EARLY PALEOZOIC SEA LEVELS AND CLIMATES: NEW EVIDENCE FROM THE EAST LAURENTIAN SHELF AND SLOPE

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INTRODUCTION

Purpose

Field studies undertaken in eastern New York in the early 1800s by Amos Eaton and others led to the birth of American geology (see review by Friedman, 1979). With this early work, geology continued as an important applied discipline, but it developed into an important intellectual and cultural activity that provided the first empirical explanations of physical and biotic change through earth's "deep time." Although almost two centuries have passed since Eaton's first work, "everything isn't known and decided" either about the geology of eastern New York or its significance in opening a window into "deep time."

This field trip (Figure 1) will illustrate recent published syntheses of eastern New York geology that help reconstruct Early Paleozoic sea-level and climate changes. The salient features of these recent syntheses are the following:

A new sequence stratigraphy. A sequence stratigraphy has been developed for the eastern New York–western Vermont shelf (Landing et al., 2003) that shows sequence boundaries at the Cambrian–Ordovician boundary (Stops 6, 7), the Tremadocian–Arenigian boundary (Stop7), and in the middle and terminal Arenigian (Figure 2). As all evidence indicates that this part of Laurentia was a passive margin until within the Late Ordovician (see Mitchell et al., 1997, for the new international convention that mandates that the Chazy, Black River, and Trenton Groups and "Knox unconformity" be assigned to the Late Ordovician), these sequence boundaries correspond to eustatic changes (e.g., Ross and Ross, 1995).

Ending "New England stratigraphy." Our work in this part of the east Laurentian shelf (Landing et al., 2003) has integrated standard lithostratigraphic descriptions from well exposed sections with new macro- and microfossil (primarily conodont) biostratigraphic data to evaluate the areal extent of shelf depositional sequences and formation- and member-level units. This has led to the recognition of regionally extensive stratigraphic units and the abandoning of many formation-level names as junior synonyms following the North American Stratigraphic Commission (1983) rules for nomenclatural priority. Work in Cambrian–Ordovician slope facies of the Taconic allochthon also shows that multiple names have long been used for the same lithologic units along the length of the allochthon. The demonstration of close lithologic similarity in "units" of the same age allowed a reduction of Taconic stratigraphic names to about one third by synonymy (Landing, 1988b; Landing and Bartowski, 1996). Ending "New England stratigraphy," in which each county seems to have its own stratigraphic nomenclature (see Appendix), helps in the reconstruction of geologic history by more accurately and simply recording the areal extent of lithofacies and their depositional environments.

Reconstructing Early Paleozoic paleoclimates and eustasy and correlating enhanced deep-water fossilization potential with greenhouse intervals. Slate colors in the Taconic allochthon are a proxy for Early Paleozoic 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 external slices of the Taconian allochthons of New York and Québec (Stops 8–11) reflect paleo-oceanographic changes. Black, organic-rich mud was deposited under a more intense and thicker dysaerobic slope water mass with sea-level rise, resultant climate amelioration (greenhouse intervals), and reduced oceanic circulation. Green (and purple and red) mud deposition reflected improved mid-water oxygenation, climate minimum (icehouse intervals), and increased deep-water circulation (Landing et al., 1992, 2002). The bedded limestones characteristic of black mudstones reflect off-shelf transport of active and prograding carbonate platforms with sea-level rise, while the abundant trace fossils in green slates reflect higher bottom-water oxygen levels. The linkage of green and black mudstone deposition to sea-level fall and rise, and thus to shelf sequence stratigraphy, will be discussed on this trip. The black mudstone and limestone alternations have supplied the majority of biostratigraphic information through the Taconic succession because the limestones yield Cambrian macro- and microfaunas transported from the shelf margin (Landing and Bartowski, 1996; Landing et al., 2002). 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, 1994) known from the Taconic allochthon. Taconic black shale intervals are equated with improved deep-ocean taphonomic conditions during greenhouse intervals—with improved preservation of biologic materials transported into a deep-water environment largely devoid of larger organisms.

While macroscale black–green alternations appear to reflect sea-level and climate changes with a periodicity of 3–5 m.y. (Landing et al., 1992), shorter duration climate cycles in the Milankovich band seem to be recorded by asymmetrical, mesoscale Logan cycles in the green-dominated mudstones (Stop 12). Logan cycles, up to 5 m-thick cycles that show an upward decrease in organic content and a corresponding upward increase in carbonate content, are redox cycles known through the Phanerozoic. 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.

Route

The route of this field trip (Figure 1) helps emphasize the wealth of geologic history and geologic provinces that are displayed by eastern New York bedrock. The trip originates in Proterozoic basement of the southern Adirondacks (deformed and metamorphosed ca. 1.1 Ga in the Grenvillian orogeny) and ends in the 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

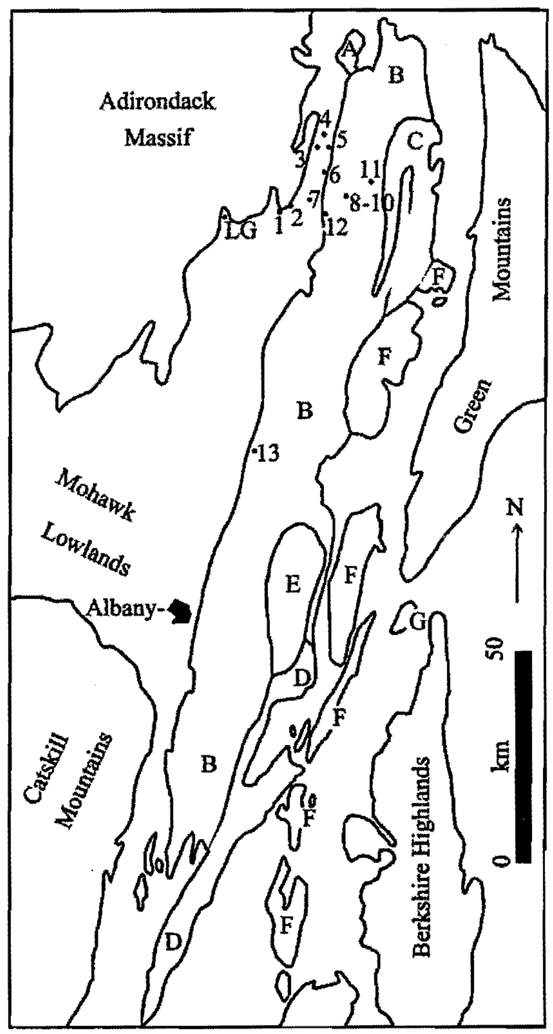

Figure 1. Generalized locality map showing locations of field trip stops (1–13)."LG" is Lake George village; major slices of the Taconic allochthon include A, Sunset Lake; B, Giddings Brook; C, Bird Mountain; D, Chatham, E, Rensselaer Plateau; F, Dorset Mountain–Everett; G, Greylock. Map modified from Zen (1967).

essentially flat-lying (albeit block-faulted) Laurentian Cambrian–Ordovician shelf of southern Warren and western Washington Counties; and then crosses N- and NE-trending block 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 deformed autochthonous Cambrian–Ordovician shelf sedimentary rocks east of Whitehall and the Champlain Canal is comparable in geologic position to the Paleozoic succession of the Great Basin. Thrusting of these Cambrian–Ordovician shelf rocks upon themselves on a thrust comparable to the Champlain thrust in the Whitehall area (see mile 31.9 discussion) has an analog in the Sevier belt of central Utah. Finally, the transport of slope and rise facies of the Taconic allochthon onto Laurentia is analogous to the history and facies of the Devonian–Carboniferous Antler orogen of central Nevada–Idaho.

ACKNOWLEDGMENTS

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ROAD LOG

A useful map for the route of this trip is the Washington County map published by JIMAPCO (Round Lake, NY), which is available in local gas stations and convenience stores. Fisher's (1984) geologic map is particularly useful. However, some of the stratigraphic names used for Cambrian–Ordovician platform and Taconic units in Fisher (1984) have been subsequently abandoned in favor of older synonyms which help emphasize the regional extent of formation- and member-level units in the Hudson, Mohawk, and Lake Champlain valleys and in the Taconic allochthon (Landing, 1988b; Landing et al., 2003; see also field trip stop discussions and Appendix).

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 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 that 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 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.

14.5 View to left (NE) of last 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 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" as mapped by Fisher, 1984).

16.4 Enter village of Fort Ann.

16.5 Turn left (North) onto Catharine Street.
16.6 T-junction with Charles Street; turn left (NW) and follow west bank of Halfway Creek.
17.7 Stop and park in unimproved parking lot ca. 75 m south of bridge over Halfway Creek. Walk ca. 90 m to NNE on dirt track to Kane Falls on Halfway Creek.

STOP 1. LOWER ORDOVICIAN AT KANE FALLS: AGE AND LITHOSTRATIGRAPHIC REINTERPRETATIONS. (30 MINUTES). A stratigraphic section for Kane Falls will be distributed on this field trip; this section is available in Landing et al. (2003, fig. 5).

Mazzullo (1974) and Fisher and Mazzullo (1976), respectively, termed the upper part of the Kane Falls sequence a "reference section" for the lower part of the lowest Ordovician "Cutting Formation" and "Great Meadows Formation" (abandoned designations). A planar-laminated silty dolostone 9.55–10.75 m above the base of this 23 m-thick section (Landing et al., 2003, fig. 5) at the top of the falls was regarded as a thin or condensed "Winchell Creek Siltstone" (abandoned term, now Sprakers Member of Tribes Hill Formation; Landing et al., 2002; see Appendix). This interpretation meant that Kane Falls is near the western feather-edge of this lowest "member" of the "Great Meadows" and that a disconformity separated the silty dolostone from the underlying "Whitehall Formation" (abandoned designation, now Little Falls Formation; Landing et al., 2003, see Appendix).

Re-investigation of the Kane Falls section (Landing et al., 2003) led to its re-interpretation. 1) There is no physical evidence for disconformity at the base of the silty dolostone. 2) The medium-gray thrombolitic dolostones and dolomitic limestones of the lower 9.55 m of the section do not resemble the light gray or white thrombolites of the upper Little Falls Formation ("Whitehall") at Steves Farm (Stop 6) or elsewhere in the Lake Champlain Lowlands. These medium-gray thrombolitic facies resemble those in the middle "Fort Ann Formation." 3) Diverse conodonts in the thrombolitic facies and rarer conodont elements in the higher laminated dolostones at Kane Falls are significantly younger than those from the Tribes Hill Formation (="Cutting"/Great Meadows," designations abandoned by Landing et al., 2003). The conodonts from Kane Falls are all referable to middle Lower Ordovician conodont Fauna D of Ethington and Clark (1971), and are comparable to those of the "Fort Ann Formation" elsewhere in the Lake Champlain lowlands.

The "moral" of this stop is the following: Mapping and stratigraphic syntheses on Lower Paleozoic carbonates on the New York Promontory require a combination of a detailed familiarity of lithofacies with adequate micro- and macrofossil investigations to allow age discrimination of broadly similar carbonate platform units.

17.6 At end of stop, return to Fort Ann on Charles Street, pass intersection with Catharine Street.
18.6 T-junction with Rte. 4; turn left (N) and continue on to Whitehall.
19.3 Cross onto uplifted (Proterozoic) block of Welch Hollow Fault and pass by ca. 1 mile of Grenvillian road cuts.
20.3 Stop along road side just south of north exit of Flat Rock Road.

STOP 2. PROTEROZOIC–TERMINAL MIDDLE CAMBRIAN NONCONFORMITY AND THIN LOWER PALEOZOIC SHELF SUCCESSION. (10 MINUTES). Approximately 4 m of east-dipping, medium–coarse grained, slightly dolomitic quartz arenite of the Potsdam Formation nonconformably overlie Grenvillian gneiss with east-dipping exfoliation surfaces. This photogenic locality records the absence of ca. 600 million years of earth history at this planar nonconformity. Flower (1964, p. 156) reported a trilobite fauna (presently unillustrated) approximately 5–6 m above the base of the Potsdam in this area, which he said includes a possible *Crepicephalus* with *Komaspidella,* and *Lonchocephalus*. Following the recent decision (January 2002) of

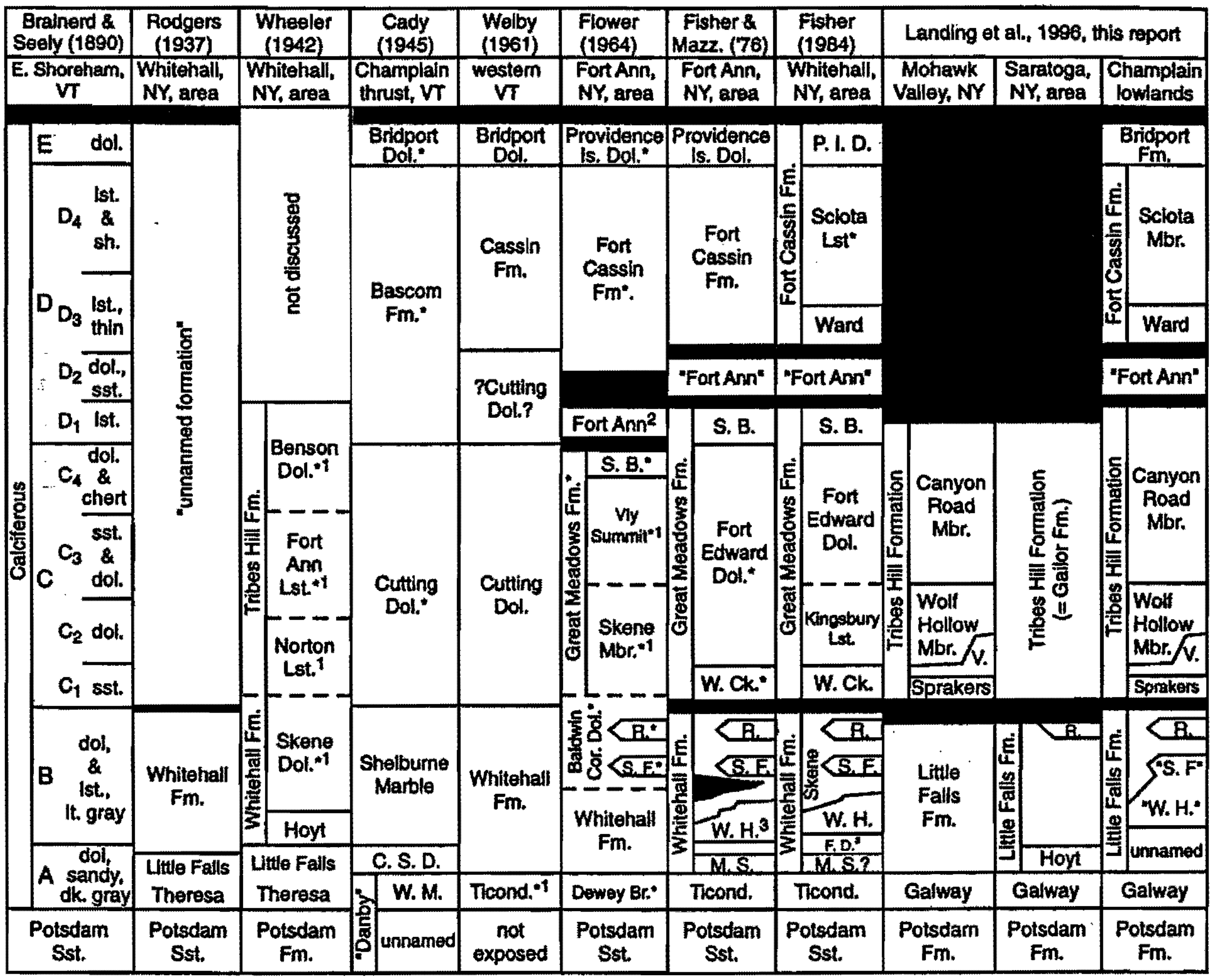

Figure 2. Uppermost Cambrian–Middle Ordovician stratigraphic nomenclature of the Laurentian platform in eastern New York and western Vermont. Cambrian–Ordovician boundary is in hiatus between the Little Falls and overlying Tribes Hill Formations. Presence of *Paraprioniodus costatus-Chosonodina rigbyi-Histiodella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

limestone (Canyon Road Member; = "Fort Edward" + "Smith Basin" Members of Fisher [1977] and Flower [1968b]) extend to the top of the Tribes Hill. The top of the Tribes Hill Formation forms the crest of the 132 m (440 foot) hill, and has a paleokarst surface with 30 cm of relief overlain infilled by arenaceous dolostone of the "Fort Ann Formation."

Conodonts from the Tribes Hill Formation comprise a low diversity, restricted marine assemblage that persists unchanged through the formation. This *Rossodus manitouensis* Zone assemblage is referable to the lowest Ordovician (middle–upper Tremadocian-equivalent), and shares no taxa either with the underlying Little Falls Formation or the overlying "Fort Ann Formation." The total replacement of the Upper Cambrian, upper *Cordylodus proavus* Zone fauna of the top Little Falls Dolostone (Stop 6) at the base of the Tribes Hill reflects the duration of the trans-Laurentian Cambrian–Ordovician boundary hiatus on the east Laurentian shelf. Similarly, the total replacement of the Tribes Hill Formation conodonts by Fauna D conodonts at the base of the "Fort Ann Formation" reflects the duration of the trans-Laurentian, intra-Lower Ordovician hiatus that occurs in the Tremadocian–Arenigian boundary interval.

46.0 At end of stop, turn back (East) on Rte 22.
48.3 Intersection with Rte 17A on right (South).
48.5 Enter Town of Granville.
48.8 Intersection with Rte 40.
49.5 Enter village of North Granville and cross into Taconic allochthon.
50.7 Intersection with west exit of Washington Co. Rte 12A, rocks immediately ahead are probably Lower Cambrian Bomoseen Member (argillaceous lithic arenites).

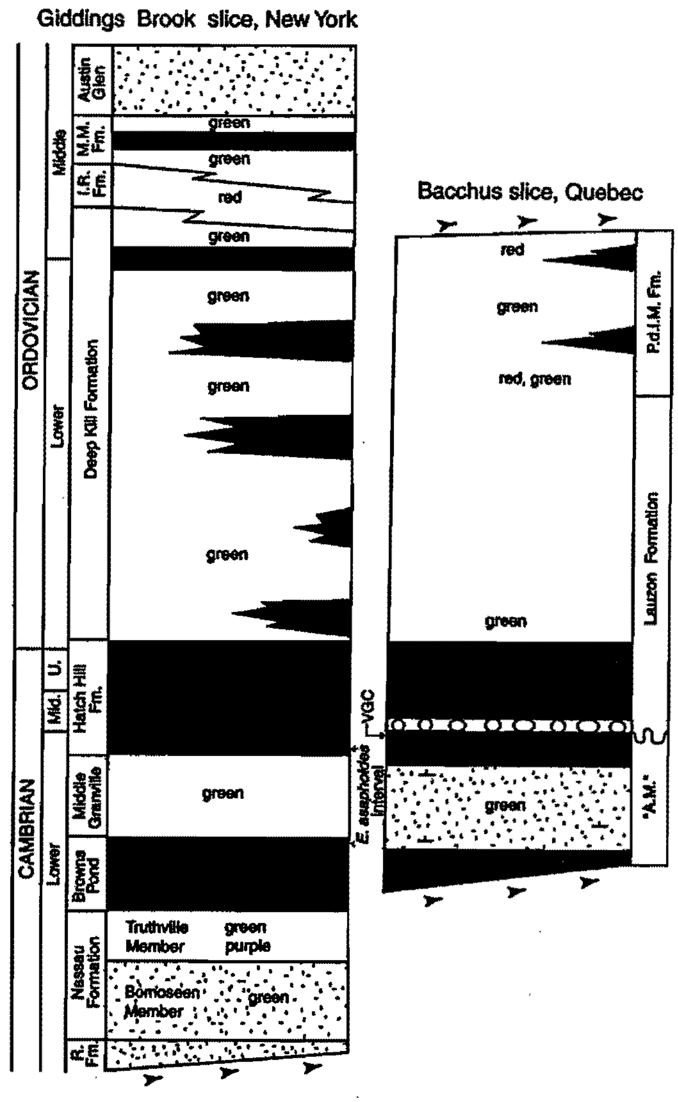

Figure 3. Correlation of proximal (Bacchus slice) and distal (Giddings Brook slice) slope facies in Taconian Quebec and New York, respectively. Figure shows regional extent of dysaerobic black shale-limestone intervals (in black) and more oxygenated, green, purple, and red shale and sand-dominated (dot pattern) facies. Abbreviations: "A.M.", "Anse Maranda Formation;" I.R. Fm., Indian River Formation; M.M. Fm., Mount Merino Formation; P.d.l.M. Fm., Point de la Martiniere Formation; R. Fm., Rensselaer Formation; VGC, *Bicella bicensis* interval at Ville Guay. Black shale-limestone intervals in Point de la Martiniere Formation with middle and upper Arenigian faunas (Rasetti, 1946, p. 698; Landing and Ludvigsen, 1984; Landing et al., 1992). Figure modified from Landing et al. (2002, fig. 3).

51.3 Intersection with east exit of Rte 12A, turn hard left (North).
51.5 Turn right onto Rte 12 in hamlet of Truthville.
51.7 Cross bridge over Mettawee River.
51.8 Turn right (East) onto Middletown Road (dirt).
53.0 Y-intersection with Loomis Road (right), bear left and continue on Middletown Road.
53.3 Intersection with DeKalb Road (paved), turn left (NW) onto DeKalb.
53.4 Intersection with Holcombville Road, turn right (North) onto Holcombville.
54.1 Drive past slate scrap heap and quarry (on left, West) in North Granville Slate.
54.8 Pass Tanner Hill Road on left (West) and continue North.
55.5 Stop just south of Browns Pond at low road cuts on both sides of road.

STOP 8. BROWNS POND: PALEO-OCEANOGRAPHIC CHANGES IN THE LATE EARLY CAMBRIAN. (15 MINUTES). This section may be regarded as the "type locality" for the late Early Cambrian Browns Pond dysaerobic interval on the east Laurentian slope (Landing et al., 2002). The Browns Pond dysaerobic interval is recognized throughout the external thrusts of the Taconic allochthon in New York–Vermont and in Taconian Québec (Figure 3).

This overturned section in the upper Browns Pond Formation shows several meters of dark gray, fine-grained sandstones and slates with thin (decimeter-thick), lensing, sandstone pebble debris flows on the east side of the cut. Small-scale current cross-bedding in the orange-weathering, dolomitic quartz aenites shows that the section is overturned. Although centimeter-wide grazing trails can be found on the top of some of the sandstone beds, burrows are rare, and fine lamination and other primary structures are not disturbed in these rocks. Rare burrows, absence of a shelly fauna, and dark gray (carbonaceous) sediments are all consistent with deposition under dysaerobic conditions (e.g., Sagemann et al., 1991).

The west side of the road cut is dominated by a thick limestone pebble to (rare) boulder clast debris flow with local dark argillaceous matrix. Trilobites, archaeocyathan, mollusk, and calcareous and phosphatic problematica of the lower *Elliptocephala asaphoides* assemblage (see Landing and Bartowski, 1996) appear in the limestone clasts at this locality (Theokritoff, 1964). None of these clasts show derivation from the carbonate platform, and they include nodular lime mudstones and bedded fossil packstones that are interpreted as allodapic clasts that accumulated as limestone on the upper slope. Pyrite-infilled and phosphate-replaced, calcareous conoidal fossils in these clasts (E. Landing, unublished data) is consistent with the deposition/lithification of these limestones in a strongly dysaerobic environment that developed on the upper slope (see Landing and Bartowski, 1996; Landing et al., 2002).

Debris-flow conglomerate lenses are common as the cap unit of the Browns Pond Formation, and some have received local stratigraphic names (e.g., Ashley Hill Conglomerate in Landing, 1984). Locally, allodapic fossil hash packstones and decimeter-thick debris lenses are the cap unit of the Browns Pond (e.g., Landing and Bartowski, 1996). In either case, the conglomerates or bedded limestones are directly overlain by a green/green gray or locally purple or red siliciclastic mudstone unit in the Taconic allochthon. This black–green transition in the late Early Cambrian is seen here at Stop 8 immediately above the conglomerate with the abrupt transition into the lower green slates of the Middle Granville Slate. These green slates form low outcrops in the pasture to the west. Stop 10 further illustrates this interval of improved oxygenation on the east Laurentian slope and relates the improved oxygenation to the latest Early Cambrian Hawke Bay regression of Palmer and James (1979). Sea-level still-stand and progradation of the shelf margin or sea-level fall at the onset of the Hawke Bay regression are mechanisms to explain the carbonate clast debris flows and allodapic limestones at the top of Browns Pond dysaerobic facies.

55.5 At end of Stop 8, turn south on Holcombville Road.
56.2 Intersection with Tanner Hill Road, turn right (west).
56.4 Park at foot of hill at lowest outcrop of brown-weathering sandstones.

STOP 9. TANNER HILL SYNCLINE:PALEO-OCEANOGRAPHIC CHANGES IN THE LATEST EARLY CAMBRIAN–MIDDLE ORDOVICIAN. (40 MINUTES). The superb Tanner Hill section was first described by Rowley et al. (1979). The walk up hill crosses the overturned east limb of a large syncline.

Dolomitic quartz arenites and interbedded, minor dark gray and black siltstones and shales form the lowest part of the section. The coarse, lensing (apparently channelized), conglomeratic sandstones become thinner bedded and finer grained higher in the section, and black shales become dominant. This entire interval up to an abrupt transition into 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 [early Tremadocian] Hatch Hill dysaerobic 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 dysarobic mudstone deposition that has been termed "Poultney A" (abandoned designation, Landing, 1988b) by Theokritoff (1959; Zen 1964; see Appendix). A sharp transition from the Hatch Hill Formation into the lowest green-gray mudstones of the Deep Kill can be observed 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 (Stops 11, 13; Figure 3).

The transtion 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 to grayish sediment color, and an alternative explanation for the color of the Indian River must be found. Landing (1988b) noted the multiple lines of evidence (e.g., occurrence of radiolarian cherts and thin volcanic ashes undiluted by background argillaceous sediment; thorough burrow-homogenization of much of the unit; presence of large, up to 3 cm-wide burrowers) 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. Cherty red slates are widespread in a number of orogens (e.g., in the Taconian allochthons from New York to western Newfoundland, southern Uplands of Scotland, Hercynian Rheinisches Schiefergebirge and Hart Mountains, and Jurassic of Japan), where they always underlie green mudstones and higher flysch. These data suggest that red, cherty, oxygenated shales in overthrust belts reflect the following history: passage of a peripheral bulge through passive margin successions; consequent flexural uplift and restriction of sedimentation on the peripheral bulge to slowly deposited pelagic muds, radiolarian cherts, and thin volcanic ashes; and final flexural down-warping and increased rates of deposition as sediment provenance changes to the emergent accretionary prism. The transition into the green-dominated, synorogenic mudstones of the overling Mount Merino and then into Austin Glen Formation flysch are present in the core of the Tanner Hill syncline.

56.4 At end of Stop 9, return to Holcombville Road.
56.6 Intersection with Holcombville Road, turn right (South).
57.3 Park at road side opposite slate pile (on East) and next to quarry on right (West).

STOP 10. OXYGENATED MIDDLE GRANVILLE SLATE AND THE HAWKE BAY REGRESSION. (15 MINUTES). This stop serves to fill in the stratigraphic interval between the rocks of Stops 8 and 9.

The large pile of brownish red and minor green slate of Middle Granville Slate on the east side of the road apparently came from the small flooded quarry on the west side of the road. If the light is good, dense *Planolites* traces can be seen on many of the bedding plane-parallel cleavage surfaces of the reddish slate, where they accompany large grazing traces up to 2 cm in width. 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.

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. This interval of improved oxygenation of slope waters is equated 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 dysaerobic interval) took place in the terminal Early Cambrian. This Lower–Middle Cambrian boundary interval eustatic rise and climate amelioration led the actual movement of poorly oxygenated slope water onto the continental shelf in such widely separated areas as northern Vermont (Parker Slate) and eastern California (Mule Springs Formation) (Landing and Bartowski, 1996).

57.3 At end of stop, continue south on Holcombville Road.
57.9 Intersection of Holcombville Road with DeKalb Road, turn left (SE) on DeKalb.
58.0 Pass intersection with Middletown Road, continue on DeKalb.
59.5 T-intersection with Steeles Bridge Road, turn right (South) over Mettawee River bridge.
59.7 Intersection with Rte 22A, turn hard left (North) onto Rte 22A.
57.9 Cross Mettawee River again.
58.8 Pass cut in slates and limestone at Raceville.
59.0 Park on right side of Rte 22A just north of road cut. Walk back to cut.

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APPENDIX

Revisions in Stratigraphic Nomenclature—Cambrian–Ordovician Platform

Tectonic setting and stratigraphic nomenclature. An apparently uniform Upper Cambrian–Lower Ordovician lithostratigraphy occurs in authochthonous sequences on the west side and south end of the Lake Champlain lowlands and in the parautochthonous Champlain slice in west-central Vermont (e.g., Fisher, 1984; Fig. 1). However, a confusing stratigraphic nomenclature obscures the regional extent of lithic units and the simple Early Paleozoic evolution of this stretch of the New York Promontory. This complexity reflects the proposal of synonymous units in New York and Vermont, usually without designation or description of type sections, detailed lithic characteristics, or 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 (Fig. 2).

Tribes Hill, "Cutting" (abandoned), and "Great Meadows" (abandoned) Formation. Ulrich and Cushing's (1910) and Wheeler's (1942) attempts to apply 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 in this part of 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" (Ulrich and Cushing, 1910) as a unit that extends from its Mohawk River valley type area into the Lake Champlain lowlands is appropriate. The "Cutting/Great Meadows Formation" of the Lake Champlain lowlands rests unconformably on latest Cambrian carbonates and forms a deepening–shoaling sequence in the *Rossodus manitouensis* Zone. These stratigraphic relationships are identical to those of the coeval Tribes Hill Formation in theMohawk River valley (see Landing et al., 1996). The vertical succession of facies in the Cutting/Great Meadows" in the Lake Champlain lowlands is also so similar to those of the Tribes Hill in the Mohawk valley that the same member-level nomenclature is appropriate (discussed below). These lithologic correspondences mean that "Cutting Formation" and "Great Meadows Formation" must be abandoned for the older synonymous term "Tribes Hill Formation."

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.

Little Falls, Galway, "Ticonderoga" (abandoned), and "Whitehall" (abandoned) Formations. 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 dolomitized) 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 the "Ticonderoga Formation" (J. Rodgers *in* Welby, 1961; abandoned by Landing et al., 2003; a junior synonym of Galway Formation in Figure 2), 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" by Galway Formation in the Lake Champlain lowlands.

"Fort Ann Formation." "Fort Ann Formation" is used provisionally for a carbonate-dominated, middle Lower Ordovician unit in the Lake Champlain lowlands that unconformably overlies the Tribes Hill Formation and (probably) unconformably underlies the Ward Siltstone member of the upper Lower Ordovician Fort Cassin Formation (see Fisher, 1984; Brett and Westrop, 1996). The checkered history of "Fort Ann" (Fig. 2) 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, the designation "Fort Ann" is an objective homonym in several important early publications that sought to establish a uniform stratigraphic momenclature in the Lake Champlain Lowlands. No type section has been designated for the "Fort Ann," and Fort Ann village itself is surrounded by Middle Ordovician flysch. "Fort Ann" is a depositional sequence that corresponds to the conodont Fauna D interval of the Lake Champlain lowlands and requires a new stratigraphic name (Fisher and Mazzullo, 1976, fig. 5; Fisher, 1977; EL, unpubl. data).

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).