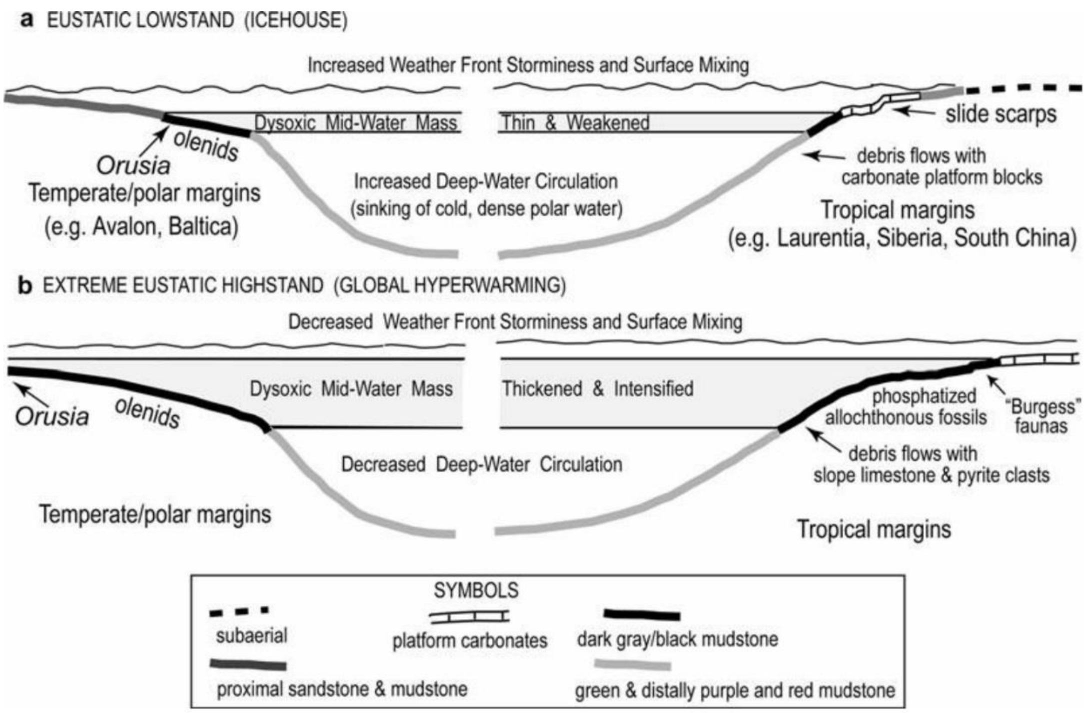

Figure 4. Global hyperwarming model for eustatic onlap (a) and offlap (b) litho- and biofacies patterns in tropical and higher latitude (respectively right and left sides of figures) paleocontinents in the Late Cambrian. Figure modified from Landing (2012, fig. 5).

Thin bedded limestones are characteristic in the black mudstones of macroscale alternations. They likely reflect, in part, off-shelf transport of carbonate from active and prograding carbonate platforms with sea-level rise and carbonate platform progradation, as well as with development of HST facies (Figure 4). However, the common occurrence of isolated to common carbonate nodules and amalgamated nodule beds that lack any fossil fragments or carbonate sand grains suggests that allochthonous (transported) carbonate is relatively insignificant as a component in the limestones in the black mudstones. Probably a much more important role in carbonate production was as a by-product of methanogenesis on the east Laurentian slope (e.g., Landing and Bartowski, 1996). Although black mudstones have relatively few trace fossils with low diversity, small sizes, and shallow penetration depths, the abundant trace fossils in green, purple, and red slates reflect higher bottom-water oxygen levels. Unfortunately, with exception of a limited number of reports (Landing et al., Submitted), trace fossils remain largely unstudied in the Taconian allochthons. The linkage of green and black mudstone deposition to sea-level fall and rise, respectively, and thus to shelf sequence stratigraphy, will be discussed on this trip.

The black mudstone and limestone intervals in macroscale alternations have supplied the majority of biostratigraphic information through the Taconic successions in NE Laurentia. This is because the limestones yield Cambrian macro- and microfaunas transported from the shelf margin (Landing and Bartowski, 1996; Landing et al., 2002; Landing et al., Submitted). Similarly, latest Cambrian–Ordovician black shales and limestones yield the majority of the graptolites (e.g., Ruedemann, 1902, 1903; Berry, 1960, 1962) and conodonts (Landing, 1976, 1977, 1993) known from the Taconic allochthons from New Jersey to western Newfoundland. Taconian black shale intervals are equated with unfavorable deep-ocean taphonomic conditions during global hyperwarming intervals—with higher preservation, and not higher production, of biologic materials transported into a deep-water environment largely devoid of larger organisms.

Although increased productivity of organic matter is commonly assumed as a way to produce organic-rich mudstones, there is no evident way in which organic productivity would significantly vary in the Cambrian–

Ordovician. Subaerial organisms were limited in this interval and there is apparently no way to have marine productivity change significantly through this time. Indeed, with exception of the terminal Ordovician (Hirnantian Stage), no evidence for significant Early Paleozoic glaciation exists (e.g., Landing and MacGabhann, 2010; Landing, 2011). What this suggests is that dense cold waters generated at high latitudes and that are often regarded as significant to the generation of high productivity zones by upwelling did not exist in the Early Paleozoic. Thus, increased preservation of organic-rich mudstones rather than changes in productivity is seen as controlling the appearance of black mudstones on the middle continental slope. In addition, black mudstones accumulated in warm epeiric seas with limited oxygen in solution. On this trip, epeiric sea deposits with an interval of dark gray to black shales (Van Wie Member of the Tribes Hill Formation on the east Laurentian platform) will be seen (Stop 4, Figure 7).

The macroscale color alternations reflect sea-level and climate changes with an estimated periodicity of 3–5 m.y. (Landing et al., 1992, 2007; Landing, 2002). Shorter duration climate cycles in the Milankovich band are recorded by asymmetrical, mesoscale Logan cycles in green-dominated Taconian mudstones (Stop 11, Figure 9). Logan cycles are up to 5 m-thick mesoscale alternations, which because they show an upward decrease in organic content and a corresponding upward increase in carbonate content, are redox cycles known through the Phanerozoic (Landing and Benus, 1985; Landing et al., 1992, 2007; Landing, 2012, 2013A, 2013B). The significant feature of the macro- and mesoscale color alternations in Taconic slates is that continental slope facies appear to be more sensitive to recording climate changes than adjacent carbonate platform facies. (modified from Landing, 2002, B6-1, B6-2).

Black, organic-rich mud in the macroscale alternations were deposited on the upper and middle continental slope under a more intense and thicker dysaerobic to anoxic (d/a) slope water mass (Stops 6–10, 12). These d/a masses developed with sea-level rise, resultant climate amelioration (very warm "global hyperwarming" intervals), reduced oceanic circulation, and reduced srorminess with a decrease in latitudinal temperature gradients. Green (and purple and red) mud deposition reflect improved mid-water oxygenation, climate minima (icehouse/cool intervals), increased deep-water circulation; often have abundant sediment-surface and deep, probing traces; and very significantly, replace black mudstones in deeper waters of the lower continental slope (Landing and Benus, 1985; James and Stevens, 1986; James et al., 1988; Landing et al., 1992, 2002, 2007; Landing, 2007, 2012; Stop 6; Figure 4).

ROAD LOG

Mileage

0.0 Depart Fort William Henry Resort parking lot. Turn right (South) onto Rte 9. Travel south on Rte 9 through village of Lake George kitsch. Small road cuts in Grenvillian Proterozoic gneiss at south end of village.
3.8 Intersection with Rte 149 at traffic light. Turn left (East).
5.3 At crest of low rise at south end of Proterozoic of French Mountain, note first view of high ridges in Taconic allochthon directly in front of vehicles.
6.5 Road sign shows vehicles are re-entering Adirondack Park.
8.0 Pass Queenbury Country Club on left. Underlying less resistant Cambrian–Lower Ordovician explains lack of relief.
8.9 Enter Washington County.
9.5 Low road cuts on left (North) in Grenvillian at south end of Sugar Loaf Proterozoic inlier.
10.5 Low road cuts in Grenvillian inlier east of Hadlock Pond fault.
13.1 Clear crest of hill and see spectacular view (if weather is clear) of N–S-trending ridges in Taconic allochthon across pastures developed on glacial outwash.
14.3 View to left (NE) of last (easternmost) ridge of Adirondacks east of Welch Hollow fault. East slope is nonconformity surface with lower Upper Cambrian Potsdam Formation eroded off.
14.8 Cross bridge over small creek with medium–massively bedded dolomitic limestone and hydrothermal replacement dolostone. The locally oolitic, thrombolitic, intraclast pebble facies exposed here are more suggestive of the Upper Cambrian Little Falls Formation, rather than the Lower Ordovician Tribes Hill Formation (e.g., "Fort Edward Dolostone" [abandoned by Landing, 2003, 2012) as mapped by Fisher, 1984).

16.4 Enter village of Fort Ann.
17.4 Turn N (left) at T-junction in Fort Ann onto Rte. 4.
19.4 Pass ca. 1.0 mile of roadcuts in Proterozoic Hague gneiss on block uplifted by Welch Hollow fault.
20.3 Stop on east side of highway just south of north exit of Flat Rock Road. Walk ca. 50 m N to Stop 1.

STOP 1: MIDDLE PROTEROZOIC–CAMBRIAN NONCONFORMITY AND RELATIONSHIP OF THIN LOWER PALEOZOIC SHELF SUCCESSION TO CONTINENTAL SLOPE OXYGENATION AND PALEOCLIMATE. (10 MINUTES) (Stop 2 of Landing 2002; Stop 1.5 of Landing et al., 2007)

The stop shows several meters of east-dipping, medium–coarse grained, slightly dolomitic, brownish-weathering quartz arenite of the Potsdam Formation (Keeseville Member) with a basal quartz pebble conglomerate nonconformably overlying middle Proterozoic Hague gneiss. We are about 7 m below an upper Middle Cambrian trilobite-bearing horizon higher in the Keeseville with *Crepicephalus*, *Komaspidella*, and *Lonchocephalus* (Flower, 1964, p. 156; Landing et al., 2007, Stop 1.4).

This photogenic locality records the absence of ca. 600 million years of Earth history at this planar nonconformity. Further north in the Lake Champlain lowlands as the south flank of the Ottawa-Bonnechere aulocogen (OBa) is approached, the non-fossiliferous, feldspathic, often fluviatile facies of the lower Potsdam Formation (Ausable Member) appears under the Keeseville (Figures 1, 3). The oldest Paleozoic unit on the Grenville orogen in the OBa of northeastern New York and Adjacent Quebec is the Altona Formation—a thin (to 84 m-thick) heterolithic unit under the Ausable that includes lower wave-deposited feldspathic sandstones and red mudstones and a higher subtidal red-mudstone and sandstone with hydrothermal dolostones (compare Landing et al., 2009, In press, with Lowe et al., 2017, 2018; Figure 3).

Stop 1 emphasizes that the Lower Paleozoic of the eastern New York shelf is very thin by comparison with Great Basin and southern Canadian Rockies sequences (i.e., 100s of meters vs. several thousand meters). The ridge crest to the east is capped by the upper Little Falls Formation and only ca. 200 m of upper Middle–Upper Cambrian overlies the Grenvillian basement. Thin Lower Paleozoic successions occur in this region of New York and Vermont due to its location on the slowly subsiding New York Promontory rift-margin of Laurentia (Thomas, 1977; Williams, 1978). For this reason, this passive margin can be expected to record Early Paleozoic eustatic changes as type 1 erosive sequence boundaries (e.g., Landing et al., 2003A). For example, the Cambrian–Ordovician boundary is a type 1 sequence boundary everywhere on the New York and western Vermont shelf and across most of the Laurentian platform except parts of the Great Basin and Southern Oklahoma aulacogen (Landing, 1988A; Landing et al., 1996, 2003, In press).

The *Crepicephalus* Chron (a "Chron" is the age of a biostratigraphic "Zone") is a time in the late Middle Cambrian in which epeiric seas covered almost all of Laurentia except for the Trans-Continental Arch (e.g., Lochman-Balk, 1971), as well as major parts of other paleocontinents. Such an interval of high eustatic levels and high global insolation would have corresponded to a time of global hyperwarming, to d/a conditions on the Laurentian continental slope (i.e., part of the Hatch Hill Formation; Figure 3), and the probability of off-shelf transport of Potsdam sands and their deposition as part of the Hatch Hill lithofacies as seen at Stop 7. (modified from Landing et al., 2007, p. 30)

20.3 At end of Stop 1, continue north to Whitehall. Rte 4 roughly follows a topographic break corresponding to the Proterozoic–Cambrian nonconformity.
21.7–23.6 Grenville gneiss and intersection with Rte 22 on right (east); road is now Rte 4 and 22 (combined). Road cuts along Rte 22 east of Comstock State Prison are important sections through conodont-, cephalopod-, trilobite-bearing Lower Ordovician Tribes Hill (="Great Meadows Formation", abandoned), Rochdale (="Fort Anne Formation", abandoned), and Fort Cassin formations (Landing et al., 1988B, 2003, 2012, Appendix 2).
24.0 Dip slope at 10–12 O'Clock is nonconformity surface on middle Proterozoic.
26.5 Hill directly in front (north) of vehicle is Skene Mountain in Whitehall. This rock under this hill corresponds to the entire terminal Middle–Upper Cambrian of the southern Lake Champlain Lowlands.
28.7 Enter Whitehall village.
29.3 At light in Whitehall, turn right (East) onto Rte 4. Drive across Champlain Canal and Wood Creek.

29.7 Rest stop at convenience store just before traffic light.
29.7 Turn left (north) at light onto William Street, drive through Whitehall village along the foot of Skene Mountain (Figure 5).
30.1 Stop sign, bear gently right (North) as William Street becomes North William Street.
30.2 Park next to bridge over lock on Champlain Canal. Stop 2 is the high road cut on the east side of North William Street.

STOP 2. POTSDAM FORMATION ROADCUT. (10 MINUTES).
(Stop 2 of Landing, 2002; Stop 2.1 of Landing et al., 2007)

Ca. 30 m of upper Potsdam (Keeseville Member) siliceous and dolomitic quartz arenite are exposed in the Whitehall area. Whitehall east of the Champlain Canal is on the Proterozoic, and the canal is cut in Potsdam sandstone (Figure 5). Herring-bone cross sets, dolomitic quartz arenite pebbles at the base of small channels/dunes, and U-shaped *Diplocraterion* burrows point to tide-influenced, high energy Potsdam facies at Stop 1. The upper Middle Cambrian Potsdam is overlain by lower Upper Cambrian dolomitic quartz arenites and quartzose dolostones of the Galway Formation higher on Skene Mountain (="Ticonderoga Formation," term abandoned, also mistakenly termed "Theresa Formation" in reports on eastern New York; Landing et al., 2003, In press). The top of Skene Mountain is upper, but not uppermost, Little Falls Formation limestone (Landing et al., 2010). (after Landing et al., 2007, p. 31)

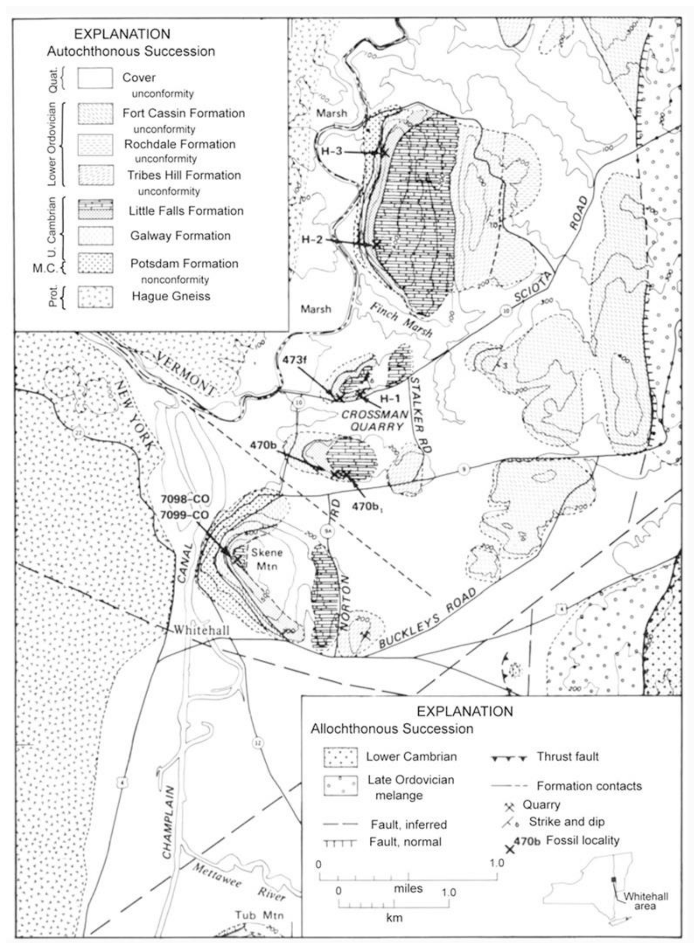

Figure 5. Geologic map of Whitehall area. Stop 2 is road cut at west base of Skene Mountain above; Stop 3, Crossman quarry; Stop 4, Rte 4 roadcut W of intersection with Buckleys Road. Contour interval 100 feet (ca. 30 m). Figure, stratigraphic nomenclature, and correlations modified from Taylor and Halley (1974, fig. 1).

30.2 At end of stop, continue north on North Williams Street; pass cuts in Potsdam Formation on the right.
30.6 Intersection with Doig Street (Washington Co. Rte 10) on left. Turn left (North).
31.2 Sharp turn to right (East); bear right on Washington Co. Rte 10.
31.6 Stop opposite old quarry on N side of Rte 10 or pull into track that enters middle of the quarry. Walk west ca. 40 m to white weathering, rounded road cut in massive dolostone at the base of the section. This cut will be inspected first, followed by a short walk to fallen blocks in the middle of the quarry, and finishing with a look at well preserved Upper Cambrian east Laurentian shelf facies at the east end of the quarry.

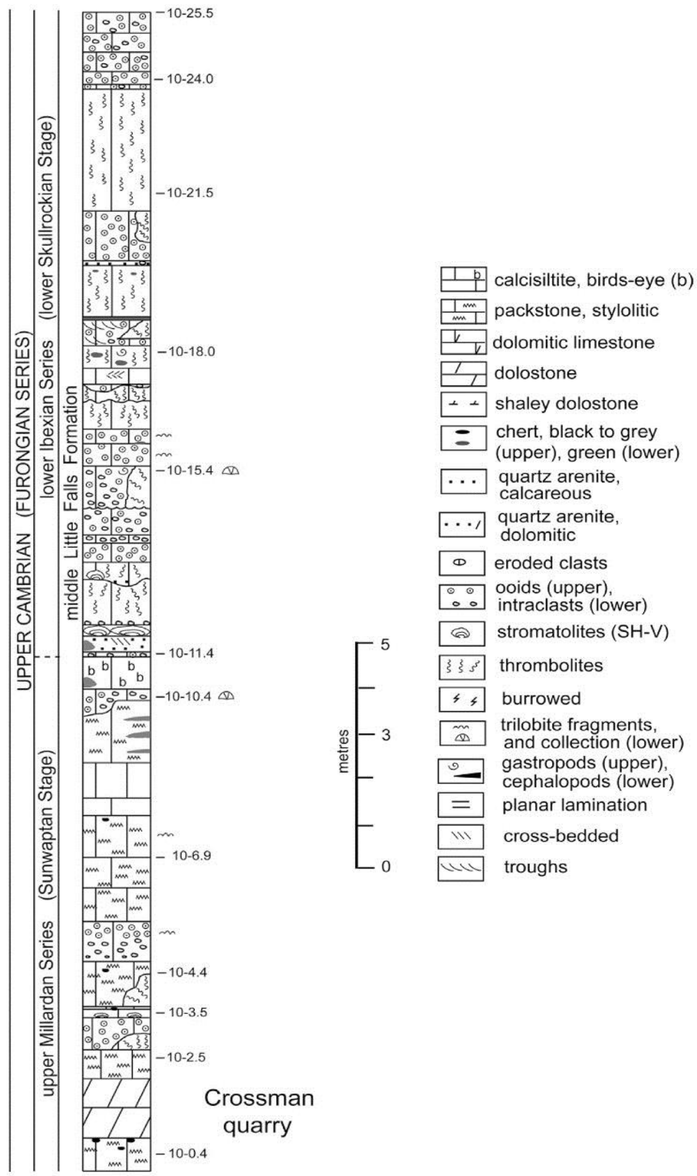

Figure 6. Cambrian stratigraphy at Stop 3 (Crossman quarry) just north of Washington County Rte 10. Conodont samples (meters above base of section) indicated by numbers to right of column (e.g., 10-10.4).

STOP 3. CROSSMAN QUARRY: UPPER CAMBRIAN LITTLE FALLS FORMATION. (20 MINUTES). (Stop 4 of Landing, 2007; Stop 2.3 of Landing et al., 2007)

NO HAMMERS! The eastern end of the quarry (Figure 5) shows ca. 18 m of medium- to massively bedded oolitic, stromatolitic, and thrombolitic limestones with 4 m of overlying calcareous quartz arenite. This shallow carbonate platform facies, represents Fisher's (1977) undefined "Warner Hill Limestone" member of the middle "Whitehall Formation" (abandoned designations). As commonly seen in Cambrian–Ordovician carbonate platform successions in eastern New York, hydrothermal dolomitization likely during the Late Ordovician Taconian orogeny has led to abrupt lateral and vertical changes from limestones with well preserved primary structures to dolostones without primary structures is seen in the Little Falls Formation at Stop 3 (see Collins-Wait and Lowenstein, 1994; Landing et al., 1996; Landing, 2007). The limestones are increasingly dolomitized with the loss of primary features in the western part of the quarry. In the western quarry, neomorphic dolostones predominate and have been termed the "Skene Dolostone"

(Wheeler, 1941) sensu Fisher (1977, 1984). These sucrosic "Skene" dolostones comprise the road cut opposite the western end of the quarry. Long term weathering of these dolostones yields buff-colored blocks that are present in the talus at the west end of Crossman quarry.

Well preserved primary carbonate structures appear in the middle part of the quarry. A photogenic block with a large, gray thrombolite capped by laminated thin, greenish weathering limestones with chert lenses and small SH-V stromatolites lies at the base of the cliff in mid-quarry.

A biostratigraphically important Late Cambrian trilobite assemblage appears ca. 3.5 m above the base of the eastern quarry wall (Taylor and Halley, 1974). A meter above this, the major trilobite replacement (biomere) that marks the Laurentian Upper, but not uppermost, Cambrian Sunwaptan Stage–Ibexian Series boundary is located at a lithofacies break that includes an intraclast pebble-ooid packstone bed (with the biomere boundary), an overlying quartz arenite, and a distinctive bed with SH-V and LLH-V stromatolites (Landing et al., 2010). Above this, a biofacies dominated by snails and other mollusks with rare trilobites and sparse euconodonts occurs in a thrombolite-dominated succession to the top of the quarry, and indicates a restricted, relatively near-shore environment (e.g., Westrop et al., 1995).

One purpose of Stop 3 is to show the lithology of non-dolomitized Upper Cambrian limestones of the Little Falls Limestone ("=Whitehall Formation," abandoned term; Landing et al., 2003A) for comparison with lithofacies of the overlying Tribes Hill Formation at Stop 4.

The second purpose of Stop 3 is to show the lithology of an extensive carbonate platform facies that extended in the Late Cambrian from eastern Laurentia and lenses out in coeval siliciclastic-dominated deposits of the Upper Mississippi Valley in western Wisconsin and Minnesota and passes west through the Black Hills and into western Laurentia. As the Late Cambrian was a time of particularly extensive epeiric seas and consequent global warming (e.g., Landing, 2010, 2011, 2012), it was also a time in which black shale deposits as those of the Hatch Hill Formation developed on the east Laurentian slope (Stop 7, 8). (modified from Landing, 2002, p. B6-7; Landing et al., 2007, p. 33, 34).

31.6 At end of Stop 4, continue east on Washington Co. Rte 10.

31.9 Intersection with Stalker Road, turn right (South). The first ridge to the east is the local top of the Cambrian–Ordovician passive margin carbonate platform (Middle Ordovician Providence Island Dolostone). A thrust relationship suggestive of the Champlain thrust further north brings the Potsdam Formation and younger Cambrian–Middle Ordovician units onto the Providence Island Dolostone. The second ridge to the east is the front of the Taconic allochthon, which overrides synorogenic, lower Upper Ordovician "Snake Hill Formation" flysch and Forbes Hill mélange (Fisher, 1984).

32.9 Stop sign at intersection with Washington Co. Rte. 9, turn right (West).

33.5 Intersection with Rte. 9a (Norton Road), turn left (south) on Norton Road and cross east end of Skene Mountain.

34.0 Intersection with Rte 4., turn left (East).

34.2 Stop at east end of high, whitish weathering road cut in Tribes Hill Formation. Although dominated by dolostone, this cut is only 0.3 km south on strike of identical, but non-dolomitized strata with well preserved primary depositional structures in the Tristates quarry (see Landing et al., 2003A; Kröger and Landing, 2007; for conodonts, trilobites, and cephalopods). Key stratigraphic divisions (Sprakers, Van Wie, and Wolf Hollow members) of the Tribes Hill Formation will be pointed out from the south side of Rte 4; only the uppermost Tribes Hill Formation (Canyon Road Member, highstand facies) is missing in the Rte 4 road cut, as well as in the Tristates quarry.

STOP 4. RTE. 4: LOWER ORDOVICIAN (UPPER LOWER TREMADOCIAN) TRIBES HILL FORMATION.
(20 Minutes)

This east-dipping section brackets most of the Tribes Hill Formation (="Great Meadows Formation," abandoned, of Fisher and Mazzulo, 1976, and "Spellman Formation," abandoned, of Fisher, 1968). Well preserved, dark grey limestones with primary structures in the Tristates quarry just 0.2 mi. to the north (see Landing, 2002, Stop 5; Landing et al., 2003), are replaced directly along strike by hydrothermal, whitish dolostones at Stop 4. As detailed by Landing et al. (1996, 2003a, 2012) and Landing and Westrop (2006), the Tribes Hill Formation, with a uniform succession of four lithologically distinctive members, can be recognized in outcrops over about 12,000 square kilometers from Dutchess County, SE New York, through the lower Mohawk River valley of east-central New York, and north through the Lake Champlain lowlands. Just north of the New York-Quebec line near Ste-Clotilde, the Tribes Hill Formation has been termed the "Ste-Clotilde Member" (Landing et al., In press).

With exception of the Great Basin and the Southern Oklahoma aulacogen, the Cambrian–Ordovician boundary is an unconformity across the Laurentian craton (Landing, 1988, 2012; Landing et al., In press). Early, but not earliest, Ordovician (i.e., late early Tremadocian) eustatic rise led to the Stonehenge transgression (Taylor et al., 1992) across Laurentia with carbonate platform deposits reaching the Upper Mississippi Valley (Oneota Dolostone) and the Rocky Mountains (e.g., Manitou Formation). These onlap units form a type 1 depositional sequence, are about the same age, and have *Rossodus manitouensis* Zone conodonts. This depositional sequence unconformity is the contact of the Upper Cambrian Little Falls Formation and Tribes Hill, with some localities showing channels up to 2.0 m deep that are filled with Upper Cambrian carbonate blocks (Landing et al., 2003A).

Figure 7. Stop 4: Hydrothermally dolomitized Tribes Hill Formation on north side of Rte 4 at the east end of the roadcut. Heavy black lines bracket Van Wie Member with regionally extensive storm beds (incraclast conglomerates) at base and middle of member and with thin gray shale laminae at this locality. Sprakers Member underlies Van Wie and Wolf Hollow overlies, Note massive thrombolites at top of section.

Rossodus manitouensis Zone conodonts have been recovered from most outcrops of the Schaghticoke d/a interval in continental slope sequences in NE Laurentia (e.g., Landing et al., 1986). This means that the extensive deposits of the Stonehenge transgression correspond to intense continental slope d/a conditions, as would be expected by the global hyperwarming model (Figures 3, 4).

The three lower members of the Tribes Hill Formation are exposed at Stop 4 (Figure 7). These include the thinner bedded, silty, locally intraclast-rich limestones (now dolomitized) of the Sprakers Member (which includes Fisher and Mazullo's, 1976, "Winchell Creek Siltstone," abandoned).

The most interesting unit of the Tribes Hill is the Van Wie Member. Although the Van Wie is never more than about 1.5 m in thickness, it occurs throughout the outcrop belt of the Tribes Hill. In all sections where it is exposed, it invariably has a basal intraclast conglomerate (to 25 cm in thickness) and a middle, thinner intraclast bed. These beds are perfect time-markers and seem to represent major storm beds in a time when dark shale appears in the Tribes Hill Formation. The Van Wie Member is composed only of black shale to the south in Dutchess County (Landing et al., 2003A). To the north and west, the shale lightens and has more limestone/dolomitized limestone beds (e.g., Landing et al., 1996), as at Stop 4. This presence of organic rich shale and the indication of d/a conditions on the NE Laurentian shelf also corresponds to the global hyperwarming model which predicts increased preservation (not increased production) of organic material in hot, oxygen-poor epeiric seas.

The Wolf Hollow Member (Fisher, 1954; = "Fort Edward Dolostone member" of Fisher and Mazullo, 1976; ="Kingsbury Limestone," abandoned of Fisher, 1984, Appendix 2) occurs above the Van Wie at the Rte 4 cut and is characterized by massive thrombolite buildups in all outcrop areas of the Tribes Hill Formation. These huge thrombolites can be seen in the upper part of the Rte 4 cut.

The highstand facies of the Tribes Hill is the Canyon Road Member (Landing et al., 1996). The Canyon Road features lower ooid wackestones and mollusk-rich carbonates above the Wolf Hollow thrombolites. Higher strata include sparsely fossiliferous carbonates with planar stromatolites and molds of gypsum and anhydrite crystals and nodules of the upper Canyon Road Member. However, the Canyon Road is absent in the Rte 4 and nearby Tristates quarry sections (Figure 5).

34.2 At end of Stop 4, continue east on Rte 4 across the railroad tracks. The low ridge in front of the vehicles is the front of the Taconic overthrust.
34.7 Turn right at Y-intersection at Fort Anne Antiques store onto County Rte 18, Pass cemetery on right which is on Taconic mélange under the Taconic master thrust.
36.2 Note low brownish outcrops on left (north) side of road. Stop on right side of road at top of low hill.

STOP 5. TACONIC OVERTHRUST. (10 MINUTES).

NO HAMMERS! This is primarily a stop for geological perspective as well as one of the best localities to photograph the base of the Taconic master thrust.

The sheared brownish sandstone at the east end of the roadcut is the upper Lower Cambrian Bomoseen Formation, which here forms the westernmost edge of the Giddings Brook slice. The ca. 2.0 m of thin-bedded, gray weathering, dark gray, fossiliferous limestone under the Bomoseen is a block of Upper Ordovician Glen Falls Limestone (Trenton Group, global Katian Stage) in what has been called the Forbes Hill mélange (Zen, 1961; Fisher, 1984).

A look to the west shows just how "compact" the geology of eastern New York is (Figure 1). As noted above, the Proterozoic basement of the Adirondack Mountains massif is analogous to the Black Hills in South Dakota; the block faulted, uplifted Proterozoic–Ordovician shelf succession in the southern Lake Champlain lowlands to the front of the Rocky Mountains; and the Taconic overthrust succession to the Nevada thrust belt.

36.2 At end of stop, continue east on County Rte. 18.
37.7 At four-way stop in hamlet of East Whitehall, turn right (South) on Co. Rte. 21. The cross road is in the Upper Cambrian part of the Hatch Hill Formation, with EL having found disarticulated olenid trilobites in a thin limestone bed on the east side of Rte. 21. This trilobite locality is ca. 50 m North of the intersection. After the intersection, drive South on strike along roadcuts in interbedded black shale and reddish (pyritic and dolomitic) weathering sandstone of anoxic/highly dysoxic Hatch Hill Formation (upper Lower Cambrian–lowest Ordovician).
38.8 After crossing creek at curve in road, pass more Hatch Hill Formation in road cut on right. After this point, the road swings east and crosses a large westerly overturned syncline in the Giddings Brook slice.
39.3 Greenish gray roadcut of Lower Ordovician Deep Kill Formation ("Poultney Formation" in many reports, abandoned designation, Landing, 2012).
40.5 At "sudden" Y-intersection, turn right (South) onto Holcombville Road. Drive south past low road cuts in black slates and thin sandsones in east-dipping, OVERTURNED upper Lower Cambrian Browns Pond Formation.
41.0 Overlook of Browns Pond to south.
41.5 Pass low roadcuts on east and west sides of Holcombville Road. These overgrown cuts comprise the upper part of the type section of the Browns Pond Formation of Kidd et al. *in* Fisher (1984), The southerly cut on the east side of the road includes black shale with thin, laminated sandstones that are almost devoid of fossils with exception of a large looping epichnial trace fossil. The northerly cut on the west side of the road

is a carbonate clast debris flow (Holcombville Member of Landing et al., Submitted) that forms the top of the Browns Pond Formation from Washington Co. to Dutchess County 160 km to the south. The pasture further west is underlain by slaty green mudstones of the Middle Granville Formation. These strata (Stop 3B and 3C of Rowley et al. (1979), Stop 8 of Landing, 2002, Stop 6.2 of Landing et al., 2007) will be better seen at Stop 6.

42.0 Stop at entrance to small newly reactivated quarry on west side of road. This stop consists of two parts. Do not descend into the quarry.

A sharp black–green mudstone transition (Browns Pond–Middle Granville formation contact; see Figure 3) is exposed at the top of the steep ramp that descends into the quarry. The Holcombville Member consists of thin limestones interbedded with black shale and capped by a massive calcareous sandstone debris flow at the top of the ramp. These strata are replaced ca. 50 m north along strike by fossiliferous, bedded turbiditic limestones that show fracturing and incipient transition into a debris flow.

The second part of this stop is an examination of the abundant trace fossils in oxic facies of the Middle Granville Formation. Bedding surfaces of the Middle Granville Formation are present on large blocks of green and red slate at the south end of the Holcombville quarry and in the hillock of scrap slate on the east side of the road. These bedding surfaces occur because of the local bedding plane-parallel cleavage. These bedding surfaces are crowded with shallow trace fossils that range up to several centimeters in diameter.

STOP 6. LATE EARLY CAMBRIAN ANOXIC–OXIC–ANOXIC MACROSCALE ALTERNATIONS.
(30 MINUTES).
(Stops 6A and 6B of Landing et al., 2007)

Browns Pond Formation and Holcombville Member

The Holcombville Road quarry is an overturned section. It begins with 2.0 m of black siliciclastic mudstones with light gray, nodular lime mudstones. The black mudstones are capped by a 30–40 cm-thick, white weathering, light gray, conglomeratic pack- to grainstone composed of limestone sand–small intraclast pebbles and trilobite fragments with black phosphatic sand grains.

This ca. 2.4 m of section is the type locality of the Holcombville Member of the Browns Pond Formation (proposed in Landing et al., Submitted). This is the top of the Browns Pond Formation and the end of the late Early Cambrian Browns Pond d/a macroscale interval on the east Laurentian continental slope (Landing and Bartowski, 1996; Figure 3). The 30–40 cm-thick limestone thickens to 2.0 m about 50 m to the north where weathered cracks on the top surface of the unit show initial fracturing and formation of a debris flow. Micro- and macrofaunal elements of the lower *Elliptocephala asaphoides* assemblage (Lochman, 1956; Bird and Rasetti, 1968; Landing and Bartowski, 1996) occur in this top member of the Browns Pond Formation (E. Landing and M. Webster, unpub. data).

Middle Granville Formation

A very abrupt change into the gray-green mudstones of the Middle Granville Formation takes place right at the top of the 30–40 cm-thick limestone clast debris flow. The lower part of this greenish macroscale interval formed by the Middle Granville Formation has several beds of nodular lime mudstone. A thin limestone clast debris flow (less than 1.0 m-thick), which may be visible if the water level is low, is composed of slumped fragments of these nodular limestones. All of the thin Middle Granville Slate is exposed in the quarry. Several beds of purple slate in the Middle Granville Formation are present higher in the quarry.

Hatch Hill Formation.

A transitional interval from the Middle Granville Formation into the Hatch Hill Formation is seen in the west wall of the quarry, where the Middle Granville changes color into a grayish hue. Black, pyritiferous mudstones of the lower Hatch Hill Formation [i.e., the Hatch Hill interval, or terminal Lower Cambrian–lowest Ordovician dysoxic/anoxic macroscale interval (Landing *et al*., 2002)] appear ca. 5 m higher. Finally, beds of dolomitic quartz arenite characteristic of the Hatch Hill Formation are found not more than 10 m stratigraphically above the west wall of the quarry.

Middle Granville Slate and Middle Granville oxic interval (MGOI) (15 minutes)

Trace fossils Trace fossils are abundant in the red and green mudstones of the Middle Granville Formation. The crude retaining wall composed of large slate slabs at the south end of the Holcombville Road quarry and the large large pile of brownish red and minor green slate on the east side of the road came from the Holcombville Road quarry.

If the light is good, dense *Planolites* and large grazing traces up to 2 cm-wide can be seen on many of the bedding plane-parallel cleavage surfaces of the green and reddish slate. The abundance of burrows, which led to the general absence of primary depositional structures in the slate, and its reddish color (produced by traces of ferric iron) are consistent with deposition of the Middle Granville Slate under a more oxygenated slope-water mass than the underlying Browns Pond Formation. Evidence for skeletalized metazoans is not present in the reddish, purple, and green mudstones of the Middle Granville Formation. Either these metazoans were not present on the bottom, or their calcareous remains were dissolved away during diagenesis.

MGOI Landing *et al*. (2002) noted that the uppermost Lower Cambrian (upper but not uppermost *Olenellus* Zone) on the New York and Québec portions of the eastern Laurentian slope is composed of red and green siliciclastic mudstones. Unfortunately, Landing (2007, also Landing et al., 2007) equated this interval of improved oxygenation of slope waters with the presumed lowered sea-levels, cooler climates, and deeper circulation of oxygenated surface waters during Palmer and James' (1971) Hawke Bay regression. Subsequent sea-level rise and the re-establishment of dysaerobic slope facies (e.g., Hatch Hill Formation and Hatch Hill dysoxic/anoxic interval) took place in the terminal Early Cambrian (Landing et al., 2002).

This interpretation has been re-evaluated with the obvious fact that the lower *Elliptocephals asaphoides* assemblage of the upper Browns Pond and Middle Granville formations is not terminal Lower Cambrian (upper Dyeran Stage in Laurentia) but is best regarded as middle Dyeran. Thus, it is older than the "Hawke Bay regression" and the improved slope oxygenation represented by the Middle Granville Formation is now called the Middle Granville Oxic Interval (MGOI, Landing et al., Submitted; Figure 3). In the course of this re-evaluation, Landing et al. (Submitted) questioned the existence of a global "Hawke Bay regressive interval," restricted the "Hawke Bay" to its type area in NE Laurentia, and regarded it as epeirogenic in origin. They concluded that units such as the Hatch Hill Formation really reflect shore-line derived sand transport from Laurentia at a time of slowly rising sea levels that led to a global hyperwarming interval. In short, Early–Middle Cambrian boundary interval eustatic rise and climate amelioration led the development of a poorly oxygenated (hot) continental shelf in such widely separated areas as northern Vermont (Parker Slate) and eastern California (Mule Springs Formation) (Landing and Bartowski, 1996). (text modified from Landing et al., 2007, p. 64)

42.0 At end of stop, turn around and go north on Holcombville Road.
43.0 Turn left (west) onto Tanner Hill Road.
43.5 Park just before (east of) lowest exposed rocks on right (north) side of road. Walk uphill and examine east dipping (overturned) section in core of large syncline. Walk through section in Hatch Hill, Deep Kill, Indian River, and Mount Merino formations (Figure 3). Stop 7 ends just west of hill crest with re-appearance of Indian River Formation red mudstones on west limb of syncline.

STOP 7. TANNER HILL ROAD: HATCH HILL D/ INTERVAL (LATE EARLY CAMBRIAN–EARLIEST ORDOVICIAN) THROUGH EARLY LATE ORDOVICIAN PALEOOCEANOGRAPHIC CHANGES ON THE EAST LAURENTIAN SLOPE
(30 MINUTES).
(Stops 6A and 6B of Landing et al., 2007)

Hatch Hill Formation deposition.
Dolomitic quartz arenites; conglomeratic sandstones; and interbedded, minor dark gray and black siltstones and shales of the Hatch Hill Formation form the lowest part of the section. (Remember that the section is overturned.) The medium- to massively bedded, coarse, lensing, conglomeratic sandstones and conglomerates of the lowest part of this interval have typically been compared to submarine channel-fill deposits in reports on Taconic geology (e.g. Keith and Friedman, 1977, 1978; Friedman, 1979; *Rowley et*

al., 1979). However, significant erosion at the base of purported channels and vertical stratigraphic successions characteristic of channels have never been described in the Taconic regions. These coarse-grained sandstones and conglomerates may simply be sand- and debris-sheets that originated at many places along the shelf–slope break and upper slope, and not from a persistent point source (submarine canyon head).

The sandstones of the Hatch Hill Formation become thinner-bedded and finer-grained higher in the section, and black mudstones become dominant. This entire interval with black mudstones up to an abrupt transition into the green-gray mudstones of the overlying Deep Kill Formation is the Hatch Hill Formation. The Hatch Hill records a long interval of persistent dysaerobic deposition on the east Laurentian continental slope (terminal Early Cambrian–lowest Ordovician [lowest Tremadocian] Hatch Hill dysoxic/anoxic interval) (see Landing, 1993; Landing *et al*., 2002).

However, the changes in relative oxygenation of slope waters through this long interval are admittedly poorly known at present. Indeed, the development of three important Upper Cambrian "Grand Cycles" on the northeastern Laurentian shelf (Chow and James, 1987) should have been accompanied by sea-level and climate fluctuations recorded by changes in relative oxygenation on the continental slope. One explanation for the lack of any apparent record for changes in relative oxygenation through this interval may be that the transport and deposition of the thick sandstones that characterize the lower Hatch Hill served to erode and obscure much of the record of relative oxygenation that is recorded elsewhere in the Taconic succession by mudstones of various colors. Even with a maximum estimated thickness of 200 m (Rowley et al., 1979), the 20 m.y. interval bracketed by the Hatch Hill Formation indicates that it is a condensed unit that may have a number of unconformities produced during the transport and deposition of thick sand sheets. These sand sheets may have been emplaced primarily during eustatic lows.

Sandstones disappear in the upper Hatch Hill in the Tanner Hill section. The upper Hatch Hill corresponds to the interval of earliest Ordovician d/a mudstone deposition that has been termed "Poultney A" (abandoned designation, Landing, 1988b) by Theokritoff (1959; Zen 1964).

Deep Kill Formation.

A sharp transition from the Hatch Hill Formation into the overlying green-gray mudstones of the Deep Kill Formation is present in the drainage ditch on the north side of Tanner Hill Road. Limited outcrop of the Deep Kill Formation likely explains the apparent absence of the black mudstone-limestone mesoscale intervals characteristic elsewhere of the formation (Figure 3).

Indian River Formation

The transition into the lowest synorogenic sediments of the Taconic allochthon is observable just west of the crest of the hill with the appearance of low outcrops of the red, thin (ca. 50 m) Indian River Slate. Fisher (1961) attributed the red color of the Indian River to off-slope transport of lateritic sediments produced on the platform during development of the Knox unconformity. However, the rapid development of bacterial films on sediment grains with their transport into marine regimes regularly leads during early burial to a grayish sediment color, and an alternative explanation for the color of the Indian River must be found.

Landing (1988b) noted three lines of evidence in proposing that the Indian River reflects very slow deposition on an oxygenated sea-floor and long sediment residence time at the sediment-water interface. These lines of evidence include: 1) occurrence of radiolarian cherts and thin volcanic ashes undiluted by background argillaceous sediment; 2) thorough burrow-homogenization of much of the unit; and 3) presence of large, up to 3 cm-wide burrowers that were active on a well-oxygenated bottom).

Indian River Formation: oldest synorogenic deposit of Taconic orogeny and its age

The cherty, red slaty mudstones of the Indian River Slate mark an important stage early in the Taconic orogeny. Landing et al. (1992) discussed comparable red mudstones in a number of orogens, where they always underlie green mudstones and higher flysch (e.g., Taconian allochthons from New York to western Newfoundland, southern Uplands of Scotland, Hercynian Rheinisches Schiefergebirge and Harz Mountains, and Jurassic of Japan).

These data suggest that red, cherty, oxygenated shales in collisional orogens reflect the following history: 1) passage of a peripheral bulge through passive margin successions; 2) consequent flexural uplift and restriction of sedimentation on the peripheral bulge to slowly deposited pelagic muds, radiolarian cherts, and thin volcanic ashes of the Indian River-type; and 4) final flexural down-warping and increased rates of deposition as sediment provenance changes to the emergent accretionary prism (initial cherty green mudstones of Mount Merino-type and overlying Austin Glen flysch). The transition into the green-dominated, synorogenic mudstones of the overlying Mount Merino and then into Austin Glen Formation flysch are present in the core of the Tanner Hill syncline north of the road.

The interpretation of the Indian River Formation as reflecting the first indication of the Taconian orogeny in continental slope facies seems also to explain why its color (red and minor green) is so distinct from other continental slope mudstones in the Taconics (Figure 3). Rather than being part of the "standard" black or green macroscale alternations that reflect eustatic and climate change by the hyperwarming model, the red color of this apparently condensed unit and presence of volcanic ashes suggest depositional controls associated with advance of the Taconic arc toward the Laurentian margin.

The age of the Indian River Formation can only be approximated because biostratigraphically useful fossils (e.g., graptolites, conodonts) have not been recovered from it—although it is possible that the radiolarians in the cherts (Ruedemann and Wilson, 1936) might allow correlation of the unit. Geochronologic dating of the ashes is certainly possible, although it has not been done.

The Indian River is likely upper Middle Ordovician (Darriwillian Stage). It is underlain by lower Middle Ordovician rocks (upper Dapingian Stage) of the Deep Kill Formation (Landing, 1976) and overlain by the lower Upper Ordovician (lower Sandbian Stage) Mount Merino Formation with *Nemagraptus gracilis* Zone graptolites (e.g., Berry, 1962).

44.0 End of Stop 7 is just west of hill crest, drive west on Tanner Hill Road.
44.5 Park on side of Tanner Hill Road at curve opposite intersection with unpaved road on left. Stop 8 is the black mudstone-rich road cut to the south.

STOP 8. CAMBRIAN–ORDOVICIAN BOUNDARY INTERVAL IN DYSOXIC/ANOXIC HATCH HILL FORMATION
(20 MINUTES)
(Stop 6.4 of Landing et al., 2007)

Graptolite and conodont biostratigraphy

As discussed above, the Cambrian–Ordovician boundary is a type 1 sequence boundary/unconformity across most of the Laurentian craton. However, stratigraphically unbroken Cambrian–Ordovician boundary intervals occur in successions marginal to NE Laurentia. This is the case in the upper Hatch Hill Formation in northern and southern localities in the Taconic allochthon (Landing, 1993). An understanding of the Cambrian–Ordovician boundary interval in the Taconics came from a re-examination of three supposed "Upper Cambrian" dendroid graptolite genera that had been repeatedly cited from Stop 8 (Berry, 1959, 1961; Bird and Rasetti, 1968; Fisher, 1984).

Examination of these specimens in the NYSM Paleontology Collection showed the assemblage was not Upper Cambrian because it is comprised exclusively of rhabdosomes of the earliest Tremadocian form *Rhabdinopora flabelliformis praeparabola* Erdtmann, 1982 (Landing, 1993). This monospecific, lowest Tremadocian dendroid assemblage was relocated in a shaly interval (42.9–43.4 m) near the top of this cut on Tanner Hill Road (Figure 22). Twelve samples were processed for conodonts, but only a sample at 22.8 m yielded conodont elements—an upper Sunwaptan Stage fauna [*Eoconodontus notchpeakensis* Zone with *E.* (*E.*) *alisoniae* Landing, 1983; *E.* (*E.*) *notchpeakensis* (Miller, 1969); *Proconodontus muelleri* Miller, 1969]. These limited biostratigraphic data indicate that the base of the Ordovician lies in the interval 22.8 to 42.9 m, an interval without any evident stratigraphic break or lithofacies change (Figure 8).

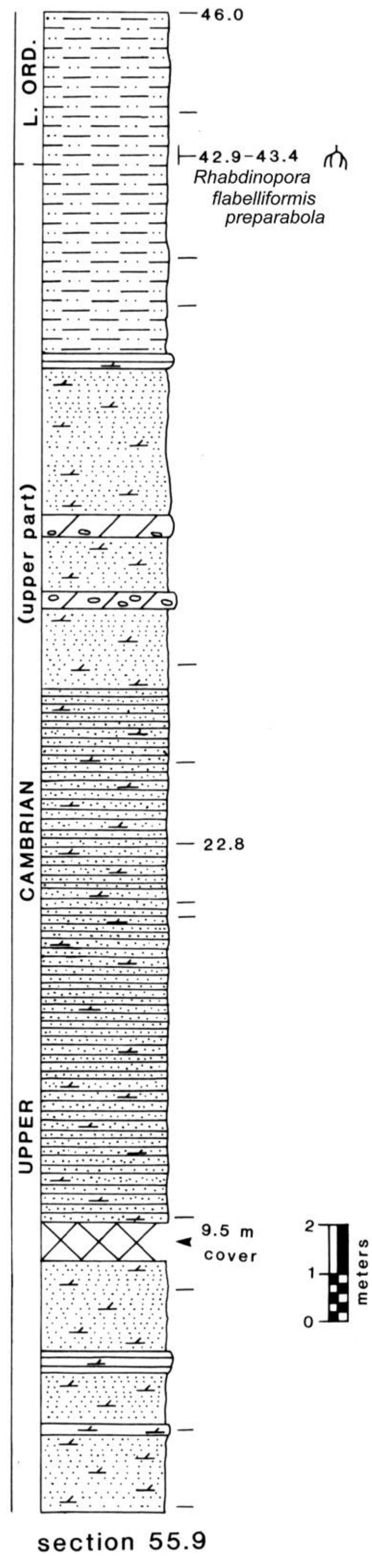

Figure 8. Cambrian–Ordovician boundary at Stop 8

Lithostratigraphy and regional comparisons

The Stop 8 succession in the upper Hatch Hill Formation is dominated by thin- to medium-bedded dolomitic quartz arenites and dark gray silt shales with debris flows with pebble-sized dolomitic sandstone clasts. By comparison, bedded limestones and carbonate clast debris flows dominate the Cambrian–Ordovician boundary interval at a locality approximately 160 km south in the southern Taconics near Hudson, New York (Landing, 1993). As in the late Early Cambrian (Landing and Bartowski, 1996), southern localities in the Giddings Brook thrust seem to have occupied a somewhat higher position on the continental slope and have more prominent bedded limestones and carbonate clast debris flows (Landing, 1993).

The presence of black mudstones of the Hatch Hill d/a interval through the boundary interval obviously does not seem to follow the global hyperwarming model. Perhaps the explanation lies with erosion of boundary interval strata across most of the Laurentian craton with eustatic fall that was not latest Cambrian but earliest Ordovician.

44.5 At end of Stop 8, reverse vehicles and drive back to Holcombville Road.

45.5 Intersection with Holcombville Road, turn right (south).
47.5 Intersection with DeKalb Road, turn left (east).
48.5 Intersection with Steel Bridge Road, turn right (south).
49.0 Intersection with Rte 22A, make hard left onto dangerous curve.
49.5 Cross Mettawee River.
50.0 Drive by Stop 9, a high roadcut on left side of Rte. 22A.
50.25 Turn right on asphalt road (Butler Road) and park. Walk back to Stop 9.

STOP 9. RACEVILLE: EARLY MIDDLE ORDOVICIAN DYSOXIC/ANOXIC INTERVAL
(15 MINUTES)
(Stop 11 of Landing, 2002)

This vertically dipping section shows a black mudstone-limestone, d/a macroscale alternation in the lower (northern) part of the section and overlying greenish-gray, siliciclastic mudstone without limestone intercalations. The ca. 2 m-thick interval of interbedded limestone and black mudstone is repeated three times in the northern half of the roadcut with the northernmost and central repetitions comprising a faulted antiform and the southern repetition fault bounded.

Most of the limestone in the lower part of the section consists of fine-grained, argillaceous lime mudstones that appears to have resulted from diagenetic remobilization of fine-grained carbonate and/or methanogenic production of nodular diagenetic carbonate. Acid dissolution of these limestones yields conodonts (e.g., *Histiodella* species) indicative of the highest (lower Middle Ordovician, lower Whiterockian) black mudstone-limestone macroscale alternation of the Deep Kill Formation (Landing et al., 1992; Landing, 2012; Figure 3). The climate maximum, eustatic high, and resultant interval of intensified dysaerobic slope water recorded by the Raceville cut is equated with earliest Middle Ordovician (Whiterockian) eustatic rise across Laurentia and with deposition of such units as the Providence Island Dolostone (Figure 3). (modified from Landing, 2002, p. B6-14)

50.25 At end of Stop 9, walk back to Butler Road parking area. Return south on Rte 22A.
53.0 Enter Middle Granville.
56.0 Intersection with Rte 22, turn right (NW) on Rte 22.
59.0 Enter village of North Granville.
59.25 Turn right (north) onto Upper Turnpike at general store in North Granville.
59.5 Cross single lane bridge on Mettawee River; park immediately north of the bridge. Walk east for ca. 0.6 km on dirt track that follows the Mettawee River. Descend to river bank at east side of ruins of a small mill(?) foundation. Stop 10 features an overturned (east-dipping), almost completely exposed section from the base of the Middle Granville through the Browns Pond Formation and down into the upper Bomoseen Formation.

STOP 10. BEST EXPOSED TACONIC SECTION: BROWNS POND AND BOMOSEEN FORMATIONS ON METTAWEE RIVER
(90 MINUTES)
(Stop 5A of Rowley et al., 1979)

Overview

An exception to the limited outcrops typical of the Taconics is the almost completely exposed succession that extends along the Mettawee River. This is an overturned (ca. 30° E) Cambrian–Ordovician succession in the Giddings Brook slice (Jacobi, 1977; Rowley et al., 1979). It was measured stratigraphically downward (i.e., upstream) from a horizon low in the Middle Granville Formation. Sample horizons are recorded as meters below the top of the section (e.g., Mett-neg 29.0; Figure 9).

The Lower Cambrian (Bomoseen–base of Middle Granville formations; Figure 9) extends upstream from the falls over the Bomoseen Formation to 0.6 km east of the Upper Turnpike bridge. The Mettawee River section is on the SE margin of Theokritoff's (1964) map area, but he mapped the interval between the Bomoseen and Hatch Hill formations as green and purple green slates, although an intervening black slate unit is prominent in this interval (Figure 3). Subsequently, Jacobi (1977; also Rowley et al., 1979) mapped this unit of black siliciclastic mudstone and limestone within the Bomoseen–Hatch Hill interval.

This black unit is the Browns Pond Formation (Jacobi, 1977; Kidd et al. *in* Fisher, 1984). Recognition of the Browns Pond Formation as distinct from the lithologically similar, higher Hatch Hill is important for mapping purposes (Rowley et al, 1979; Fisher, 1984) and demonstrates that the two formations represent temporally distinct intervals of strong d/a on the east Laurentian continental slope. This has implications for regional and global geological and climatic history (Landing, 2000, 2007, 2012; 2013A, B).

The Mettawee River section received little early paleontological attention. Walcott (1912, p. 188, USNM locality 21a) reported a linguloid brachiopod and trilobites he identified as "*Olenellus*?", "*Ptychoparia* sp.", and "*Microdiscus connexus* (Walcott)" from a "limestone below the first fall of Mettawee River, above the North Granville bridge…" but did not illustrate the specimens and gave limited provenance information. Without modern study, Walcott's (1912) identifications only indicate a Laurentian late Early Cambrian (Waucoban) age. This fauna could have come from any Lower Cambrian unit in the section as high as the lower Hatch Hill Formation (Figure 3).

The turbiditic limestones and thin debris flows at the top of the Browns Pond Formation (Holcombville Member of Landing et al., Submitted) earlier yielded the oldest acid-resistant microfossils from the southern Taconic allochthon (Landing and Bartowski, 1996). This suggested that older limestones and calcareous clast debris flows exposed through the Browns Pond and extending down into the upper Truthville Formation (Figures 3, 9) on the Mettawee River might have biostratigraphically significant faunas that could provide an upper age bracket on the origin of the east Laurentian passive margin in offshore facies, and also a bracket on the earliest d/a interval on the east Laurentian continental slope.

Lithofacies and sediment provenance

Most of the Browns Pond and Truthville formations on Mettawee River are a low energy facies of planar laminated mudstone and scattered mm-thick sandstones. The succession demonstrates for the first time that the Browns Pond is dominated by thin (cm- to several mm-thick), argillaceous lime mudstone-rich distal turbidites that may have sand- to rare granule-sized clasts of black lime mudstone. A near lack of trace fossils in the Browns Pond (noted below; also Landing, 2012) suggests the substrate was low in oxygen and metazoans were probably rare. The most abundant body fossils are echinoderm sclerites that comprise a few thin lenses and small ripples (to 1 cm-high) and were likely washed off the east Laurentian shelf or upper slope (horizons Mett-neg 112.5; -neg 62.5, -neg 28.5; Figure 9).

Decollement surfaces in the middle Browns Pond (Figure 9) suggest rapid deposition and easterly transport of weakly compacted mudstone. Weak compaction, soft mud at the sediment–water interface, and low oxygen bottom waters that led to black, organic-rich mud deposition (Landing, 2012) with locally abundant pyrite (Figure 9) suggest that Browns Pond and Truthville shelly fossils are allochthonous (e.g., Thayer, 1983).

Carbonate clast debris flows occur in the Truthville and Browns Pond. The clasts are fine grained, dark colored, and laminated and were locally derived, and not from an Iapetus Ocean-facing shelf or upper slope. Thus, debris flows clasts in the Browns Pond and Truthville yield limited skeletal fossils.

As proposed earlier (Landing, 2007, 2012, 2013a, b), the succession of the Mudd Pond Member quartzite and late Early Cambrian age of the uppermost Browns Pond (Landing and Bartowski, 1996) suggest these units are the slope equivalent of the shelf Cheshire Formation (quartz sandstone tidalite) and Dunham Formation (now dolostone-dominated) (Figures 3, 9). This lithologic correlation and the soft, strongly d/a substrate

Trace fossils and bottom water oxygenation

Planolites burrows at the base of thin sandstones of the upper Bomoseen persist into the Truthville Formation where they appear at the base of a few thin sandstone laminae (Figure 9). The Browns Pond has

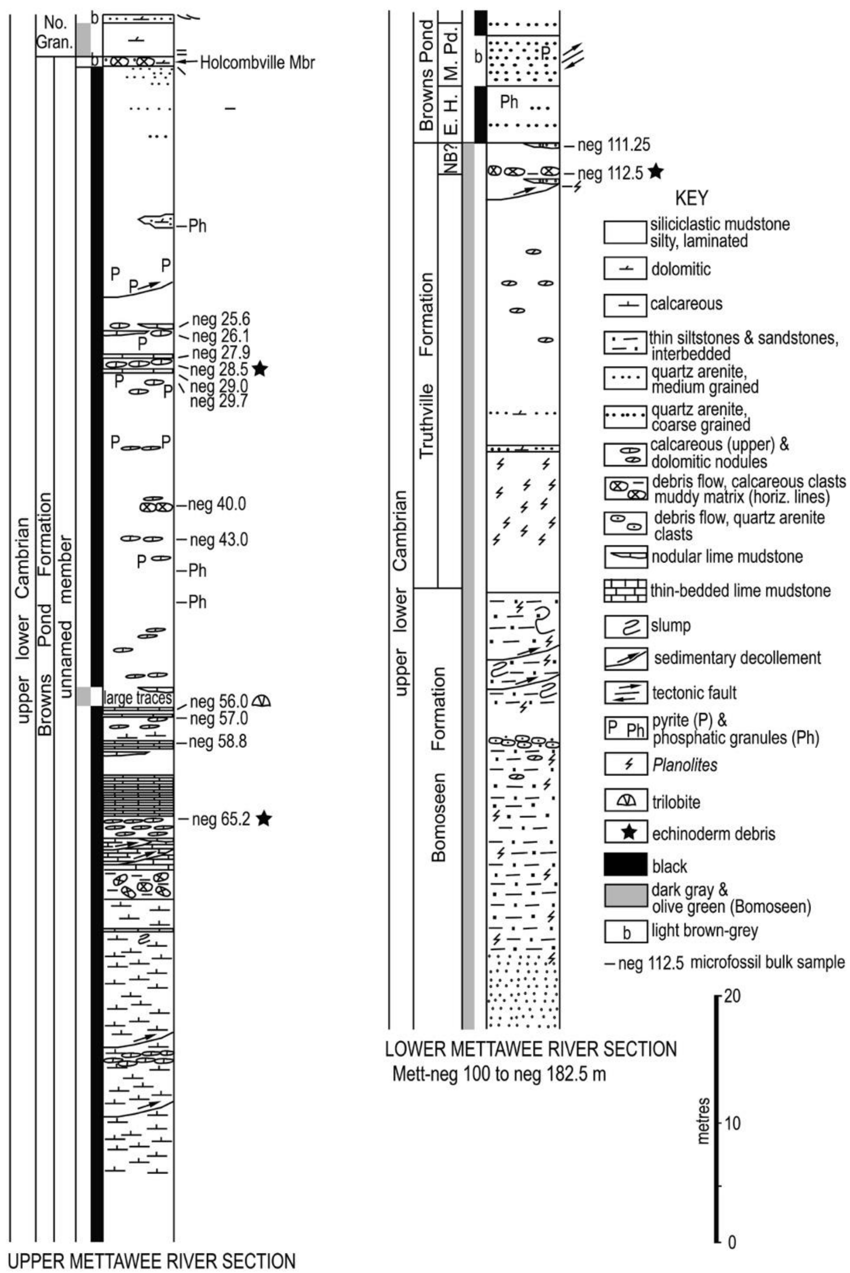

Figure 9. Section along the Mettawee River downstream from the falls on the Bomoseen Formation to c. 0.6 km upstream from the Lower Turnpike bridge at North Granville village, N.Y. Abbreviations: E.H., Eddy Hill Member; M. Pd., Mudd Pond Member; No. Gran., North Granville Formation.

of the Browns Pond would mean that the abundant, fine-grained carbonate component of bedded carbonates and secondarily transported debris flows came off the Dunham shelf (Figure 3) and that much of the fossil debris was similarly transported.

rare trace fossils with a few *Planolites* at Mett-neg 71.6 to Mett-neg 82 m on bedding surfaces and in slabbed sections.

Most of the Browns Pond Formation lacks any traces, which is consistent with it's interpretation as a strongly d/a facies (Landing, 2007, 2012, 2013A, B). The only large traces found in our study are black anastomosing forms limited to an interval of green weathering, medium grey mudstone (Mett-neg 55.0 to Mett-neg 56.5) that records a more oxic time on the sea floor (e.g., Landing, 2012). The large traces suggest *Megagrapton* Książkiewicz, 1968, a distinctive graphoglyptid known from large polygonal nets with common right angle branches (e.g., Książkiewicz, 1970). However, recent analysis of graphoglyptids (Fan et al., 2018) shows that *Megagrapton* actually has burrow segments intersecting at a variety of angles and thus allows a tentative assignment of the Browns Pond traces to "*Megagrapton*?" These large traces are not restricted to a bedding surface; they are endichnial and the product of a burrowing organism.

Ichnofossils of the Taconic allochthon have not received modern study, and the Browns Pond specimens can only be compared with the spartan original description and illustration of *Fucoides flexuosus* Emmons, 1844. They were compared with specimens in the NYSM Paleontology Collection that were collected from the "Cambrian roofing slates" in the vicinity of Middle Granville village that have been assigned to Emmon's ichnospecies. Both the Browns Pond and Middle Granville specimens have been tentatively assigned to *Megagrapton*? *flexuosus* (Landing et al., Submitted). Walcott (1890, p. 603) complicated an understanding of Taconic Cambrian ichnofossils by synonymizing all previously named, elongate taxa with the thin (i.e., thread-like) looping trace *Helminthoidichnites* Fitch, 1850. This synonymy meant that the much wider looping traces of the genotype *Gordia marinus* Emmons, 1844, became *H. marinus* (Emmons, 1844). Walcott (1890, pl. 52) illustrated large and anastomosing traces comparable to those from Mettawee River as *H. marinus*?

Late Early Cambrian age of syrift and passive margin (Truthville–lower Hatch Hill Formation)

A significant "younging" of the oldest units deposited along the margin of the New York Promontory (Figure 3) is indicated by re-evaluation (Landing et al., Submitted) of the biostratigraphic information on mineralogically immature, likely synrift deposits in the Taconic allochthon (i.e., Rensselaer and Bomoseen formations). In addition, small skeletalized faunas appear below and persist through the Browns Pond d/a interval to provide an upper age bracket (late Early Cambrian; middle Dyeran Age in Laurentia) on the rift–passive margin transition along the New York Promontory.

Reactivation of rifting or persistence of rifting into the late Early Cambrian (late Dyeran) and into the middle Middle Cambrian is suggested by the first marine transgression of the Ottawa-Bonnechere aulacogen and the coeval, on-strike subsidence of the Franklin Basin on the northwest Vermont shelf (Landing, 2007, 2012, 2013A, B; Landing et al., 2009, In press; Webster and Landing, 2016; Figure 1). The occurrence of *Oldhamia*-bearing trace fossil assemblages from the Rensselaer and Bomoseen formations comports with Dyeran and not Ediacaran or earliest Cambrian rifting and production and accumulation of immature sediments on the Iapetus-facing margin of the New York Promontory, as well as the Quebec Reentrant and Newfoundland Promontory. Recent study (Herbosch and Vaniers, 2011) shows that the trace fossil *Oldhamia* is biostratigraphically useful and not a form that could range even down into the Ediacaran. Indeed, *Oldhamia* is known worldwide from strata that are no older than the late Early Cambrian, and its occurrence in the Rensselaer and Truthville formations thus brackets the transition in NE Laurentia from a rifted margin in the late Early Cambrian in the Taconics of New York and Quebec (see Swett and Narbonne, 1993; Landing et al., Submitted) and western Newfoundland (Lindholm and Casey, 1990).

The trilobite *Olenellus* from the Cheshire Formation has been reported as the oldest body fossil on the northeast Laurentian passive margin (Osberg, 1969; Allen et al., 2010). However, *Olenellus* was actually reported to occur much below the Cheshire in chemically immature (synrift) arkoses at Clarksburg Mountain, northwest Massachusetts (Walcott, 1888). The Clarksburg Mountain rocks with purported *Olenellus* were mapped as "Cheshire" by Ratcliffe et al. (1993) with the "Cheshire" claimed to nonconformably overlie gneisses in southern Vermont and adjacent Massachusetts (e.g., Rankin et al., 1989; Hatcher, 2010; Allen et al., 2010). However, Walcott's (1888) *Olenellus* report is from rocks that occur only ca. 30 m) above the nonconformity with middle Proterozoic gneisses. This occurrence in conglomeratic arkoses brought to the "Mendon Formation" (Brace, 1953, p. 33; Skehan, 1961), and now best assigned to the Pinnacle Formation (Landing, 2007, 2012, 2013a, b; Webster and Landing, 2016; Figure 3). Walcott's (1888) supposed *Olenellus* specimen was never illustrated and a search of the USNM collections by MW did not lead to its recovery. Thus, a presently unidentified trilobite has been found in the oldest synrift sedimentary rocks on what became the NE Laurentian shelf, with the trilobite indicating a late Early Cambrian (Epoch 2) correlation comparable to that of the oldest known rocks (i.e., Rensselaer or Bomoseen formations) of the Taconic allochthon. This generalized correlation supports the conclusion that Iapetan rifting persisted or was re-established on the NE Laurentian margin in the late Early Cambrian.

Higher Mettawee River strata provide information on post-synrift deposits on the continental slope of NE Laurentia. The age of these deposits are provided by fossils from the Mettawee River section and other localities. The middle Dyeran *Elliptocephala asaphoides* assemblage spans the upper Browns Pond–lower Hatch Hill formations. This assemblage brackets the d/a intervals known from these two formations and the more oxic strata of the Middle Granville Formation (Landing and Bartowski, 1996; Landing 2012; Figure 3). The Mettawee River section shows that small skeletalised taxa known from the *E. asaphoides* assemblage persist lower through the Browns Pond and into the relatively oxic facies of the upper Truthville Formation (Landing et al., Submitted).

The likely sediment source of the carbonate-rich Browns Pond Formation and its fossils was the Dunham Formation on the eastern shelf of the New York Promontory (Figure 3). This slope–shelf correlation accords with correlation of the Mudd Pond Member quartzite with Cheshire Formation tidalites on the shelf (Landing, 2007, 2012). This correlation of shelf and continental slope units would make the lowest calcareous mudstones of the Browns Pond Formation equivalent to the shelf-margin Moosalamoo Phyllite that underlies the oldest NE Laurentian carbonate platform carbonates (Forestdale Marble; Figure 3).

These correlations mean that a significant amount of rift–passive margin rocks on the NE Laurentian shelf (Pinnacle–Dunham) and slope (Rensselaer–Browns Pond) are lower and middle Dyeran. This remarkable history of events that took place in the earlier Dyeran is actually incomplete as the Middle Granville Formation (and Middle Granville Oxic Interval, or MGOI), its shelf-equivalent HST, and the lowermost Hatch Hill Formation, are all middle Dyeran (upper *Elliptocephala asaphoides* assemblage interval). Thus, reestablishment of reduced slope water circulation and deposition of dysoxic/anoxic mudstones of the lower Hatch Hill Formation beginning in the middle Dyeran in the Taconics of eastern New York and adjacent Vermont are significantly older than the upper Forteau and lower Hawke Bay formations (upper Dyeran) of western Newfoundland.

The MGOI is proposed as replacement for the earlier named “Hawke Bay Oxic Interval” in theTaconics by Landing (2012; “HBOI” abandoned by Landing et al., Submitted). Correlation of the lower Hawke Bay Formation in western Newfoundland as upper Dyeran means that it is the lower, but not lowermost, part of the lengthy Hatch Hill d/a interval (middle Dyeran to lowermost Ordovician; Landing 2012) that really correlates with the Hawke Bay Formation and “events” (Landing et al., Submitted). As concluded by the latter authors, the designation “Hawke Bay Events” (“HBE”) should probably be limited to NE Laurentia where a comparable rifting history that persisted into or was reinitiated in the late Early Cambrian along the Newfoundland and New York promontories and included similar, likely coeval, lower passive margin successions (Bradore–Hawke Bay and Cheshire–Monkton formations).

The paradigm that the Hawke Bay Events necessarily featured major eustatic regression and an interregionally extensive unconformity should be questioned as noted by Nielsen and Schovsbo (2015) who regarded the “Hawke Bay regression” in Baltica as an epeirogenetic event. Similarly, Knight et al. (2017) also suggested that the “type” Hawke Bay Event unit, the Hawke Bay Formation in western Newfoundland may also be the record epeirogenic activity, not eustatic changes. Indeed, available evidence can be used to interpret the Hawke Bay Formation not as a regressive sedimentary unit but as an HST lithosome. By this proposal, the Hawke Bay, and possibly Monkton Formation in NE Vermont, were deposited either during an interval of reduced rate of sea-level rise and development of a shallow-water siliciclastic by-pass shelf with significant offshore transport of shoreline-derived quartz sand (Landing et al., Submitted). The qualification “local epeirogenic uplift” is appropriate in NE Laurentia as approximately coeval (upper Dyeran–Middle Cambrian) deposits of the Parker Formation in NW Vermont that are correlated with the Hawke Bay Formation record an abrupt and continuing epeirogenic foundering of the Franklin Basin and at least the eastern part of the Ottawa-Bonnechere aulocogen (Landing et al., 2009; Webster & Landing, 2016). (modified from Landing et al., Submitted)

59.5 At end of Stop 10, turn around and return to North Granville.

59.75 Turn right (west) at intersection with Rte. 22.

62.0 Intersection with Rte. 40, turn left (south) on Rte 40. The ridge to the left (east) of Rte 40 is formed of more resistant rocks at the western edge of the Taconian allochthon. The SSW trend of Rte 40 from this point to just north of Troy follows the front of the allochthon and edge of the Giddings Brook slice. Rte 40 meanders back and forth from the edge of the allochthon and onto erosionally less resistant, structurally underlying Upper Ordovician “Snake Hill” synorogenic flysch and wildflysch (see Landing et al., 2003b; English et al., 2006) and, in the area of Middle Falls, onto Lower and Middle Ordovician shelf carbonates.

63.0 High road cut on left (east) is in overturned Deep Kill Formation. The road cut shows repetitions of meter-scale Logan cycles that are relatively tectonized (faulted). Better preserved Logan cycles will be seen at Stop 11. This road cut is Stop 12 of Landing (2002).

78.0 Stop at T-junction in Argyle village, turn left (south) and continue on Rte 40.

80.0 Stop on edge of Rte 40 close to ca. 10 m-high cut with prominent banded slaty mudstones (Logan cycles) on left (east) side of road. CAUTION! Traffic can be heavy so cross road after discussion only with care.

No hammers on this superb locality, take pictures only. When examining road cut, stay close to the steel barrier or walk inside the barrier and hug the rocks.

STOP 11. LOGAN CYCLES IN THE DEEP KILL FORMATION: MESOSCALE CYCLES IN THE MILANKOVITCH BAND.
(15 MINUTES)

This is one the most assessible and well preserved outcrops that shows the color and lithologic alternations characteristic of Logan cycles (Landing and Benus, 1985; Landing et al., 1992) in the Lower–lower Middle Ordovician Deep Kill Formation. NO HAMMERS AT THIS STOP!

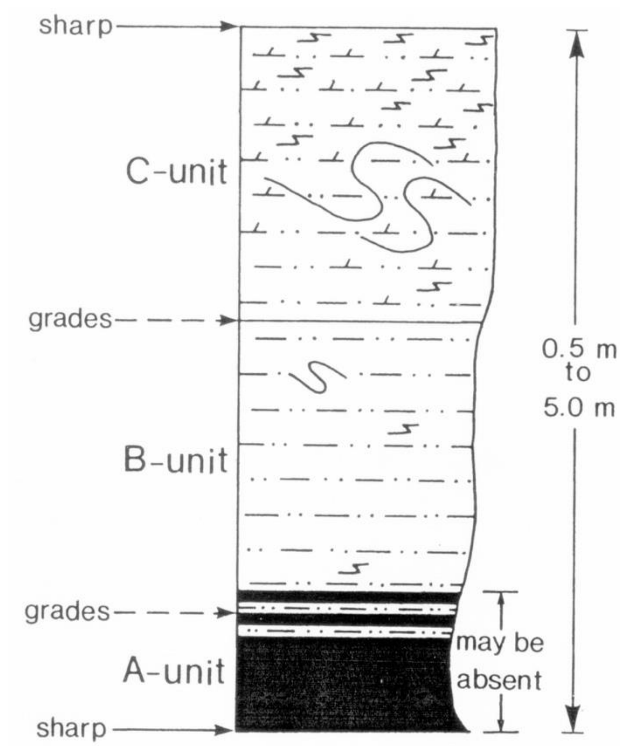

Figure 10. Stop 11: internal stratigraphy of Logan cycles (mesoscale cycles). Contacts with under- and overlying Logan cycles are "sharp;" transitions between units A–C of a Logan cycle are transitional ("grades"). Modified from Landing et al. (1992, fig. 8).

The road cut lies close to the leading (west) edge of the Taconic allochththon and Giddings Brook slice. The section is overturned and dips gently to the east. The utility of Logan cycles (Figure 10) in geological field work is that the upward transition of muddy intervals provides tops-sense in successions that otherwise lack much in the way of primary structures. Thus, successions with ABCABC, BCBC, or ABABABCABC, etc. alternations can be invariably used to determine tops-sense in a "monotonous" mudstone or slate sequence because A-units form the base of tripartite Logan cycles and C-units form the top.

About six Logan cycles are present in this ca. 8 m-thick section. Most of the cycles are BC cycles, and lack the lower black mudstone that appears in many, but not all, Logan cycles (Figure 10). The buff-weathering, dolomitic C-intervals are often the thickest part of the Logan cycles at Stop 11 and grade imperceptibly down into greenish B-intervals. Several of the Logan cycles show the abrupt upward transition from the C-interval into the black mudstone (A-unit) of the overlying Logan cycle.

Well preserved Logan cycles that extend through a completely exposed section through the Floian Stage at the leading edge of the Taconian allochthon at Levís, Québec, appear to have an average duration of less than 100 k.y. (Landing et al., 1992). EL's experience is that only the more proximal parts of Laurentian slope successions (i.e., the Levis area in Québec and the central and southern Giddings Brook slice in eastern New York) show Logan cycles, while more distal successions are comprised of completely oxic mudstones with green, purple, and red color.

Logan cycles should be seen as potentially economically significant as they comprise the dominant depositional motif in the deeper-water, organic-rich, Miocene petroleum source rocks on the southern margin of the Mediterranean (Landing et al., 1992). However, the rocks of the Giddings Brook slice record a much higher burial temperature, with euconodont elements typically opaque black in color and showing a C.A.I. (Color Alteration Index) of 4.0, which means that any organic materials have been transformed into graphite (e.g., Landing, 1976, 1993).

80.0 At end of Stop 11, continue south on Rte 40.

87.6 Pass by intersection with Bald Mountain Road on right. The old Bald Mountain limestone quarry was developed in a giant block of white weathering, massive limestone with a mollusk-dominated fauna (e.g., Cushing and Ruedemann, 1914, p. 75–80). This macrofauna and conodonts (E. Landing, unpub. data) indicate a late Early Ordovician (Floian) age, and allows interpretation of the Bald Mountain limestone as a massively bedded block of Fort Cassin Formation torn off the outer carbonate platform by Taconian thrusting. The block lies under the Taconic masterthrust in early Late Ordovician wildflysch (see Zen, 1967, p. 31, 32, 36).

88.5 Enter village of Middle Falls.

89.5 Turn left (south) on Rte 40. For the next several miles, Early Ordovician carbonate platform units under the Taconic allochthon are exposed in low cuts along the east side of Rte 40.

92.1 Note cut in vertical beds of lower Trenton Group (Upper Ordovician, Katian) limestones and thin interbedded black mudstones along east side of road and opposite wide dirt pull-off on west side of road. This is a good place to bring class trips, as it provides a panorama that includes the Devonian of the Catskill High Peaks to the southwest, the Proterozoic Grenvillian of the southernmost Adirondacks to the west, and the Lower Cambrian of the Taconic allochthon on the hill crest immediately east. In addition, the Upper Ordovician "Knox unconformity" can be investigated at the very north end of the outcrop. The "Knox unconformity" is seen at the contact of relatively proximal, brachiopod-dominated limestones of the Trenton Group with underlying, brown weathering dolostones (age presently undetermined, possibly early Middle Ordovician and referable to the Providence Island Dolostone).

103.3 Stop light, continue straight on combined Rte 40 and 67 into village of Schaghticoke.

104.2 Turn right on curve immediately after red brick church and park in Hoosick River overlook parking area. Until recently, the rocks in Schaghticoke gorge below the dam could be accessed by walking downslope under the Rte 40 bridge. Unfortunately, the response to drinking parties and a few drownings has meant that an iron fence has been put along the gorge, and this makes access difficult. What will be done for Stop 12 will be a photographic overlook downstream from the eastern part of the bridge. Two areas on the north bank and on the upstream side of the island in the middle of the Hoosick where black mudstones of the Schaghticoke dysoxic/anoxic interval crop out can be seen. After this, CAREFULLY cross the bridge roadway, and the same Schaghticoke d/a interval can be seen tectonically repeated several times from a viewpoint directly down from the NE end of the bridge.

STOP 12. SCHAGHTICOKE GORGE: LATE EARLY TREMADOCIAN DYSAEROBIC INTERVAL.
(40 MINUTES).
(Stop 13 of Landing, 2002).

The section appears to comprise a tectonically isolated slice at the leading edge of the Taconic allochththon and Giddings Brook slice. This is the type section of the upper lower Tremadocian (Lower but not lowermost Ordovician) "Schaghticoke Shale" (term abandoned by Landing, 1988b, and grouped as the lowermost part of the Deep Kill Formation).

Schaghticoke gorge features the structural duplication of a thin (ca. 4 m) black mudstone-limestone macroscale alternation in greenish-gray slaty mudstones. Graptolites from the black mudstones (Ruedemann, 1903) are representative of the lower Ordovician Matane faunas known along the leading edges of the Taconian allochthons in Québec. Unfortunately conodonts from limestones in the Schaghticoke d/a interval in the Hoosick River gorge are limited to stratigraphically long-ranging protoconodonts (Landing, 1976; E. Landing unpublished data). The lithology of this middle–upper Tremadocian black shale-limestone macroscale alternation is remarkably similar to the coeval (based on graptolites) black shale-limestone macroscale alternation exposed for 400 km along the south shore of the St. Lawrence River in Québec and which yields *Rossodus manitouensis* Zone conodonts (Landing et al., 1986). The Schaghticoke d/a interval of climate maximum and intensified dysaerobia on the Taconic continental slope and elsewhere along the Laurentian margin (Landing, 2012) is equated with the eustatic rise and the Stonehenge transgression (Taylor et al., 1992) that led to deposition of the Tribes Hill Formation as a type 1 depositional sequence (Stop 4).

104.2 At end of stop, continue south on Rte 40.

104.9 Turn right (west) at intersection with Rte 67 and continue driving west.

119.0 Drive through village of Malta, NY, on Rte 67.
120.0 Rte 67 intersects Northway (U.S. Interstate 87), take entrance ramp (Exchange 12) to north. Most of route is on low-lying terrane developed on Late Ordovician Utica Formation (black mudstone with abundant graptolites). A few miles south of Lake George village, note road cuts in middle Proterozoic Grenvillian orogen (Adirondack basement).
141.0 Exit Northway at Exit 22 (Lake George village and Fort William Henry), end of trip.

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APPENDIX 1

STOP A1: "WEST CASTLETON FORMATION" TYPE SECTION IS HATCH HILL FORMATION

Location

Stop A1 features the completely exposed core of the Scotch Hill syncline (Figure 11) on the north side of Scotch Hill Road at the hamlet of West Castleton, Vermont. This photogenic section is located between Glen Lake and Lake Bomoseen. This section with two thick intervals of thin-bedded dolomitic quartz arenite (lower to 3.75 m and upper 1.3 m thick) is complemented by two overgrown road cuts just to the south on the east side of Scotch Hill Road. The more northerly road cut is 30 m north of the intersection of Scotch Hill Road and Corvell Road (unpaved) and exposes 5.5 m of east-dipping black shale and thin, lenticular, cross-laminated, orange-weathering dolomitic sandstones. The sandstones comprise ca. 30% of the short section. The second section extends for 300–500 m south of the intersection of Corvell and Scotch Hill roads and includes ca. 5.0 m of black shale and thin bedded, cross-laminated, orange-weathering dolomitic sandstones (ca. 50% of section).

Purpose

As it is relatively distant from the other stops of field trip A5 further south, this important locality could not be accommodated into the trip schedule but should be visited by the participants at another time.

Problems with the "West Castleton Formation" (abandoned)

Zen (1961) proposed the "West Castleton Formation" based on the, then probably much better exposed, road cut on Scotch Hill Road south of the hamlet of West Castleton. As the rocks in the road cut strike directly into the syncline only a short distance north at West Castleton, the synclinal succession is obviously also "West Castleton Formation." The syncline in "West Castleton" is immediately underlain by purple and red slates (Zen, 1961, pl. 3, fig. 2 caption) that have yielded an *Elliptocephala asaphoides* assemblage from an interval of thin bedded limestones (Schuchert, 1937, p. 1038). The road cut has not yielded fossils, although Swinnerton (1922) noted but did not illustrate a purported *Olenellus*.

Figure 11. Stop A1: Lower Hatch Hill Formation in core of Scotch Hill syncline, north side of Scotch Hill Road between Glen Lake and Lake Bomoseen at hamlet of West Castleton, Vermont. Although traditionally assigned to the type "West Castleton Formation" (designation abandoned by, e.g., Landing, 1988b, etc.), the thick intervals of dolomitic quartz arenite sandstones in the lower and middle parts of the dark gray to black slatey mudstone-dominated outcrop, the persistence of thin dolomitic sandstones to the top of the outcrop, and the significant proportions of dolomitic quartz sandstones lower in the type section demonstrate the lithologic similarity with characteristic Hatch Hill Formation facies throughout the western Taconic allochthon. In addition, immediately underlying strata consist of green to red siliciclastic slates with fossiliferous limestones (*Elliptocephala asaphoides* assemblage) that are comparable to the Middle Granville Formation that underlies the Hatch Hill Formation throughout the western Taconic allochthon.

The red and green slates with a limestone interval below the "West Castleton" show the "West Castleton" is underlain by the rocks identical in lithology and with the same fauna as the Middle Granville Formation (Stop 6). The presence of these red and green slates just under the "West Castleton" in the core of the Scotch Hill syncline indicates that the type section of the "West Castleton" is low in the formation and is late Early Cambrian. It should be noted that most of the northern part of Scotch Hill Road before the easterly curve at Glen Lake follows along the Middle Granville–"West Castleton" contact.

What seems to have developed from Zen's (1961) description of the West Castleton is a seeming belief in the dominance of black siliciclastic mudstones in the formation (e.g., Potter, 1971, Ratcliffe et al., 2011), although substantial amounts of dolomitic quartz arenite occur in the unit both in the currently observable rock in the road cuts and in the core of the Scotch Hill syncline (Figure 11, also "Location" above)).

This presence of dolomitic sandstones in the "West Castleton" type section makes the formation quite similar lithologically to the Hatch Hill Formation, which Theokritoff (1959) described as consisting of black mudstones and interbedded orange weathering (dolomitic) sandstones. Given this lithologic similarity, the "key" distinction between the Hatch Hill and "West Castleton" seems to have been a belief that the former was Upper Cambrian and the latter Early Cambrian (Zen, 1964, see descriptions of the two formations)—a mistaken distinction that is essentially maintained in the Vermont Geologic Map (Ratcliffe et al., 2011).

Indeed, Theokritoff's (1959) "Late Cambrian" graptolites have been reevaluated and show that the upper Hatch Hill in the northern and southern Taconics is lowest Ordovician (Stop 8; Landing, 1993). Similarly, the succession at Judson Point, Columbia County, eastern New York (Bird and Rasetti, 1968), shows that a Hatch Hill-type facies extends down into the upper *Elliptocephala asaphoides* assemblage interval and extends upward through the middle Middle Cambrian at Judson Point. Recent investigation of the succession at and further south along strike of Judson Point (by EL) shows that this Hatch Hill-type facies is underlain by green mudstones with thin limestones and a carbonate clast debris flow at a locality 935 m SSE from the base of the Judson Point section. This locality lies the recently bulldozed (Spring 2018) entrance road into No. 164 Southers Road. The presence of a lower *Elliptocephala asaphoides* assemblage (i.e., Landing and Bartowski, 1996) in the thin limestones in green mudstone represents the upper Middle Granville Formation and records an identical succession to that at West Castleton.

Rowley et al. (1979, p. 197) first began a tentative re-evaluation of the distinction of the Hatch Hill and "West Castleton Formation" by noting that the "distinction (of the formations) is marginal" and suggesting that the "West Castleton" "may be better regarded as a facies of the Hach Hill." Subsequently, Landing (1988b, 1993, 2002, 2007) synonymized the "West Castleton" with the Hatch Hill―a repeated nomenclatural decision and evaluation not reflected in any way in the Geologic Map of Vermont (Ratcliffe et al., 2011). Thus, the Hatch Hill Formation and Hatch Hill d/a interval represent a long-term (late Early Cambrian–earliest Ordovician) interval with organic-rich mudstone deposition on the east Laurentian continental slope (e.g., Landing et al., 2002).

The other problem with the "West Castleton Formation" is that two somewhat similar d/a mudstone-rich intervals exist in the Taconic succession, and lithologic similarity has led to long-term confusion of the Browns Pond Formation with the Hatch Hill/"West Castleton" in the Taconics. However, careful mapping and good outcrops allows distinction of the Browns Pond and Hatch Hill by the former's appearance a short stratigraphic distance above the Bomoseen Formation (Stop 9) and the presence of Dale's (1899) green and red "Cambrian roofing slates" (i.e., Middle Granville Formation and upper "Bull Formation" of the Vermont Geologic Map) between the two black mudstone intervals (e.g., Stop 6). The invariable presence of the red and green slates precludes any statement that the Browns Pond is "interbedded" with the "West Castleton" (Ratcliffe et al., 2011).

This reliance on stratigraphic succession as an important aid in distinguishing the Browns Pond and Hatch Hill/"West Castleton" formations has allowed a re-evaluation of Bonham (1950) and Lochman's (1956) localities with *Elliptocephala asaphoides* assemblages in the central Taconics (see Potter, 1972, appendix 4). All of these localities occur in successions that include the underlying Bonoseen Formation and are thus referable to the Browns Pond Formation, and not to the Hatch Hill/"West Castleton." The conclusion, as in Landing (1988b) is that "West Castleton Formation" must be abandoned in favor of the coeval and lithologically identical Hatch Hill Formation.

In appreciation

Jim and Bunny Whitman genially gave permission to examine the synclinal succession in the back yard of their cottage. The property has been owned by the Whitman family back to Jim's grandparents, Mary and Jim Larkin. Jim Larkin was a slate quarryman of Welsh descent.

APPENDIX 2

Revisions in Stratigraphic Nomenclature—Cambrian–Ordovician Platform

Tectonic setting and stratigraphic nomenclature. A very uniform upper Middle Cambrian–Lower Ordovician lithostratigraphy occurs in authochthonous sequences on the north and west sides and to the south of the Lake Champlain lowlands in southern Quebec and SE Ontario and adjacent New York. This succession is also present in the parautochthonous Champlain slice in west-central Vermont and easternmost New York (e.g., Fisher, 1984; Figures 1, 3). This frankly "layer cake" lithostratigraphic succession was deposited after down-faulting and submergence of the mouth of the Ottawa-Bonnechere aulacogen (OBa) beginning in the late Early Cambrian with deposition of the Altona Formation through the middle Middle Cambrian. Altona deposition was followed by deposition of the fluviatile arkoses of the Ausable Member of the Potsdam Formation in the OBa and as far south as the central Lake Champlain lowlands.

Following Ausable Member deposition, marine transgressions took place across a depositional surface with minimal, essentially /˚, depositional slope across the Grenville basement and across the Ausable Member in the OBa and northern Lake Champlain lowlands. This post-Ausable depositional setting meant the final establishment of the post-rifting passive margin and deposition of mineralogically mature quartz sandstones (Keeseville Member of the Potsdam Formation) and overlying Beekmantown Group with lower quartz sand- and carbonate-rich (Galway Formation) and higher dominantly carbonate deposits of the higher Beekmantown Group (Little Falls–Providence Island formations). As now interpreted, the carbonate-dominated units of the Beekmantown Group are separate type 1 depositional sequences that comprise formation-level units with uniform member-level lithostratigraphy, characteristically formation-distinct macro- and microfossil assemblages (trilobites, cephalopods, gastropods, conodonts), and likely are separated from each other by hiatuses of longer duration than the time represented by each formation (e.g., Landing, 2007, 2012; Kröger and Landing, 2010)

A confusing stratigraphic nomenclature for the shelf succession has obscured the regional extent of lithic units and the simple pre-Taconic orogeny evolution of this stretch of the New York Promontory (Figure 12). In part, this complexity, with an unnecessarily large number of named lithostratigraphic units, reflects casual stratigraphic practices that featured naming units without designation or description of type sections, detailed lithic characteristics, or specified upper or lower contacts. These contacts were often changed arbitrarily, and lateral correlations were commonly established by assertion rather than by biostratigraphic or lithostratigraphic analyses (Figure 12, see discussion below of Tribes Hill Formation). An additional problem resulted from hydrothermal dolomitization during the Taconic orogeny that resulted in quite rapid lateral transitions from limestones with well preserved depositional fabrics to dolostones that lack much in the way of primary fabric (Stops 3, 4)—a situation compounded by a seeming "need" to give the coeval non-dolomitized and dolomitized intervals separate formal lithostratigraphic names (see Little Falls Formation, below). In a number of cases, observance of stratigraphic naming procedures (e.g., North American Commission on Stratigraphic Nomenclature [NACSN], 2005) meant that units, as formations, were subdivided into a number of formations with the name of the subdivided formation assigned to one of the parts (i.e., undesirable restiriction by the NACSN)

Synonymous units that essentially differ because that occur in different map areas or in map areas studied by different workers without a broader experience in the region's field geology have persisted in the literature by a sort of scholasticism. This unquestioning regard for the older literature somehow did not allow revisions or any consideration of the synonymization of identical lithostratigraphic units. Thus, Fisher (1954) and Fisher and Mazzulo (1976) used distinctive stratigraphic names, Tribes Hill Formation and "Great Meadows Formation," for the same unit (Tribes Hill) in the Mohawk River valley and southern Lake Champlain lowlands ("Great Meadows"), while using "Gailor Dolomite" (Fisher and Hansen, 1951) for identical strata in the Saratoga, NY, area just about midway between the Mohawk and Lake Champlain regions (Landing and Westrop, 2006) . The contacts of lithologic untis were often changed arbitrarily, and lateral correlations were commonly established by assertion rather than by biostratigraphic or lithostratigraphic analyses (Figure 12).This complexity also reflects the proposal of different names for lithologically identical, laterally continuous, and coeval and, thus, synonymous units in New York and Vermont. A lack of consideration of much of the available literature, as in the recently updated Vermont geologic map (Ratcliffe et al., 2011), means that a uniform stratigraphic nomenclature that should have been applied to the Vermont–New York shelf still does not exist in widely available publications.

Potsdam, Galway, Little Falls, Galway, "Ticonderoga" (abandoned), and "Whitehall" (abandoned) formations. Landing et al. (2009, In press) have discussed the nomenclature of the Potsdam Formation and limited it to the grade of "formation" and not "group," and detailed that Potsdam Formation deposition did not persist either on the NE Laurentian shelf or in the Ottawa-Bonnechere aulacogen into the Early Ordovician (e.g., Lowe et al., 2017, 2018). An error on the revised Vermont Geologic Map (Ratcliffe et al., 2011, legend) limits the range of the Potsdam to the "Upper Cambrian," although the unit ranges only into the middle Upper Cambrian and its upper part (Keeseville Member) is upper Middle Cambrian at its base (Stop 1, this report). [It might also be noted that the correct age of the Monkton Formation in Vermont has always been late Early Cambrian (late Dyeran) and not "Middle Cambrian" as on the revised Vermont Geologic Map (Ratcliffe et al., 2011, legend)].

Rodgers (1937) proposed "Whitehall Formation" for a temporally-defined, carbonate-dominated, lowest Ordovician unit in the Lake Champlain Lowlands (Fig. 2). His "Whitehall" overlay an unfossiliferous, but presumably, Upper Cambrian interval referred to the Little Falls Formation of Clarke (1903) in the Lake Champlain Lowlands. However, the "Whitehall" and Little Falls Formations unconformably underlie the Tribes Hill Formation in the Lake Champlain Lowlands and Mohawk Valley, respectively, and both "units" are now known to range only into the uppermost Cambrian. The "Whitehall" ranges into the uppermost *Cordylodus proavus* Zone (Landing et al., 2003), and the Little Falls in the Mohawk valley ranges into the middle *C. proavus* Zone (Landing et al., 1996).

The Little Falls Formation has always been regarded as a carbonate-dominated (now largely hydrothermally dolomitized; Stop 3, this report) unit that overlies a mixed dolostone and quartz arenite "transitional facies" (i.e., the Galway Formation of Fisher and Hansen, 1951) above Potsdam Formation quartz arenites in the Mohawk valley (e.g., Wilmarth, 1938, p. 1194–1196; Zenger, 1981). Similarly, the "Whitehall" overlies the mixed dolostone and quartz arenite facies of a purported "Ticonderoga Formation" (J. Rodgers *in* Welby, 1961; abandoned by Landing et al., 2003A; a junior synonym of Galway Formation in Figure 12), and the latter overlies the Potsdam in the Lake Champlain lowlands. These data on lithologic composition, upper and lower contacts, and age support Ulrich and Cushing's (1910) recognition of the Little Falls Formation (="Whitehall Formation," abandoned) and the replacement of "Ticonderoga" (abandoned) by Galway Formation in the Lake Champlain lowlands. Unfortunately, the status of the "Ticonderoga Formation" (abandoned) does not seem to have been considered, and the term "Ticonderoga Formation" still appears on the revised Vermont Geologic Map (Ratcliffe et al., 2011).

Tribes Hill, "Cutting" (abandoned), and "Great Meadows" (abandoned) Formation. Ulrich and Cushing's (1910) and Wheeler's (1942) proposal of a unified stratigraphic nomenclature to the Upper Cambrian–Lower Ordovician of the Mohawk valley and southern Lake Champlain lowlands showed a great appreciation for the lateral continuity of stratigraphic units on the New York Promontory. Although dismissed without adequate discussion by Fisher and Mazzullo (1976, p. 1443), Ulrich and Cushing's and Wheeler's recognition of the Tribes Hill Formation extending from the Mohawk River into the Lake Champlain lowlands is appropriate.

The "Cutting/Great Meadows Formation" (terms abandoned; Landing et al., 1988A; Landing, 2002, 2007, 2012) of the Lake Champlain lowlands rests unconformably on latest Cambrian carbonates and forms a deepening–shoaling sequence in the *Rossodus manitouensis* Zone. These relationships are identical to those of the coeval Tribes Hill Formation in the Mohawk River valley (see Landing et al., 1996). The vertical facies succession in the "Cutting/Great Meadows" is also identical to that of the Tribes Hill in the Mohawk valley so that the same member-level nomenclature is appropriate (Stop 4, this report; discussed below). These lithologic correspondences mean that "Cutting Formation" and "Great Meadows Formation" must be abandoned for the older synonymous term "Tribes Hill Formation," a well published stratigraphic reevaluation not present in the revised Vermont Geologic map (Ratcliffe et al., 2011, legend), with the latter not noting that there is a type 1 sequence boundary at the base of the Tribes Hill Formation that is the trans-Laurentian shelf Cambrian–Ordovician boundary (e.g., Landing et al., In press). The revised Vermont Geologic Map shows the "Whitehall Formation (designation abandoned) ranging into the lowest Ordovician, without incorporating then available bio- and lithostratigraphic work that shows the top of the Little Falls Formation as Upper, but not uppermost Cambrian, both in eastern New York and on the Vermont side of Lake Champlain (Landing et al., 2003A, 2007, 2010). [The Cambrian–Ordovician boundary unconformity also extends into deeper water facies, and the revised Vermont Geologic Map (Ratcliffe et al., 2011) incorrectly shows the Gorge Formation of the Franklin Basin extending into the Lower Ordovician, while a Gorge–Highgate Formation succession without an intervening unconformity is incorrect (e.g., Landing et al., 2007)]

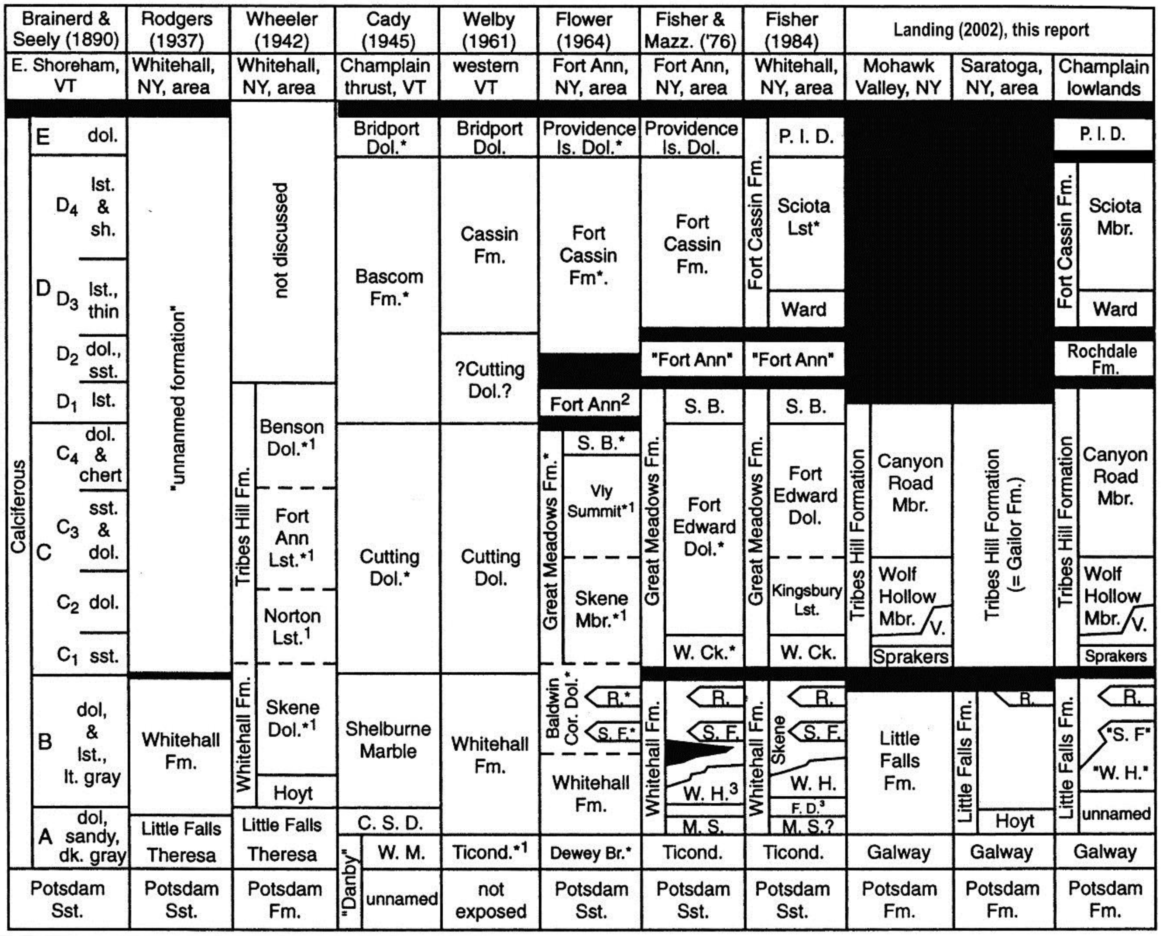

Figure 12. Upper Cambrian–Middle Ordovician stratigraphic nomenclature of the Laurentian platform, eastern New York and western Vermont. Cambrian–Ordovician boundary is hiatus between the Little Falls and Tribes Hill formations. *Paraprioniodus costatus-Chosonodina rigbyi-Histiodella holodentata* Interval conodonts (Ethington and Clark, 1981, = Fauna 4 of Sweet et al., 1971) through Providence Island Formation (E. Landing, unpub. data) indicates Beekmantown Group extends into Middle Ordovician. International agreement means that overlying strata of Chazy, Black River, and Trenton groups are Upper Ordovician, and the "Knox unconformity" is the lower bracket of the Upper Ordovician. Symbols: asterisk (*) is first proposal of stratigraphic name; superscripts 1–3 are abandoned units by 1—inadequate location of type section, description of lithology, or contacts, 2—no type section, lithologic description, or contacts provided, 3—unit is synonym of earlier named unit; quotation marks, for reasons 1–3 unit not recognized in this report. Abbreviations: Bridport Dol., Bridport Dolostone, abandoned; C. S. D., Clarendon Springs Dolostone, abandoned; Dewey Br., Dewey Bridge Dolostone, abandoned; F. D., Finch Dolostone, abandoned; M. S., Mosherville Sandstone, abandoned; P. I. D., Providence Island Dolostone; R., Rathbunville School Limestone, Ri., Ritchie Limestone, abandoned; S.B., Smith Basin Limestone, abandoned; S.F., "Steves Farm Limestone," informal designation; Ticond., Ticonderoga, abandoned; V, Van Wie Member; W. Ck., Winchell Creek, designation abandoned; W. H., Warner Hill Limestone, designation abandoned; W. M., Wallingford Member. Figure modified from Landing (2002, fig. 2) and Landing et al. (2003A, fig. 2).

Members of the Tribes Hill Formation. Landing et al. (1996) proposed the Sprakers Member for lower Tribes Hill strata that extend upward from the unconformity with the Little Falls Formation to a shale-dominated reentrant (Van Wie Member of Landing et al., 1996) under the cliff-forming Wolf Hollow Member of Fisher (1954). The Sprakers changes laterally from intertidal carbonates and overlying wave-deposited fossil grainstones and calcisiltites in the western Mohawk valley into micro-cross-laminated silty dolostones and fine-grained dolomitic sandstones in the east (Landing et al., 1996, fig. 2, Hoffmans section). The Sprakers Member at Hoffmans is lithologically similar to Fisher and Mazzullo's (1976) "Winchell Creek Siltstone."

Dark shales with lenticular intraclast and calcisiltite beds of the thin (ca. 1.5 m) Van Wie Member mark the maximum highstand of Tribes Hill deposition in the Mohawk valley (Landing et al., 1996; Landing, 1998). Similar, dark, pyritiferous silt shale and lenticular dolomitic sandstones with bidirectional (wave-generated) cross beds in the upper "Winchell Creek Siltstone" at Tristates Quarry and Comstock (Stops 5, 7) are referred herein to the Van Wie Member (Figure 2). The Tribes Hill is thicker in the Lake Champlain lowlands (e.g., 69 m at Comstock vs. 30 m in the Mohawk valley), and the stratigraphic distance from the top of the Van Wie to the lowest thrombolites is also somewhat more [4.5 m and 10 m at Tristates Quarry and Comstock (Fig. 3) vs. 1.0–4 m in the Mohawk valley; Landing et al., figs. 2, 3]. Interestingly, a lenticular quartz arenite dune in the middle Van Wie at Comstock and Tristates Quarry seems to correspond to the intraclast pebble storm bed in the middle Van Wie in the Mohawk valley (Landing et al., 1996, figs. 2, 3).

Recognition of the Sprakers and Van Wie members as divisions of the lower–middle "Winchell Creek Siltstone" (Fisher and Mazzullo, 1976; abandoned herein) means that a Winchell Creek-type facies reappears above the Van Wie and is transitional into the cliff-forming, thrombolitic facies in the middle Tribes Hill. Fisher (1962b; Fisher and Mazzullo, 1976) referred the carbonate-rich interval of the middle–upper "Great Meadows" to a "Fort Edward Dolostone" member without designating a type section in the Middle Ordovician flysch terrane of the Fort Edward, NY, area. Fisher (1984) later "undesirably restricted" (see North American Stratigraphic Commission, 1983) the "Fort Edward" by separating out the lower thrombolitic interval as a "Kingsbury Limestone" and retaining "Fort Edward" for the remainder. This restriction created an objective homonym of "Fort Edward" in Fisher's (1977, 1984) own publications.

Thrombolites appear only in the upper Wolf Hollow Member in the Mohawk valley (Landing et al., 1996). This highstand facies is now recognized above the Van Wie Member in the Lake Champlain lowlands (Figure 2). The Wolf Hollow Member is recognized as the senior synonym of the upper "Winchell Creek", "Kingsbury," and "Fort Edward" Members (all units abandoned) in the Lake Champlain lowlands, where it extends from the top of the Van Wie to the top of the thrombolite build-ups, as in the Mohawk valley.

The Canyon Road Member (Landing et al., 1996), which is the upper member of the Tribes Hill Formation in the Mohawk valley, includes lower intraclast-fossil hash beds and higher evaporitic dolostones above the highest Wolf Hollow thrombolites (Landing et al., 1996). A similar, carbonate-dominated, aggradational or progradational highstand facies is marked in the Lake Champlain lowlands by replacement of Wolf Hollow thrombolite build-ups by overlying ooid wackestones and higher, mollusk-rich lime mudstone. This lime mudstone is Flower's (1968a) "Smith Basin Limestone" (see Stop 7 discussion). The most appropriate stratigraphic designation for the entire supra-thrombolite, carbonate-dominated interval of the upper Tribes Hill Formation in the Mohawk valley and Lake Champlain lowlands is "Canyon Road Member." "Smith Basin Limestone" is regarded as an informal submember for the massive lime mudstone unit of the uppermost Canyon Road Member in the Lake Champlain lowlands.

Rochdale Formation. Regional litho- and biostratigraphic work indicates that the Rochdale Formation extends through the Lake Champlain lowlands south into southern Dutchess County, New York (Landing et al., 2012). Rochdale Formation, first named for Rochdale, NY, replaces "Fort Ann Formation" (designation abandoned) as a carbonate-dominated, middle Lower Ordovician (late Tremadocian) type depositional sequence. This second Early Ordovician depositonal sequence in the Lake Champlain lowlands that unconformably overlies the Tribes Hill Formation and unconformably underlies the Ward Siltstone member of the upper Lower Ordovician Fort Cassin Formation (see Fisher, 1984; Brett and Westrop, 1996; Landing et al., 2012). The designation "Fort Ann" previously abandoned) is continued in use on the revised Vermont Geologic Map, the unit is not represented as a distinct depositional sequence, and its age is mistakenly given as "Arenigian" (now Floian) by Ratcliffe et al. (2011, legend).

The checkered history of "Fort Ann" (Figure 12) includes its proposal as an undescribed middle member of the Tribes Hill Formation (Wheeler, 1942), and its redefinition (Flower, 1968b) as a formation above the Tribes Hill (i.e., "Great Meadows") Formation in the Lake Champlain lowlands. Thus, "Fort Ann" is an objective homonym of itself (!) in several important early publications that sought to establish a uniform stratigraphic nomenclature in the Lake Champlain lowlands. No type section was ever designated for the "Fort Ann," and it should be noted that Fort Ann village itself is built on Late Ordovician flysch.

Upper Beekmantown Group The two upper formations of the Beekmantown Group are the Fort Cassin and overlying Providence Island formations, which extend (under various names) from Dutchess County, SE New York, through the Lake Champlain lowlands, and into the Montreal–Ottawa areas of the Ottawa-Bonnechere aulacogen. Each formation is a separate type 1 depositional sequence with the lower Ward Member (fine sandstones) of the Fort Cassin unconformably overlying the Rochdale Formation. The Fort Cassin is a middle to upper Lower Ordovician (Floian) unit. In turn, the lower Middle Ordovician Providence Island Formation (defined on Providence Island in Vermont but referred to by a junior synonym as "Bridport Dolostone," designation abandoned, on the Vermont Geologic Map by Ratcliffe et al., 2011) unconformably overlies the Fort Cassin as a type 1 depositional sequence as the uppermost unit of the Beekmantown Group; it yields lower Llanvirnian conodonts.

The Providence Island Formation is unconformably overlain by the Chazy Group, with the unconformity defining the trans-Laurentian Middle–Late Ordovician boundary at the Sauk–Tipeecanoe Megasequence boundary (see summaries in Brett and Westrop, 1996; Landing, 2007, 2012; Landing and Westrop, 2006; Landing et al., 2007; Landing et al., 2012; Figure 3). The Vermont Geologic Map (Ratcliffe, 2011, legend) does not incorporate the depositional sequence history and unconformities through the upper Beekmantown, shows the upper Fort Cassin as Middle Ordovician (Llanvirnian) although trilobites and published conodont work limits the formation to the middle Lower Ordovician (Brett and Westrop, 1996; Landing and Westrop, 2006), and does not show the Providence Island Formation as a regionally extensive unit.

Revisions in Stratigraphic Nomenclature—Taconic Allochthon

A dismaying number of stratigraphic names has been generated for Cambrian–Ordovician units along the ca. 200 km length of the Taconic allochthon from Sudbury, Vermont, to Beacon, near Poughkeepsie, New York (see Zen, 1964). In part, this practice has been a natural consequence of problems involving correlation into the more highly metamorphosed higher (and eastern) thrust slices. However, it is unfortunate, in particular, that separate nomenclatural schemes exist for the northern, central, and southern parts of the Giddings Brook slice (see Zen, 1964; Fisher, 1977) because adequate outcrops and biostratigraphic controls allow reconstruction of the stratigraphic succession and detailed correlations along the length of the slice.

The tectonic history of the Giddings Brook succession (i.e., rift margin feldspathic quartz and lithic arenites [latest Precambrian?–Early Cambrian Rensselaer Formation], Early Cambrian–Middle Ordovician passive margin slope deposits that record sea-level and paleo-oceanographic changes correlateable for long distances along along the slope [Stops 8–13], and progressive evidence for convergence beginning in the Middle–Upper Ordovician [Indian River–Austin Glen formations, Stop 9] led to a uniform stratigraphy that can be recognized in the Sunset Lake, Giddings Brook, and Bird Mountain slices (Landing 1988b). In general, the lithostratigraphic scheme outlined by Rowley et al. (1979) in the northern part of the Giddings Brook slice is appropriate for the external slices. Two exceptions to this scheme were noted by Landing (1988b):

Deep Kill Formation and its synonyms. "Deep Kill Formation" (Ruedemann, 1902) is the senior synonym for the "Schaghticoke Shale" (Ruedemann, 1903; Stop 13); "Poultney Slate" (Keith 1932), particularly "Poultney B and C" of Theokritoff (1959; Zen, 1967); and "Stuyvesant Falls Formation" (Craddock, 1957; Fisher, 1961, 1962). Although Fisher (1961) incorrectly argued that Ruedemann (1902) defined the Deep Kill as a biostratigraphic unit from what is now known to be two slices at the sole of the Taconic master thrust, Ruedemann (1919), Ruedemann and Cook (1930) and Ruedemann et al. (1942) emphasized the "Deep Kill Shale" as a greenish-gray mudstone-dominated, lithologic and map unit of Early Ordovician age (now known to range into the early Middle Ordovician; Landing, 1976) in the central and southern Taconics.

As noted in this field trip and in Landing et al. (1992), the Lower Ordovician, macroscale black shale-limestone–green shale alternations at the type section of the Deep Kill Formation, are recognizeable in "Poultney B and C" and the "Stuyvesant Falls." Considerable confusion has always attended mapping of the black mudstone-dominated interval termed "Poultney A" by Theokritoff (1959; see Zen, 1964, p. 65; Stop 8). Its definition was primarily biostratigraphic, with the assignment of this black shale-limestone interval as a lowest "Poultney Shale" "member" solely on the basis of its Early Ordovician age. "Poultney A" is not distinguishable from the upper "Germantown Formation" and "West Castleton Formation" (Zen, 1964, p. 65), and the latter three units have been abandoned and synonymized with the Hatch Hill Formation (Landing 1988b).

Austin Glen and "Pawlet" Formations. A second problem is posed by names applied to the Upper Ordovician synorogenic flysch because interpreted tectonic setting has influenced nomenclature. "Pawlet Formation" has been used in the northern Taconics (e.g., Rowley et al., 1979) to refer to flysch in stratigraphic continuity with the allochthonous Taconic sequence, and "Austin Glen" has been preferred for coeval "parauthchthonous"? or allochthonous flysch at the leading edge of the allochthon (Potter, 1972; Fisher, 1977). Lithologic similarity of this medium- to massively-bedded arenite-dominated unit within and along the leading edge of the allochthon and the onset of its deposition late in the early Late Ordovician (upper *Nemagraptus gracilis* Chron) lead to the conclusion that Austin Glen Formation is a senior synonym of "Pawlet Formation" (abandoned designation; Landing, 1988a).

Browns Pond, Hatch Hill, "West Castleton," and "Bull" formations. As discussed in Appendix 1, the type section of the "West Castleton Formation" can be confidently referred to the Hatch Hill Formation, with most fossiliferous outcrops of the "West Castleton" in New York now understood to be referable to the Browns Pond Formation. These conclusions have been earlier detailed (e.g., Landing, 1993, 2007, 2012; Landing et al., 2007), but the revised Vermont Geological Map (2011, legend) incorrectly maintains use of the "West Castleton Formation" (abandoned) as a mapping unit in Vermont, and by implication in the Taconic succession of eastern New York.

It should also be emphasized that recognition (Rowley et al., 1979) and later formal naming of the black mudstones of the Browns Pond Formation as a unit under the red and green "Cambrian roofing slates," or Middle Granville Formation (Kidd et al. *in* Fisher, 1984), means that the traditional "Bull Formation" (*fide* Ratcliffe et al., 2011) actually includes three formations: the Truthville, the Browns Pond, and the Middle Granville formations. For this reason, the "Bull Formation" must be abandoned as a mapping unit, and "Bull Formation" (abandoned) should not appear on the revised Geologic Map of Vermont.