FAULT SYSTEMS OF THE TACONIC FORELAND; WHITEHALL, NY TO WEST HAVEN, VERMONT [ALL KINDS OF FAULTS!]

William S.F. Kidd, formerly of Geological Sciences, University at Albany, Albany, NY 12222
Stephen S. Howe, Atmos. & Environmental Sciences, University at Albany, Albany, NY 12222
Chul Lim, formerly of Geological Sciences, University at Albany, Albany, NY 12222
Email address: wkidd@albany.edu

INTRODUCTION AND SUMMARY

Map-influencing faults of all displacement kinds are observed in the anomalously narrow Taconic orogenic foreland belt in the region where it crosses the New York - Vermont border between Whitehall, NY and West Haven, VT. Outcrop and map evidence for the relative age and displacement of these faults can be seen on this trip. In general, transported Cambro-Ordovician rocks of the continental shelf/platform and of the off-shelf strata in the Taconic Allochthon are affected by thrust faults of a range of ages relative to development of folding and cleavage in particular rock packages. The thrusts all predate large-scale strike-parallel east-side-down normal faulting, in most places in the area to be visited apparently localised, in a large displacement (1000m or more), on one such fault, the Mettawee River Fault. The youngest of the fault sets consist of cross-strike, strike-slip faults, mostly ENE- to NE-trending, some of which have mappable apparent left-lateral displacement, cutting thrusts and the normal fault. Movement on the strike-slip fault system at West Haven was accompanied in this area by fluids shown by our measurements of fluid inclusion homogenization to have been at temperatures sufficiently high to be most likely of Ordovician (Taconic) age. These oblique faults probably had a prior history as components of a trench forebulge normal fault system; they may have influenced at that time and perhaps also earlier the sedimentation on the Laurentian continental shelf, and therefore they may have been localised by an old inherited fracture/fault system in the underlying Grenville basement of this area. More generally, forebulge normal fault scarp topography, whose development mostly predated thrust arrival at any position, are perhaps also responsible for the repeated detachment and stacking of thin slices of the medial Ordovician limestones of the uppermost carbonate shelf which are extensively developed in the area of this field trip. The lower contacts of these slices show evidence of thrust fault transport, and do not support a model of large-scale olistostromal origin. Because the trip is confined to the area affected by thrusts, we will not see unmodified forebulge-type normal faults in autochthonous basement and platform strata, but they occur just to the west along southernmost Lake Champlain. And there are other kinds of fault affecting geological maps of the area which may be mentioned during the trip.

STRATIGRAPHIC CONSIDERATIONS

The stratigraphy defined in the autochthonous Cambro-Ordovician shelf strata near Whitehall (Fisher, 1985) includes: basal clastics (Potsdam sandstone, Ticonderoga dolomitic sandstone); massive dolostones (Whitehall formation, which include a limestone unit, Warner Hill limestone); a second sequence of mixed carbonate and clastic units (Great Meadows formation; which includes Winchell Creek arenite/siltstone, Fort Edward dolostone, & Smiths Basin limestone); a second mostly dolostone unit (Fort Ann formation; which includes many impersistent thin limestones); and a second sequence of mixed carbonates and clastics (Fort Cassin formation; which includes the Ward siltstone, Sciota limestone, & the Providence Island dolostone). The more distinctive of the lithic units are readily mappable and traceable in the gently-dipping section of autochthonous strata along the whole length of the area of this field trip.

In the transported Champlain system thrust sheets, however, things are not so readily separated. Hayman & Kidd, (2002a) maintained, and we agree, that the stratigraphy to use within the Champlain system thrust sheets is best kept simple – a basal quartzite, an overlying dolomitic section, capped by a Chazy and younger limestone section. The middle of this simple sandwich largely contains massive (and monotonous) dolostones; very locally in Vermont, distinctive units (a thin (<10 meters) limestone, and a siltstone horizon) can be found within them. This massive dolostone with a few discontinuous and thin limestone horizons, in the Shoreham Thrust sheet in the area of the field trip, must be a distal facies of some part of the autochthonous succession near Whitehall. We call this the Providence Island facies as almost all of it most closely resembles descriptions of the Providence Island unit in the

Whitehall succession, but we do not mean to imply any age constraint by this purely lithostratigraphic label. Only the base of the Pinnacle Thrust sheet is seen north of the latitude of Whitehall in the area of the trip, and it consists of quartzites and dolostones equivalent to part of the Potsdam, and perhaps of the Ticonderoga units of the Whitehall autochthonous strata.

Taconic units of the northern Allochthon in the area of the field trip are all slates with exceptions for arenites contained in the Hatch Hill, thicker limestone breccias and an arenite of the Browns Pond, and cherts of the Mt Merino.

The medial Ordovician grey shales and silty shales of the area are an orogenic flysch deposit; syn-orogenic clastic materials shed from the active Taconic orogen to the east. In the area of the field trip, coarser clastic materials are quite uncommon, compared with the area around Albany and farther south. Most of the material to be seen on this trip, deposited originally over subsiding shelf rocks, was deformed by overriding thrust sheets, and transported to some (unknown) extent; much of it is now melange in the sense it contains a characteristic pervasive lenticular fracturing/"cleavage", termed phacoidal by some. The exception is in the northern area of the trip, around West Haven, where well-cleaved grey slates with silty laminae in places outcrop extensively, and are called Hortonville (Zen, 1967); these are probably a lithological equivalent to the medial Ordovician grey shale and melange farther south. We think from their structural condition that they should be regarded as a (western) part of the Taconic Allochthon, and that they are likely to have been significantly thrust-transported.

SOME ASPECTS OF THE FAULT SYSTEMS AND TECTONIC SETTING

This field trip visits outcrops of the Champlain thrust system which was responsible for large (>80 km) thrust transport of the shelf section carried by it around Burlington; the thrust system projects to depth and thus is dynamically related to the overlying Taconic thrusts, and collectively forms a decollement beneath the Green Mountain crystalline core of the Taconic orogen (Rowley, 1982).

The Cambrian-early Ordovician strata of the Taconic Allochthon were first identified by Bird and Dewey (1970) as continental rise and middle Ordovician foredeep sedimentary facies, with refinements placing them in the setting of an island arc-passive continental margin collision made by subsequent work (Rowley et al., 1979; Rowley and Kidd, 1981; Bosworth and Rowley, 1984). This requires a restoration of these rocks to their depositional site as far-traveled tectonically rooted thrusts such as are found in modern arc-continent collisions (Rowley and Kidd, 1981). A more recent contribution (MacDonald et al 2017) proposes that the western margin of the Taconic orogen is merely a rear-arc fold-thrust belt, consequent on older subduction/collision event(s) farther east.

The simplest model of such a foreland thrust system predicts a forward-propagating system where thrusts young to the west. However, relationships of thrusts found in the Taconic foreland require at least some late deformation (Zen, 1972; Rowley and Kidd, 1981; Stanley and Ratcliffe, 1985). One explanation for late deformation derives from observations of outcrop structures, fabrics, and map patterns in the Taconic foreland requiring at least one out-of-sequence thrust towards the front of the Taconic thrust system. This thrust was (perhaps awkwardly) named the Taconic Frontal Thrust due to its position at the western front of the Taconic Allochthon near Whitehall, NY (Bosworth et al., 1988).

The Taconic Frontal Thrust cuts the Taconic Basal Thrust, the thrust responsible for the initial transport of the rise-facies Taconic sequence (Bosworth and Rowley, 1984). Most of the deformational patterns at both the outcrop and map scale can be explained with this model of Middle Ordovician forward propagating thrusting, with a component of out-of-sequence thrusting, the latter perhaps in part of the Acadian rather than the Taconic orogenic event (Zen, 1972; Hames et al., 1991; Chan and Crespi, 2001).

A key structure in understanding the geology of the exceptionally narrow Taconic thrust belt in the area of this field trip is the Mettawee River Fault, first recognised by Fisher (1985), a late strike-parallel eastward-downthrow normal fault that significantly truncates all the thrusts of the Champlain Thrust system. A consequence of the Mettawee River Fault is that it eliminates Champlain thrust slices from map view, by an amount which varies along its trace (Fig 1). Evidence for normal faulting and inferences of its age found by Lim et al (2005) in the Taconic thrust melange belt and on the frontal Taconic fault near Troy, NY suggests that these, and the Mettawee River

Fault, are more probably Ordovician (Taconic) rather than Acadian structures. Lim and Kidd (2008) suggested the change to extension from shortening was a result of a propagating breakoff of the subducted lithospheric slab.

The middle Ordovician outer trench slope was the site of normal faulting, between the synconvergence flexural forebulge and the trench (Cisne et al, 1982; Bradley and Kusky, 1985; Bradley and Kidd, 1991). Hayman and Kidd, (2002a,b) proposed that these prethrusting faults localised many of the along- and across- strike lithic unit changes within the Champlain system thrust sheets. On this trip, faults of this origin (near West Haven) are inferred to have interacted with at least one thrust of the Champlain thrust system, but subsequent components of both strike-slip and dip-slip displacement on the oblique faults have further complicated the relationships.

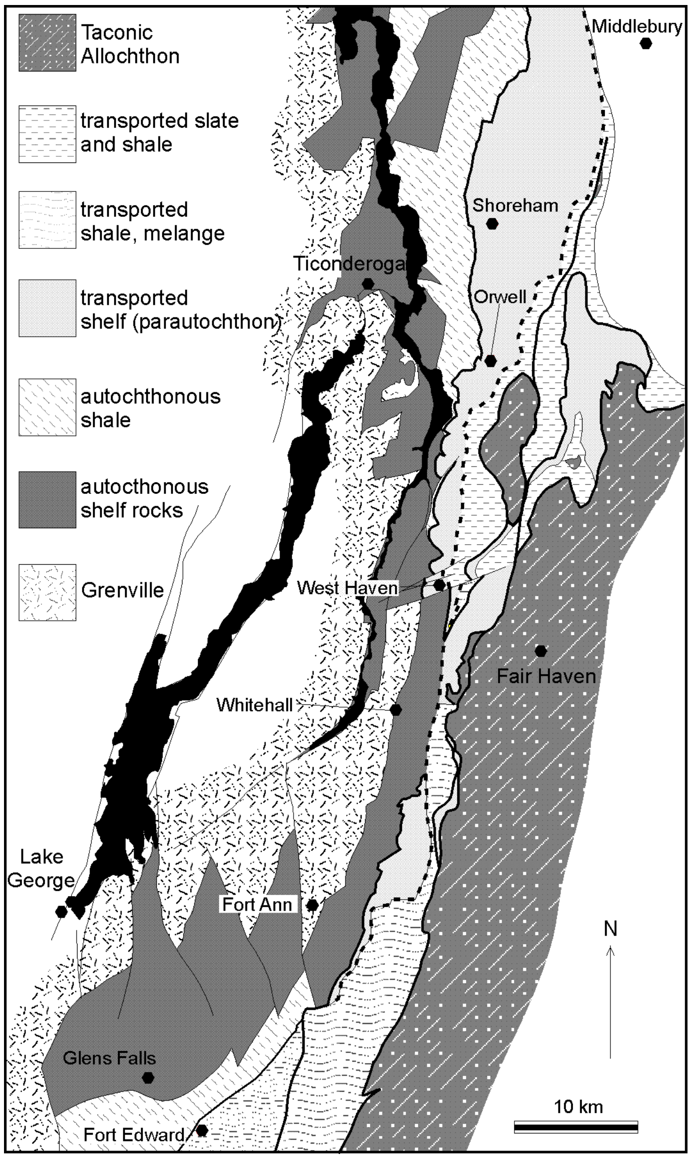

Figure 1. Regional map of west-central Vermont to the upper Hudson River valley of New York illustrating the trace (thicker lines) of the Champlain thrust system. The Mettawee River Fault (thick dashed line) places deformed and low grade metamorphosed shale and flysch, and to the north of Whitehall, imbricated upper shelf carbonates, against the transported shelf (parautochthon). South of the disappearance of the transported shelf, the western thrusts of the Champlain thrust system climb into the melange belts of the Hudson Valley flysch and melange (Kidd et al, 1995); it is unclear exactly where in this belt the trace of the Mettawee River Fault runs. Diagram modifed from Hayman & Kidd (2002a).

VEIN FLUID INCLUSIONS AND FLUID TEMPERATURES

Fluid inclusions in veins associated with faults can give information about the contemporary fluid temperatures, and may constrain the possible source(s) of the fluids from which the veins grew. The temperature information, in the absence of geochronological data, may also permit a constraint to be placed on the age of the veins and the associated faulting. Lim et al (2005) reported on the structural history and fluid inclusions of calcite and quartz-calcite veins associated with thrust and later cross-cutting but strike-parallel normal sense faults in the Ordovician melange west of the Taconic Allochthon (see Fig. 2). In the NY Capital Region near Albany, both the thrust and the younger normal-sense veins have fluid homogenization temperature ranges (280-190C) significantly higher than those in nearby Devonian Helderberg Limestones affected by Acadian thrusts (most are 130-100C, max. 170C). The inference is that the veins and associated faults in the Ordovician melange of the NY Capital Region, including those immediately adjacent to the western bounding fault of the Taconic Allochthon, are all Ordovician-age structures. The absence of any original normal-sense veins cutting thrusts in the Helderberg thrust belt tends to support this interpretation. All inclusions from veins in the Ordovician melange have low salinity, consistent with a metamorphic fluid source at greater depth down-dip to the east in or under the Taconic thrust prism.

Only thrust sense veins were observed and sampled in Ordovician melange north of the NY Capital Region, and these show (Fig. 2) somewhat lower homogenization temperature ranges, apparently declining to the north, to about 190-220C at the Mettawee River locality of Stop 1A of this trip, and to about 150-210C in the slates adjacent to the Mettawee River Fault exposed near West Haven at stop 6B of this trip. Note that these are still well above the typical 100-130C homogenization temperatures found in samples from the Acadian Helderberg thrust belt near Albany.

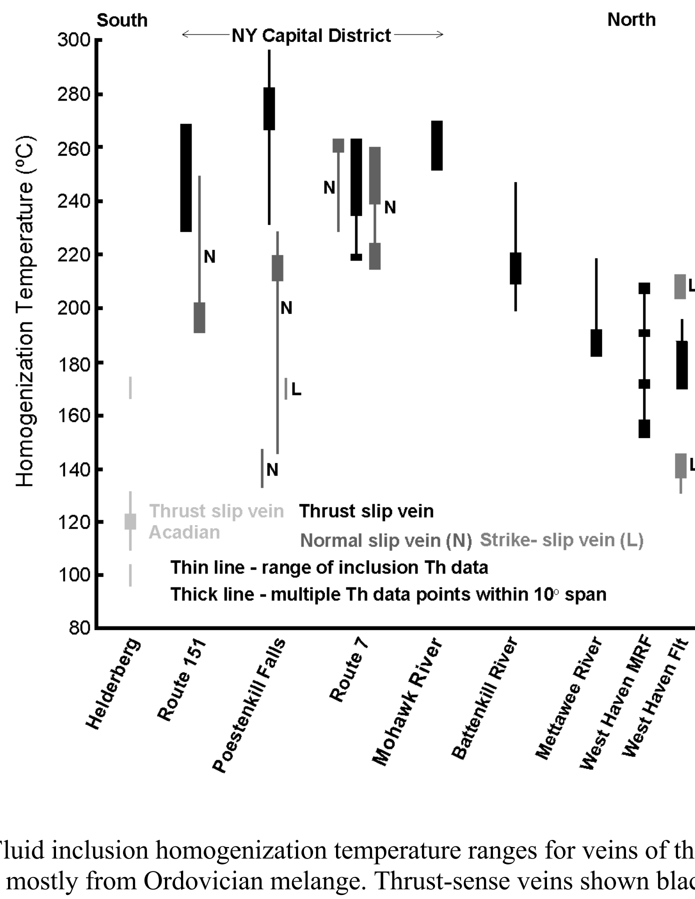

Figure 2. Fluid inclusion homogenization temperature ranges for veins of the Taconic foreland thrust belt, mostly from Ordovician melange. Thrust-sense veins shown black; normal-sense veins shown dark grey (N); strike-slip left lateral veins shown medium-grey (L). Compiled from data in Lim et al (2005), with addition of West Haven Fault.

After finding the outcrop at West Haven (stop 7A of this trip) where N-S striking probable thrust-sense calcite veins in the limestone are offset by ~E-W left-lateral strike-slip veins, we sampled these, and measured fluid inclusion homogenization temperatures. The summarised results are included in Fig 2, and temperatures for the older veins of 170-195C fall within in the range found for thrust-sense veins nearby in the outcrop of stop 6B. Temperatures for the cross-cutting strike-slip veins yielded two groups of restricted temperature ranges, with two different samples having homogenization temperatures ~205-215C, and one other sample ~135-145C. Interpretation of the lower temperature range might be that it is from younger vein growth after introduced hot fluids had cooled; or that they are secondary inclusions formed after the rocks had cooled significantly. However, the higher range above 200C found in two samples, which we suggest constrains the initial fluid temperature along the strike-slip fractures, we think is good, or at least suggestive evidence that these veins are Ordovician. Although we do not have measurements from veins of normal sense outside the NY Capital Region, we do observe that the Mettawee River normal Fault cuts all thrusts of the Champlain Thrust system, in the area of this field trip. The WSW-ENE strike-slip faults cut the Mettawee River Fault (Fig 8; stops 6B, 7C), so we suggest that all faults seen on this trip, including these, are Ordovician (and Taconic) structures.

ACKNOWLEGEMENTS

Parts of this field guide and some of the stops visited are derived from text and figures in Bosworth and Kidd (1985) - for stops 1A, 1B, 4, and 5; some other parts derive from text and figures in Hayman and Kidd (2002a) - for stops 1A and 6A and 6B; the material descriptions for the other stops are new.

Detailed geological mapping that contributes to understanding of this area and the fault structures in it can be found in several theses and dissertations completed in the Geological Sciences at SUNY Albany; Louise (Delano) Jacobi (1977); David Rowley (1979, 1983); Christof Steinhardt (1983); Jennifer Granducci (1995); Nick Hayman (1997), as well as unpublished maps by Pan Yun and Ed Rodgers. In addition, undergraduate students participating in the Albany field mapping course over many years helped by locating outcrops and in identifying some key localities. Maps made by Steve Tice and John Moss near Whitehall were particularly helpful, and participants in the course in 1998-2001, 2005 and 2006 helped in untangling the geology nearer West Haven. Permission by numerous landowners to enter their properties is greatly appreciated and in particular the owners of the Book Farm are thanked for allowing numerous visits over many years. The current owners of Coggman Creek Farm at West Haven are also thanked for permitting us to drill samples from the unique outcrop near their house.

ROAD LOG AND STOP DESCRIPTIONS

Assembly Point – Fort William Henry parking lot, Lake George Village, Saturday, 13th October, 2018, 8.30 am.
If more convenient to meet at Stop 1, arrive there no later than 9am.

MILEAGE

Miles	Incr.	Directions
0.0	0.0	Intersection US Rte 9 and NY Rte 149 about 4 miles south of Lake George Village NY. Go east on Rte 149.
11.7	11.7	Intersection NY Rte 149 and US Rte 4, Fort Ann NY; turn left onto Rte 4 northbound.
15.5	3.8	Intersection (with light) US Rte 4 and NY Rte 22 at Comstock NY; turn right onto Rte 22.
19.7	4.2	Intersection NY Rte 22 and NY Rte 40 (to right); Sheehan Rd Ext (to left); turn left.
19.9	0.2	Go 0.2 mile to end of Sheehan Rd Ext; intersection with Grey Goose Rd and Upper Turnpike; turn part left onto Upper Turnpike.
20.9	1.0	Go 1.0 miles to gravel parking area on right [43.470907, -73.369207] - **Stop 1**
		Walk down the path from the center of the east side of the parking area to the outcrop at the river [43.471240, -73.368354].

Caution - If wet, the path down can be slippery since it passes through well-rounded fluvial pebble gravel and underlying lake clays; the sloping bedding surfaces of the carbonate outcrops at this locality can also be treacherous in places. Poison ivy occurs here

STOP 1A: METTAWEE RIVER FAULT AT THE TYPE LOCALITY

[NO HAMMERS OR SAMPLING PLEASE - NY DEC REGULATIONS]

The carbonates here along the west bank of the river are mapped by Fisher (1985) as early Ordovician Providence Island Formation, and dip about 10-20 degrees east; they are the upper part of a thrust-transported section above the Comstock (= Pinnacle) Thrust. The lowest part of the section here consists of dolostones; the upper 4 meters contains limestone beds; we think it is possible that the part of the section containing limestones is either basal Chazy or Black River. These show some bedding surfaces with well-developed ripples, and small mudcracks, and selectively dolomitized burrows. Local meter-scale folding of periclinal geometry affects these beds near this end of the section. Across the river at this point, you can see the dark mid-Ordovician non-calcareous shales which are there partly disrupted with phacoidal melange-type fabric. In the low cliff, a gently east-dipping planar vein of fibrous quartz cuts the deformed shales; the vein has top to west, thrust sense of shear. Walk north along the west bank of the Mettawee River on the mostly dolostone outcrop. About 170 meters north [43.473241; -73.368196], dark highly deformed mid-Ordovician shales extend from the east bank across the river to an almost complete section at the small rapids. Depending on the streamflow, it may or may not not be possible to examine the shale closely. The contact of the deformed shale with the dolostone beds at the west side of the stream is not quite fully exposed (even at the lowest water we have seen, there is a gap of 10 cm or so), but is clearly sharp, and parallel with bedding in the dolostones. This is somewhat surprising, for a contact which maps out a short distance to the north as a sharp fault that unquestionably truncates this and other lower units of the carbonate shelf stratigraphy, as well as the major thrust fault which duplicates this sequence (see the map of Fisher, 1985). Also surprising, for a fault that must have substantial normal sense displacement, is the fact that most or all quartz fiber slickensides in the shale here give thrust sense of displacement. We could infer either that the normal fault mapped to the north passes east of this outcrop within the shale belt, or west within the transported shelf carbonate section (of course badly exposed in that particular place), or that the motion is confined to a surprisingly narrow zone along the contact; the full exposure at Stop 6B suggests the latter possibility is more likely than one might be inclined to think based on this outcrop at Stop 11 alone.

Walk back to the south end of the carbonate outcrop on the west bank of the river [43.471240, -73.368354]. If the water is high or it is raining, Stop 1B will be omitted. If conditions permit, scramble along the west bank to the south, and through the scrub along the west side of the old mill race cut at the waterfall, then walk south along the west bank of the river for about 1 km.

STOP 1B: DEFORMED FLYSCH AND MELANGE BELOW CONTACT WITH TRANSPORTED CHAZYAN SHELF CARBONATES, IN THE BANKS OF THE METTAWEE RIVER

The Mettawee River here provides a superb series of exposures (location in Fig 3) that cross from parautochthonous shelf carbonates (mostly dolostones) at the access point, south past the waterfall (43.470990; -73.367826) through alternating zones of flysch-type dark shales, and shale melange, to a large sliver of Chazyan carbonate (mostly limestones, starting at 43.462450; -73.362534) (Fig. 3). The eastern part of the carbonate sliver is poorly exposed in the river, but mapping demonstrates that this fault contact (the Taconic Frontal Fault) cuts obliquely across Taconic stratigraphy and large-scale fold axial traces, and is therefore a post-slaty cleavage generation structure (Fig. 3).

The allochthonous carbonate at this locality and along the western edge of the Allochthon in general has been interpreted and shown on a published map by Fisher (1985) as blocks-in-shale (i.e., olistoliths) rather than as coherent fault slivers. This locality (and stop 5) provide excellent examples to test these two alternative hypotheses. The carbonate/melange contact exposed in the woods across the river here can be walked for nearly 2 kilometers as a continuous, unbroken structure along strike, with internal fold axes in the carbonates approximately parallel to the general contact trend (Selleck and Bosworth, 1985, Plate 1A).

The carbonate must be in the form of a large, probably composite sheet. Minor secondary disruption near its margins is undoubtedly present (of structural and perhaps sedimentary causes), but we maintain that the origin of this and other km-(length)-scale carbonate sheets adjacent to the Allochthon was by detachment of thin slices from the top part of the underthrusting shelf rocks and their incorporation to and imbrication at the base of the advancing thrust pile. We think based on our mapping of all this belt north to West Haven that it is highly misleading to describe the geometry of the large carbonate bodies along the western edge of the Allochthon as "blocks-in-shale", and that it is most unlikely that they arose as primary sedimentary slump features (further discussed in Rowley and Kidd, 1982).

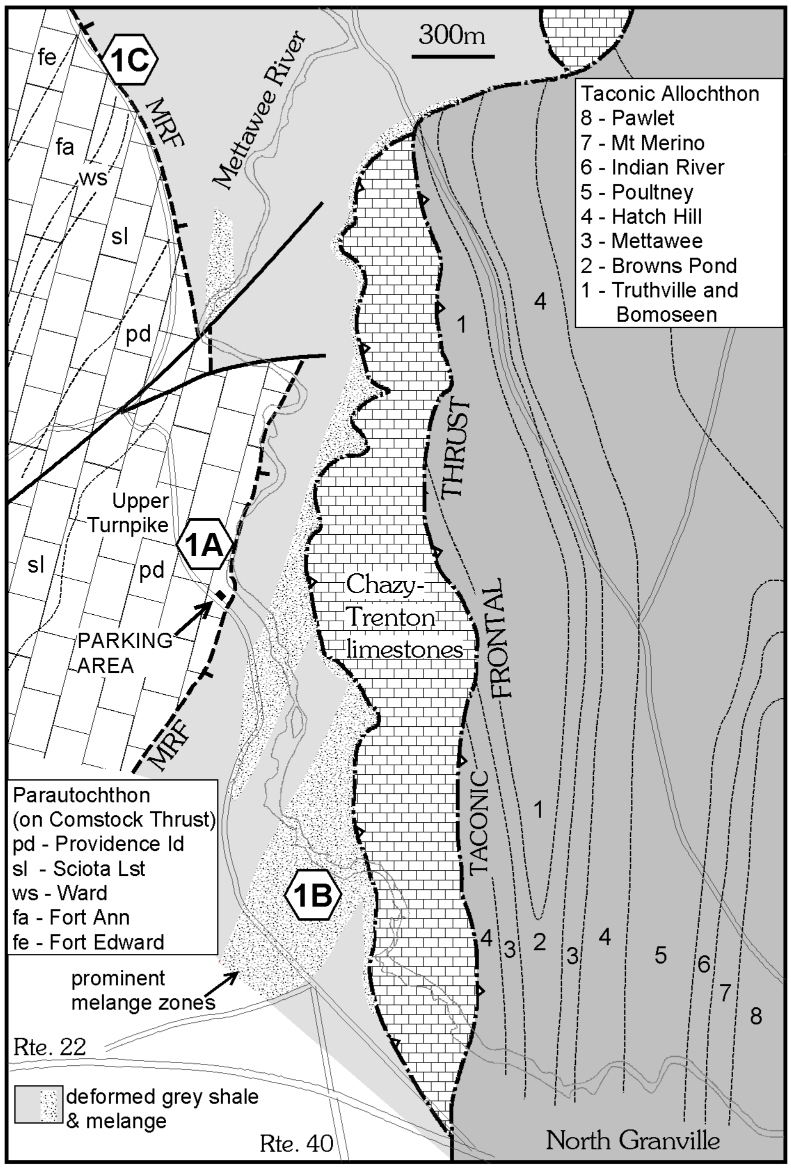

Figure 3. Geological map of the vicinity of the Taconic Frontal Thrust near the Mettawee River northwest of North Granville, NY, showing locations of stops 1A, 1B, and 1C. Geology modified after Selleck and Bosworth (1985); units in the parautochthonous shelf from Fisher (1985).

Walk back to the parking area.

22.3 1.4 Turn right out of parking area, go north 1.4 miles on Upper Turnpike, park on right side of road where it reaches its highest point [43.489336, -73.375452] - **Stop 1C**.

Please stay on the road and its margins; we do NOT have permission to enter the field or woods here

STOP 1C: METTAWEE RIVER FAULT ALONG UPPER TURNPIKE

Two outcrops of shale melange occur a short distance into the field to the east, where outcrop on the west side of the road and into the woods adjacent exposes dolostones of the Cambro-Ordovician shelf (here Fort Ann Fm according to Fisher, 1985; see Fig. 3). These outcrops demonstrate the existence of the Mettawee River Fault as an east side down normal fault and closely constrain its position.

24.3	2.0	Continue another 2.0 miles on Upper Turnpike, park on right side of road about 150 meters before a low point in the road and a sharp left curve just beyond [43.515749, -73.382460] - **Stop 2**

STOP 2: POTSDAM/TICONDEROGA ARENITES AND THE COMSTOCK (PINNACLE) THRUST.

In low roadside exposure on the west side of the road gently-dipping Upper Cambrian sandstones can be seen, mapped by Fisher (1985) as Ticonderoga and upper Potsdam Formations. The map shows they can be systematically traced for 9 kilometers to the south and, for a shorter distance, to the northeast of this place. Along with the overlying carbonate shelf sequence they demonstrate a major thrust duplication of almost the whole thickness of the local Cambro-Ordovician continental shallow marine platform/shelf sequence. The thrust carrying these strata was termed the Comstock Thrust by Fisher (1985); it climbs rapidly at a lateral ramp 9 km south of this locality (see Fig. 4, and Hayman & Kidd, 2002a; Stop 12) and can be traced a further 11 km carrying limestones of the uppermost part of the Ordovician shelf sequence before it climbs again, into the shale-melange belt, near Smiths Basin.

This small outcrop is not photogenic, and the thrust itself is not exposed here (exposures of it have been found in the woods to the west and southwest), but the map demonstrates its reality, and also that it and the sheet of shelf strata it carries are cut and truncated by the Mettawee River Fault (normal, east side down). Limestones of medial Ordovician age form a low outcrop at the sharp corner in the road to the north, and a larger outcrop on the other side beyond, and are shown by Fisher as Isle La Motte Formation (= Middlebury limestones) and form the foot wall of the Comstock Thrust here. It is probable that the original thrust relationship has been modified at this location by a later ENE-trending fault, but this does not significantly change the basic overthrust relationship.

Hayman & Kidd (2002a, b) provide reasons why this thrust should be specifically identified structurally as the southern extension of the Pinnacle Thrust exposed near Shoreham VT, but it is also helpful to understand that this thrust is the lowest (westernmost) thrust of the overall Champlain Thrust system in this area from Whitehall south to Fort Ann; lower components seen in Vermont (Shoreham Thrust; Main Champlain Thrust) die out southward with their displacements transferred upward along lateral ramps.

26.3	2.0	Continue on Upper Turnpike (at 1.7 miles cross Mettawee River bridge) to intersection with Washington Co. Rte 12, stop sign, turn right.
27.4	1.1	Go 1.1 miles on Rte 12 to intersection with Beckett Road, turn left.
29.0	1.6	Go to intersection with stop sign at Washington Co. Rte 18; turn left (watch out for fast traffic from either direction).
29.3	0.3	Go about 0.25 mile - park on right [43.538499, -73.347383] - take care not to get mired in the ditch; turn on hazard flashers; watch for fast traffic before exiting vehicle; walk about 150m west to roadside outcrop on north side [43.539244, -73.348779] - **Stop 3**.

Warning - poison ivy occurs on this outcrop, and most abundantly in the road verge in front of it

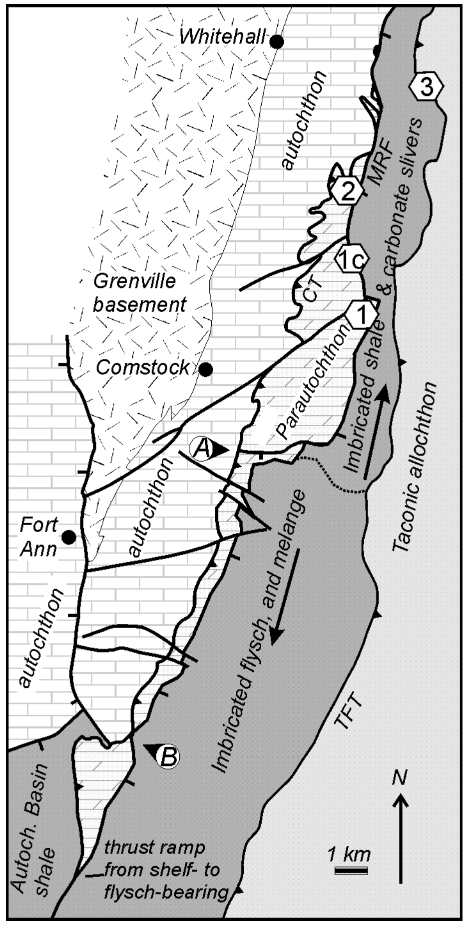

Figure 4. Geological map of the Taconic foreland between Smith's Basin and Whitehall, NY, showing locations of stops 1, 2, and 3, and the trace of thrusts and normal faults between the Taconic frontal thrust (TFT) and the autochthonous Cambro-Ordovician shelf sequence. At the points marked with labeled triangles, the westernmost thrust of the Champlain system (Comstock Thrust - CT) climbs section abruptly (A), and changes footwall lithology (B), across faults with normal sense slip prior to thrusting. MRF - Mettawee River (normal) Fault. Geology modified after compilation by Fisher (1985); diagram from Hayman and Kidd (2002a).

STOP 3: FRONTAL FAULT OF THE TACONIC ALLOCHTHON AS A POST-CLEAVAGE THRUST

This outcrop (location shown on Fig. 4) is one of a very few places where the western fault contact of rocks of the main Taconic Allochthon is fully exposed; you will see three of them on this field trip. The roadcut exposes cleaved arenites and siltstones belonging to the early Cambrian/latest preCambrian Bomoseen unit of the Taconic Allochthon stratigraphy (a member of the Bull Fm. of Zen, 1967). A gently east-dipping fault contact on a meter or less thickness of dark phacoidal melange-fabric shale is present, although it may require a small amount of digging to complete the exposure. Below the shale, fine-grained medial Ordovician limestones (Glens Falls/Orwell) dipping gently eastward form the western part of the outcrop. The limestones map as a thin (c.10m.) slice above a much larger thickness of medial Ordovician shale and shale melange exposed to the west. This is the same relationship inferred in the Mettawee River section at Stop 1B, although there a different and younger Taconic rock unit locally maps adjacent to the fault. Note that the cleavage in the Bomoseen dips moderately to steeply east and must be truncated by the more gently east-dipping fault. This relationship is consistent with the oblique truncation of map-scale tight-isoclinal folds and their axial traces at the fault in this region, folds to which this cleavage is an axial surface fabric. Bomoseen arenites and siltstones are typically greenish chloritic colours, but in this exposure they are grey to dark grey, particularly near the fault contact with dark medial Ordovician shales affected by phacoidal melange-fabric cleavage. We think that fluid hydrocarbons migrating in the fault channel while it was active penetrated into the lowest Taconic rocks here and (now dehydrogenated carbon) are the cause of the colour difference. The low-angle attitude of the fault exposed here (and shown by local detailed mapping into the stream just to the north) suggests it is a thrust.

Near Troy, NY, in the gorge of the Poestenkill, sense of shear evidence suggests that the more steeply-dipping fault exposed there is an east-side-downthrown normal fault which has cut and displaced the original Taconic thrust contact (Lim & Kidd, 2008). Similarly, a large roadcut on NY route 9G west of Hudson, NY exposes a sharp vertical fault contact that is also probably a normal fault. Such post-thrust normal faulting is also seen in calcite veins developed within the Ordovician melange terrain of the NY Capital District (Lim et al, 2005), and in the Mettawee River Fault seen at stops 1, 6B, and 7C on this trip (the trace of which projects well to the west of this locality; see Fig. 4). In this outcrop and more generally in the northern part, however, we think that an older thrust relationship is preserved at the western margin of the Taconic Allochthon, with the transport at this place being post-folding and cleavage development in the Taconic Allochthon strata.

29.7	0.4	Continue west for 0.4 mile on Washington Co. Rte 18 to intersection with Beckwith Road; turn right.
30.7	1.0	Go to stop sign at intersection with US Rte 4; cross over (very carefully - fast traffic) onto Washington Co. Rte 9B.
31.2	0.5	Go to intersection at stop sign with Washington Co. Rte 9. Turn left.
31.4	0.2	About 0.1 mile cross railroad tracks; at 0.2 mile turn right onto Carlton Road at triangular intersection.
32.1	0.7	Go about 0.7 mile and park on right just before intersection with Lanphere Lane (on left) [43.575141, -73.347418] - **Stop 4**

STOP 4: FOLDED THRUSTS OF TACONIC ALLOCHTHON SLATES (PLUDE'S QUARRY).

Locality marked on Fig. 6. Plude's Quarry (Fig. 5) provides another of the few known exposures of Taconic Allochthon continental rise rocks lying upon the underlying melange/flysch sequence. Along Carlton Road the shales and minor thin silty wackes of the Taconic flysch are broken into a phacoidal melange fabric, seen in the lowest part of the western face of the outcrop. Going up the western outcrop face, a contact of this material overlain by slates with a planar slaty cleavage can be found. This is the Taconic Frontal Fault, again; but mapping by us (as shown in Fig. 6) clearly demonstrates that here, this fault, and the immediately underlying carbonate slice (not exposed in this outcrop), are folded on a map scale. Higher up the outcrop face, harder greyish-green slates contain thin fine-grained ribbon arenites and are consequently identified as belonging to the Poultney Formation of the Taconic Allochthon sequence. In the northern outcrop face of the old quarry, the regional slaty cleavage in those rocks passes down into the grey slates without arenites, that are above grey "shales" with phacoidal melange fabric at the western base of this face. The Poultney rocks above are clearly folded with the slaty cleavage as an axial surface fabric. A previous description of this outcrop (Bosworth and Kidd, 1985), suggested that there is an older, folded (thrust) fault, crossed by the slaty cleavage, that occurs between the Poultney slates above, and the grey slates below, and that this structure may be of the same generation as the early, folded, "Taconic Basal Thrust" of Rowley and Kidd (1981). The gray slates in this interpretation would be a transported constituent of the Middle Ordovician flysch ("Hortonville" lithology). Alternatively, but perhaps less likely, they might be an arenite-poor section of the Poultney unit and that no significant fault occurs at this contact internal to the rocks showing slaty cleavage in this outcrop. What do you think?

In either case, the local geological map shows that the fault expressed by melange fabric at the lower western side of the quarry is also folded, but this fault structure is not required to pre-date or overlap in time the cleavage affecting Taconic Allochthon rocks. The underlying limestone slice that is also affected by folding shows a solution cleavage, variably developed; while this is plausibly the product of the local strain that transported and folded the limestones, this does not mean that it is the same age as the slaty cleavage expressed in the Poultney slates in the quarry. This solution cleavage is more likely to have developed later in the overall Taconic imbrication/transport sequence, just before or during the transport of the shelf limestone, and after the thrust emplacement of the Taconic Allochthon above the limestone.

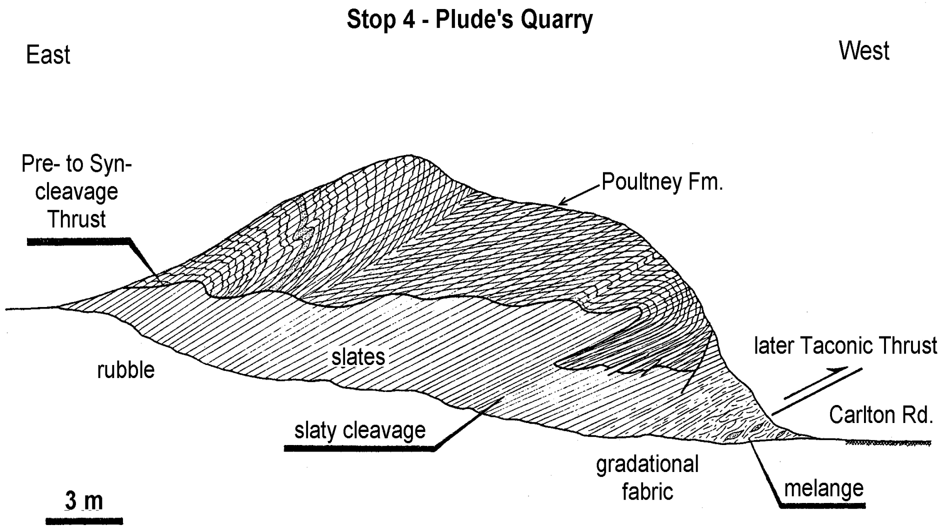

Figure 5. Westernmost thrust carrying Taconic Allochthon on slates, exposed in face of Plude's Quarry, Stop 4; location marked on Fig. 6). The geological map (Fig. 6) shows that this thrust, marked by shale melange, and an underlying limestone thrust slice, are folded locally on a large scale. In the quarry, allochthonous Poultney Formation slates overlie grey slates along a contact which may be an older thrust, affected by folding and cut by the slaty cleavage. It is possible that the grey slates are also part of the Poultney (and that there is no early thrust), but they more closely resemble an Ordovician flysch lithology ("Hortonville"). If this identification is correct, the contact cannot be stratigraphic, but would have to be a largely pre-slaty cleavage thrust, with thrusting and folding perhaps in part synchronous, as the amplitude of the fold in the thrust surface in the easternmost anticline is less than the amplitude in the folded Poultney. Slightly modified from Bosworth & Kidd (1985).

32.8	0.7	Continue on Carlton Road 0.7 mile to intersection with Westcott Road; turn left.
33.9	1.1	Go to end of Westcott Road at stop sign intersection with Co Rte 11; turn left.
34.0	0.1	Park on right about 100 meters down the road [43.592398, -73.344854]; walk another 50 meters down to outcrop on the north side [43.592133, -73.345231] - **Stop 5**

Warning - be cautious about where you step up to the rock face - in places, large blocks are visibly detached, and may be very unstable

STOP 5: THRUST OF MEDIAL ORDOVICIAN LIMESTONES OVER SHALY MELANGE

Locality indicated on Fig. 6. Carbonate exposures such as this one form lenticular belts bounded by medial Ordovician shales and shale melange (flysch) in a zone near this vicinity up to a few kilometers wide between the western edge of the Taconic Allochthon and the eastern edge of gently east-dipping, unfolded strata that rest with intact unconformable relationship on crystalline Grenville basement (such as those exposed along Rt 4 just east of Whitehall, and on Warner Hill visible a few kilometers due west of this locality). Where contacts are exposed, such as here, evidence for faulted lower contacts of limestone over shale are seen. In particular, the underside of the limestone is coated with fibrous vein-type slickensides, the lineation plunging ~120° close to down-dip. Truncation of stratification in the limestone is seen locally. An abundance of veins in the limestone within about 50cm of the thrust surface suggests hydrofracturing and high fluid pressures during thrusting. A crude, lenticular cleavage in the underlying shales is deflected adjacent to the fault surface. A small horse of shale, isolated above the main thrust surface by a duplex mechanism, can be seen about half way along the exposure of the thrust (Fig. 7).

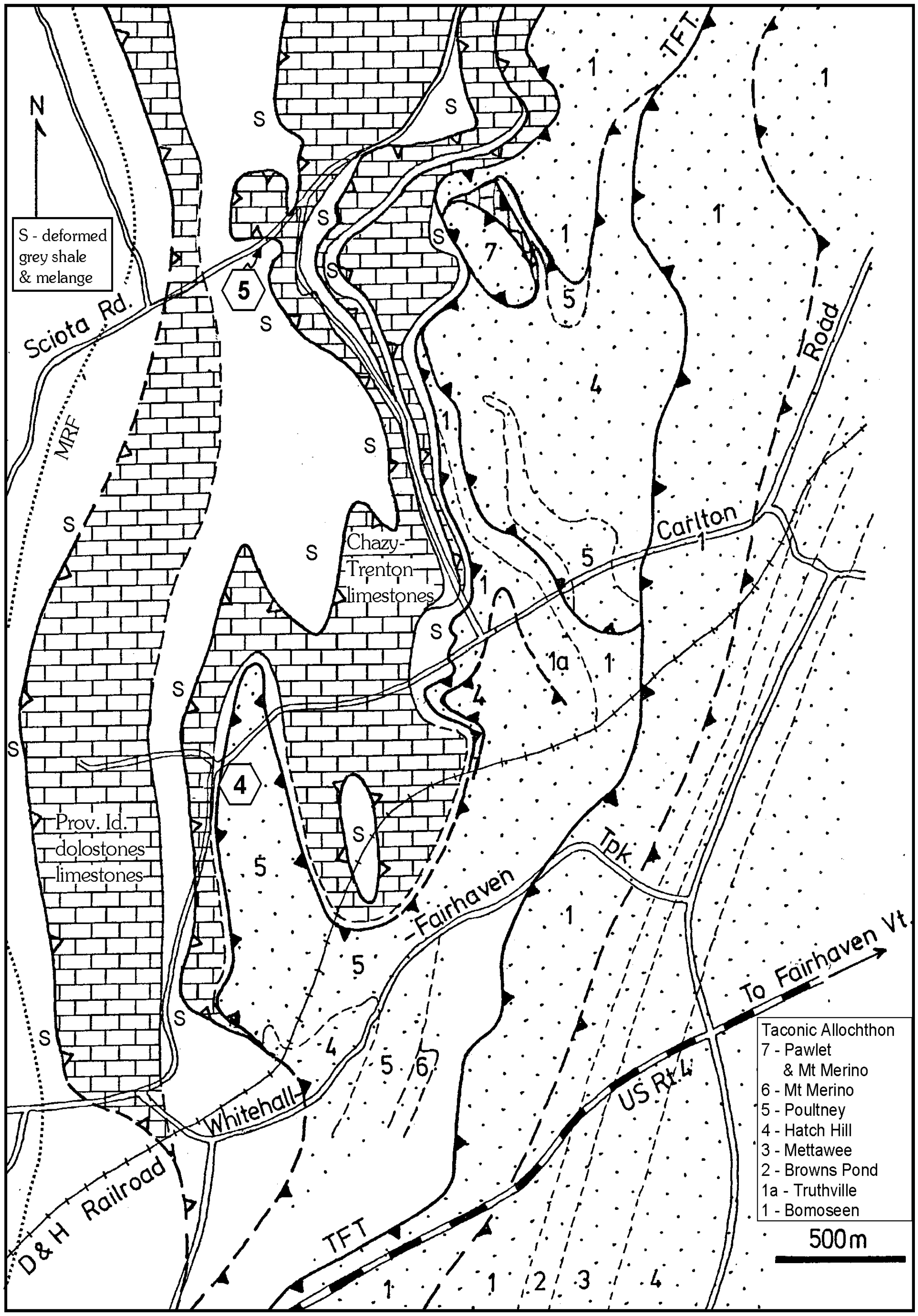

Figure 6. Geological map of the Taconic foreland fold and thrust belt northeast of Whitehall, NY, showing locations of stops 4, and 5, and the trace of thrust faults between the Taconic Frontal Thrust (TFT) and the Mettawee River (normal) Fault (MRF). Geology mapped by W. Kidd; modified from the versions shown in Bosworth & Kidd (1985), and Bosworth et al (1988).

Towards the western limit of the overlying carbonate sheet a detached sliver of carbonate about a meter long lies in the cleaved shale just below the prominent fault surface. This may be a structurally detached piece or (less likely because of its shape) an olistolith. Similar lozenge-shaped pieces of medium-grained graywacke up to about 1/2 m long occur sparingly in the phacoidally-cleaved shale in the western part of the cut. Slickensided surfaces suggest that they too are products of structural disruption ("structural slicing"), although an olistolithic origin for these small objects cannot be discounted.

The shale and siltstone is locally bedded, with minor folds in part of the outcrop. Most is pervasively disrupted by the phacoidal cleavage whose microstructural character, with abundant evidence for shear offsets, is clearly related to faulting (Bosworth and Vollmer, 1981; Bosworth, 1982, 1984). This carbonate and other exposures like it are shown on the New York State geological map and by Fisher (1985) as giant olistolithic blocks. We find this interpretation of the outcrops to be unconvincing and prefer an interpretation, as shown on Fig. 6, where the carbonates and stratigraphically overlying shales form thin thrust sheets accreted beneath the Taconic Allochthon. Demonstrable tight folds and internal duplex faults within these carbonate sheets account for the many places where stratigraphic continuity is disrupted within them.

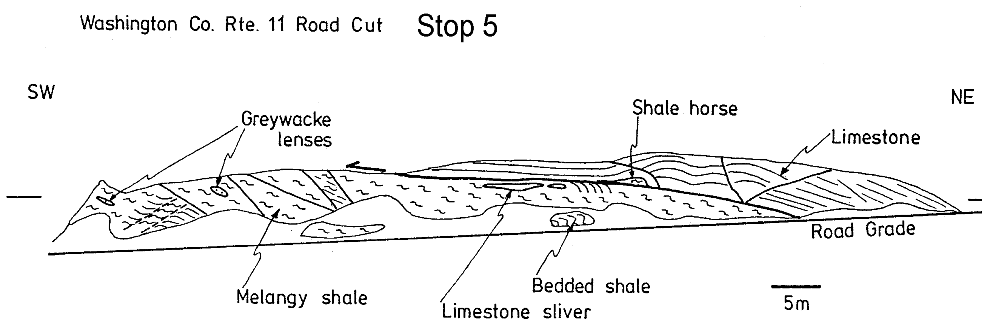

Figure 7. Profile exposed in road cut on north side of Washington County Route 11, 0.35 mile east of intersection with Sciota Road. Location marked on Fig. 6. Ordovician Isle La Motte (Middlebury) limestone thrust over medial Ordovician melangy shales. Diagram from Bosworth & Kidd (1985).

34.3 0.3 Continue down Washington Co. Rte 11 to intersection with Washington Co. Rte 10; turn right.

38.6 4.3 Go north on Washington Co. Rte 10;
at 2.5 miles cross (slowly) Poultney River Bridge, NY-Vermont border; road becomes Book Road
at 3.2 miles pass Book Farm;
at 4.3 miles park on right on grass verge [43.645701, -73.347671]; dirt road intersects on left.

Lunch stop may involve driving or walking detour on dirt road to Book's pond and picnic area (~0.3 miles each way; not included in road log).

Roadside outcrop about 160m walk south along Book Road [43.644500, -73.348832] - **Stop 6A**
and
Outcrop in woods and streambed about 500m walk ENE through the field to the east of the road [43.647590, -73.341250] - **Stop 6B**

STOP 6A: SHOREHAM THRUST EXPOSURE ON BOOK ROAD

In the center portion of this roadcut exposure, grey-black non-calcareous shale (mid-Ordovician) up to 1 meter thick, with a pronounced phacoidal cleavage indicative of large shear strain, occurs below a sharp contact with highly fractured massive dolostones ("Providence Island" lithology). This is the Shoreham Thrust, and mapping of the surrounding area (Fig. 8) shows unequivocally that it is here the westernmost thrust in the Champlain System - in other words that the "Main Champlain", or Orwell Thrust farther north

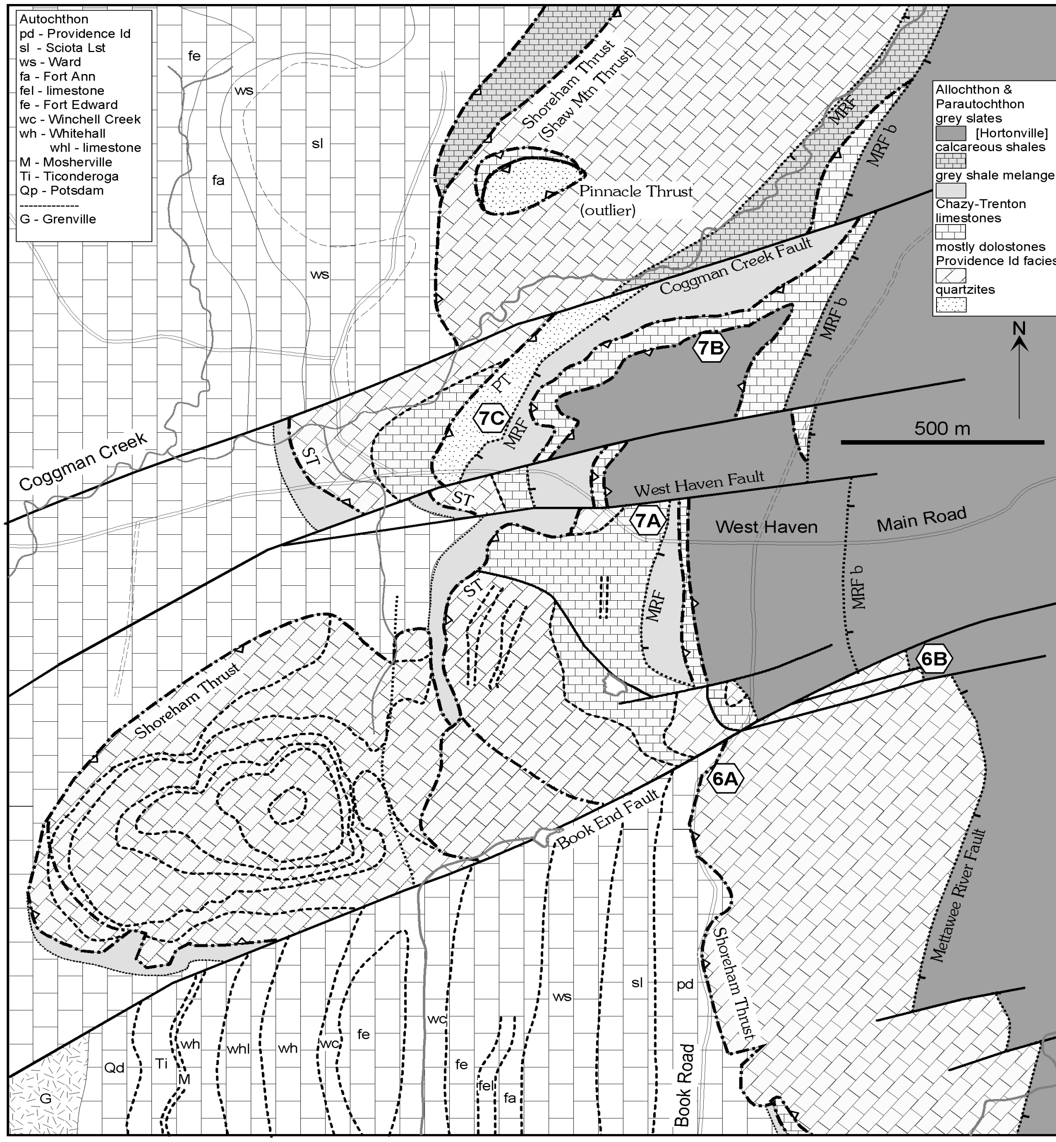

Figure 8. Geological map of the Taconic foreland fold and thrust belt at West Haven, VT showing locations of stops 6A and 6B; and 7A, 7B, and 7C. The trace of thrust faults of the Champlain Thrust system crossing this map are the Shoreham Thrust (ST), and the Pinnacle Thrust (PT). Local exposure of the thrust carrying allochthonous grey slates (Hortonville) is found at stop 7B. The Mettawee River (normal) Fault (MRF) is exposed at stop 6B; this fault is interpreted to split into two strands north of the left-lateral Book End Fault. The dissection of the thrusts by the MRF and the younger strike-slip faults make the local geology exceptionally complex. Geological mapping, compilation and interpretation by W. Kidd, including information from Steinhardt (1983), and Granducci (1995).

has disappeared (Hayman and Kidd, 2002a, b). To the south across the Vermont-New York border, near the Poultney River, the Shoreham Thrust also disappears, first because it is truncated by the Mettawee River normal Fault, although minor folding and incipient ramps can be detected in shelf rocks at its expected position in a outlier which occurs east of Whitehall. A major WSW-ENE cross-fault (the Book End Fault) passing north of this outcrop at stop 6A cuts and displaces the autochthonous shelf section and the Champlain Thrust System stack, crossing Book Road at the parking spot. The Shoreham Thrust is offset by this structure with an apparent left lateral displacement of about 2 kilometers. Two other faults like this one pass through the next valley north near West Haven hamlet. These cross faults are discussed in the description of Stops 6B and 7 below.

STOP 6B: METTAWEE RIVER FAULT NEAR WEST HAVEN

ASK PERMISSION AT BOOK FARM BEFORE ENTERING - find Book Farm along Book Road 1.1 miles south of specified parking place

From parking place, enter field on east by walking between the two fences, opening the gate if necessary (and closing it behind you) - please do not climb over it or the fence. Follow the grassed-over track into the edge of the woods (about 100 meters), then along the edge of the woods (about another 200 meters), then angle down the crest of a low ridge in the meadow (about another 100 meters) to the edge of the woods crossing the low ridge. Outcrop of fractured tan-weathing dolostone ("Providence Island" lithology) is found just inside the woods at this point.

Use the sketch map below to navigate and understand the geology from this point on. About 60 meters east of the first dolostone outcrop, in the bed of the stream near the south end of the small ravine, dark slates ("Hortonville"), of presumed mid-Ordovician age, are exposed in contact with the dolostones [43.647590, -73.341250] . This contact is clearly a steep (60º) east-dipping fault, truncating the moderately east- dipping thick bedding in the dolostones, and the cleavage in the slates. Given the regional context, with no thick dark slates occurring west of this point, but rather the carbonates of the Shoreham Thrust slice, then the underlying autochthonous Cambro-Ordovician "Whitehall facies" shelf sequence, with Potsdam sandstone/quartzite at its base lying unconformably on Grenville basement, this fault must be a normal fault, and is in fact the Mettawee River Fault first proposed by Fisher (1985) in New York. It is the only complete exposure of this fault, although our mapping demonstrates that it runs continuously from the Mettawee River (stop 1A) north through this locality at least as far north as the latitude of Shoreham, VT, and all along this length it truncates regionally the thrust stack of the Champlain Thrust System.

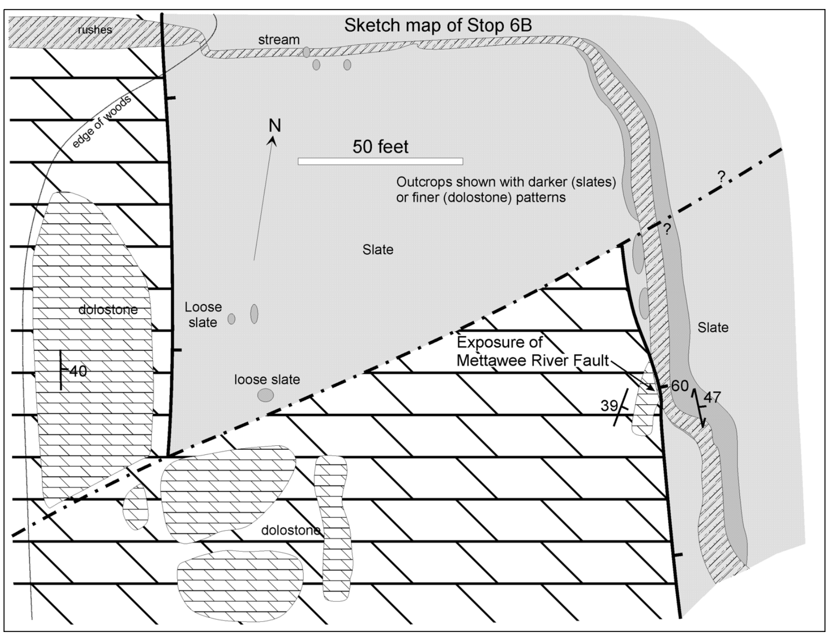

Figure 9. Outcrop and geologic map of Stop 6B – exposure of the Mettawee River Fault near West Haven, VT. Diagram from Hayman & Kidd (2002a).

We suspect that it extends significantly farther north and south than this, but there is a lack of clear truncation of components of the Champlain Thrust System beyond these extents. One reason for suspecting a larger along-strike extent is the minimum displacement, which can be constrained from cross-sections, and which demand at least 1000 meters of throw, and perhaps more than 1500 meters. This fault cuts out large, significant parts of the Champlain Thrust stack, and is one of the main reasons why previous attempts failed to trace the major thrust faults of the System southward. What age is this normal fault? We have no direct younger age limit in the mapped area, other than the observation that it is cut and displaced by the WSW-ENE faults which also cut the Shoreham Thrust. In fact this set of local outcrops (see Fig. 9 sketch map) shows that relationship directly, with a smaller splay of the larger WSW-ENE fault displacing in an apparent left-lateral sense the dolostone-slate contact (the Mettawee River Fault).

Evidence to be shown in the outcrop of the next stop (Stop 7A) demonstrates that these apparent strike-slip offsets on the WSW-ENE faults are from actual strike-slip displacement; discussion of the age and origin of this youngest faulting type and orientation is included with Stop 7A.

39.0 0.4 Continue north on Book Road to crossroads intersection with Main Road at West Haven; turn left.
39.1 0.1 Go west 0.1 mile on Main Road and park on right on road verge before driveway to Coggman Creek Farm (red barn); do not block any access, please. [43.651369, -73.349745].
Stops 7A, B and C. (all walking).
[7A 43.65216, -73.35094]; [7B 43.65738, -73.34863]; [7C 43.654645, -73.356594]

ASK PERMISSION AT THE FARMHOUSE TO VISIT THIS OUTCROP AND THE OUTCROP OF STOP 7B. DO NOT GO TO THE OUTCROP UNLESS YOU HAVE PERMISSION. NO HAMMERS ALLOWED.

At the barns, follow the track west 50 meters to the low lying limestone outcrop surfaces.

STOP 7A: VEINS AND LEFT-LATERAL STRIKE-SLIP FAULTING IN LIMESTONE AT WEST HAVEN

On the main part of the outcrop, abundant calcite veins of two generations can be seen. The older set strike about N-S and mostly dip moderately to very steeply east. Their displacement sense is not particularly significant for this field trip, and is undetermined in most cases, but east-over-west thrust sense has been seen, as well as some strike-slip component in places, of dextral sense. The significant vein set for our purpose is the one striking between E-W and WSW-ENE, which in all cases cut N-S veins, and can be shown in a number of examples to displace subvertical instances in a sinistral sense. From this outcrop, the only one around West Haven where we have found this evidence, we infer that the apparent displacements on the WSW-ENE faults mapped here resulted from real left-lateral strike-slip displacement, not entirely from steeply directed north-side-down slip cutting gently-moderately east-dipping strata and thrust faults.

We sampled by drilling short cores of some of the veins in this outcrop, and looked for suitable fluid inclusions in doubly polished sections to measure fluid homogenization temperatures, and freezing temperatures, to determine the salinity for the fluids forming the veins. Refer to the vein fluid inclusion discussion in the introduction for overview and details. To summarise the essential point: low salinity fluid inclusions having homogenization temperatures up to 205-215C were found in the younger WSW-ENE veins having left-lateral strike-slip offset. Fluids in the fractures at burial depth when the veins formed would have been above this temperature, the amount depending on the depth, which we do not know. However, by comparison with results from Ordovician (Taconic) and Devonian (Acadian) vein fluid inclusions in the Albany area, we think this temperature is high enough to be indicative of an Ordovician age. Devonian veins (thrust sense only) from the Acadian foreland fold and thrust belt there are distinguishably lower, most around 120-130C. We are not aware of any reason to suppose that Acadian fluids are likely to have been significantly hotter in western Vermont compared with the Albany area, and we note an absence of both strike-parallel normal faults and WSW-ENE cross-faults cutting the Acadian Helderberg fold-thrust belt. So we think the WSW-ENE faults crossing the Taconic foreland thrust belt in this area are strike-slip faults (at least in their later/last slip episodes), and Ordovician (Taconic) in age, and are the youngest of the sets of structures of the Taconic event.

Whether they are Ordovician, or younger, what is their tectonic origin? Thrust faults are easy to understand in the context of the Taconic arc-continent convergence (Bird and Dewey, 1970), and strike-parallel normal faults in that general context similarly have modern exemplars, both of pre-thrusting origin from slab-pull on the downgoing lithosphere (Schoonmaker et al, 2005), and extension late in and/or after convergence from slab detachment (Davies & Blanckenburg, 1995) or regional stress removal by large-scale plate boundary reorganisation. Strike-parallel strike-slip faults also are no problem to accommodate by strain partitioning of plate motion (McCaffrey, 1996). Cross-strike strike-slip faults of small displacement, on the other hand, are usually secondary linking structures (tear faults) for thrust (or perhaps with oblique slip for normal fault systems), and these commonly also serve as fault segment delimiters for earthquake slip zones. We think this may be the explanation for these WSW-ENE faults in the Taconic foreland but there is a problem; there are no known contemporary thrust or normal faults of the right relative age, nor any of a compatable slip direction! The WSW-ENE faults cut the Mettawee River normal fault, which itself cuts the youngest thrust in the Champlain Thrust stack. Even if we are wrong about the age constraint inferred from the fluid inclusion minimum temperature, the Acadian thrust slip direction for this sector of the northern Acadian Appalachians is also not towards WSW. Perhaps there could be small displacement blind thrust segments in the flat-lying platform sediments of the Taconic foreland, with WSW-directed slip, that would be the very last activity of the Taconic orogen, and to which these strike-slip faults form tear fault linking structures?

There are other features of the geology apparently associated with the West Haven cross-fault zone that we have noted: a) the abrupt change in the medial Ordovician strata across it from non-calcareous shales occurring to the south, to significant thicknesses of calcareous shales (Cumberland Head and Stony Point Fms) to the north. In addition, b) changes in thickness of the early Ordovician Ward Siltstone appear to be associated with this zone, and perhaps also with other faults of this orientation near and south of Whitehall. The implication is that these faults have developed using older fractures in the basement, and that these older structures also may have influenced subsidence patterns and deposition of sediments of the shelf both before and during the approach of the Taconic thrust stack.

Also, c) the map complexity near West Haven implies that the Shoreham Thrust interacted with an already fault-displaced irregular floor, from normal faulting on these oblique structures before the thrust stack interacted with it; it is admitted that inadequate outcrop and want of 3-D information prevent any clear demonstration of this. However, the same structural history inferred here can be observed if you visit outcrop adjacent to the Split Rock Point Fault [44.267592; -73.337305] near Westport NY where normal displacement on the NE-striking fault is expressed by the juxtaposition of Grenville gneisses and medial Ordovician calcareous shales; the dipping shales bent up by the normal-sense shear strain are cut by calcite veins showing clear evidence of strike-slip displacements, of both dextral and sinistral sense.

> From the barns, walk north across the fields to the edge of the woods where a small stream bed (often dry) enters the woods [43.65678, -73.34888]. Follow the track into the woods on the west side of the stream bed; where the slope increases, the stream bed exposes continuous outcrop in a small cliff (a waterfall when the stream is running) and the banks and bed of the stream above and below.

STOP 7B: FLAT-LYING THRUST FAULT OF TACONIC SLATES OVER CALCAREOUS SHALES AND LIMESTONES SOUTH OF COGGMAN CREEK

The small waterfall cliff, and the stream bed above, expose grey slates with a well-developed, moderately east-dipping cleavage. At the base of the small cliff, these slates rest on a practically flat thrust fault carrying them over dark calcareous shales. These calcareous shales pass down into limestones which form the rest of the outcrop in the stream bed and on the valley walls adjacent. The limestones are medial Ordovician Glens Falls, Orwell, and perhaps Middlebury equivalents, similar to those seen at stop 3, 5, and 7A (but are, we think - see map of Fig. 8 - not part of the same thrust slice as at stop 7A). The transported slates possess a well-developed planar slaty cleavage and so in a structural sense belong with the Taconic Allochthon. Their lithology, the same seen at stop 6B, monotonous, slightly silty, pale to medium grey slate, with thin silty laminations seen in some places, has been given the name Hortonville Slate by Zen (1967) in the area of the main Taconic Allochthon to the east. It is probably a medial Ordovician-age deposit, a facies of the orogenic flysch clastics accompanying the Taconic convergence, but significantly farther-transported than the melange, shales and turbidites of the Hudson Valley. Along structural strike, to the NNE near Benson, these rocks adjoin the Sunset Lake slice of the Taconic Allochthon, and we regard them as an enlarged addition/extension of the Sunset Lake slice. If this interpretation is valid, then the thrust exposed here is essentially another exposure of the western marginal fault of the Taconic Allochthon.

If you are using this field guide independently, you need to return to the Main Road at West Haven, go west along the road 0.3 mile, and ask permission at the house on the north side of the road to visit the outcrop of Stop 7C. If permission is obtained, the outcrop is about 150 meters north of the house.
If permission was previously obtained, return from Stop 7B to the edge of the woods and walk west along the edge for about 450 meters, passing limestone outcrops in the woods extending from near stop 7B until reaching the point where the ridge crest starts descending towards the west and enters the woods. Down the slope to the north at this point, the last limestone outcrop occurs above an exposure of dark melange-fabric shale just below it, showing that the thrust at the base of this limestone sheet runs here. From the point on the ridge, go approximately southwest contouring around the ridge end, and descend slightly into another (usually dry) streambed running roughly west.

STOP 7C: METAWEE RIVER FAULT AND QUARTZITES OF THE PINNACLE THRUST WEST OF WEST HAVEN

See Fig 8 for location and geological surroundings. Exposures of dark partly melange-fabric shale occur intermittently in the bed and low bank of the stream to just before a sharp increase in the gradient over a rock ledge exposing well-lithified quartz arenites/quartzites. Below these, down stream, dolostones also outcrop. These arenites are part of the Potsdam/Ticonderoga unit of the Cambro-Ordovician shelf sequence, lying above the (here unexposed) Pinnacle Thrust, and must be separated from the melangy shales seen a few feet upstream by the principal strand of the Mettawee River Fault.

These quartzites also outcrop on the crest of the hill across Coggman Creek to the north, where they form an isolated erosional outlier of the Pinnacle Thrust, which overlies mainly dolostones of the Shoreham (locally termed Shaw Mountain) Thrust. We think the quartzite exposures near Root Pond a few kilometers to the northeast also form isolated remnants of the Pinnacle Thrust sheet, and that isolation by truncation of the Mettawee River normal Fault is a key to understanding their relationships, as it is for the similar occurrences of such quartzites in the same structural setting all the way from here at Stop 7C to Whitehall NY, where they can be shown to continue in the hanging wall of the Comstock thrust, as seen at Stop 2.

Walk back up the ridge on the north side of the stream to the field, and thence back to the barns at the Coggman Creek (old Richardson) Farm.

END OF TRIP.
To return to Lake George:

42.6	3.5	Turn around; go east on Main Road. At 0.1 mile pass Book Road intersection; 1.0 mile pass Best Road intersection (on left); 1.4 miles pass Stage Road intersection (on left; Main Road here takes sharp turn to right); 2.2 miles cross Hubbardtown River bridge; 2.7 miles pass Hackadam road intersection (on right); 3.5 miles stop sign intersection with Vermont Rte 22A. Turn right. [*For Burlington and other northern destinations using I-89, turn left*]
45.0	2.4	Go 2.4 miles south on Vermont Rte 22A to entrance ramp for US Rte 4 West; turn right up the ramp, join Rte 4 westbound. [*For Rutland and points eastern, go under the Rte 4 bridge and take the eastbound ramp*]
53.2	8.2	At 1.7 miles Vermont-NY border at Poultney River; at junction at light in Whitehall with NY Rte 22, turn left.
63.8	10.6	Follow US Rte 4 south10.6 miles to intersection at light in Fort Ann with NY Rte 149; turn right onto Rte 149.
75.5	11.7	Follow NY Rte 149 to intersection at light with US Rte 9 - end of log; turn right and go ~4 miles to Lake George Village [*For Albany, and points south and west, turn left, go 0.7 miles on Rte 9 to the second light, (Rte 23 intersection); turn right, go 0.2 mile to ramp entrance on left for I-87 south*].

REFERENCES

Bird, J. M., and Dewey, J. F., 1970, Lithosphere plate-continental margin tectonics and the evolution of the Appalachian orogen: Geological Society of America Bulletin, 81, 1031-1060

Bosworth, W., 1982. Evolution and structural significance of master shear zones within the parautochthonous flysch of eastern New York: Vermont Geology, v.2 (Symposium on Taconic Geology), 6-13.

Bosworth, W., 1984. The relative roles of boudinage and "structural slicing" in the disruption of layered rock sequence: J. Geol., v.92, 447-456

Bosworth, W. and Vollmer, F.W., 1981. Structures of the medial Ordovician flysch of eastern New York: deformation of synorogenic deposits in an overthrust environment. J. Geol., v.89, 551-568.

Bosworth, W. and Rowley, D.B., 1984. Early obduction-related deformation features of the Taconic Allochthon: analogy with structures observed in modern trench environments. Geol. Soc. Amer. Bull., v.95, 559-567

Bosworth, W., and Kidd, W.S.F., 1985. Thrusts, melanges, folded thrusts, and duplexes in the Taconic Foreland. pp. 117-146 in Lindemann, R.H., (editor) Field Trip Guidebook, 57th Annual Meeting, New York State Geological Association, 27-29 September 1985, Skidmore College, Saratoga Springs, NY.

Bosworth, W., Rowley, D. B., Kidd, W. S. F., and Steinhardt, C., 1988, Geometry and style of post-obduction thrusting in a Paleozoic orogen: the Taconic Frontal Thrust System: Journal of Geology, v. 96, p. 163-180.

Bradley, D. C., and Kidd, W. S. F., 1991, Flexural extension of the upper continental crust in collisional foredeeps: Geological Society of America Bulletin, v. 103, p. 1416-1438.

Bradley, D. C., and Kusky, T. M., 1986, Geologic evidence for the rate of plate convergence during the Taconic arc - continent collision: Journal of Geology, v. 94, p. 667-681.

Chan, Y.-C., Crespi, J. M. and Hodges, K. V. 2001, Dating cleavage formation in slates and phyllites with the 40Ar/39Ar laser microprobe: an example from the western New England Appalachians, USA: Terra Nova, v 13.

Cisne, J. L., Karig, D. E., Rabe, B. D., and Hay, B. J., 1982, Topography and tectonics of the Taconic outer trench slope as revealed through gradient analysis of fossil assemblages: Lethaia, v. 15, p. 229-246.

Davies, J.H., and von Blanckenburg, F., 1995, Slab breakoff; A model of lithosphere detachment and its test in the magmatism and deformation of collisional orogens: Earth and Planetary Science Letters, v. 129, p. 85–102.

Jacobi, Louise D. 1977. Stratigraphy, Depositional Environment and Structure of the Taconic Allochthon, Central Washington County, New York. Unpublished MSc. thesis, State University of New York at Albany.193pp +ix +2p. abstract; 4 folded plates (map, sections, stratigraphy) online at http://www.atmos.albany.edu/geology/webpages/ldelano.html

Fisher, D. W., 1985. Bedrock geology of the Glens Falls-Whitehall region, New York: New York State Museum Map and Chart Series, v. 35.

Granducci, J.L., 1995. Stratigraphy and structure at the southern end of Lake Champlain in Benson, Vermont. Unpublished MSc. thesis, State University of New York at Albany. 106 pp., +xi; 2 folded plates (maps); online at http://www.atmos.albany.edu/geology/webpages/granduci.html

Hames, W.E., Tracy, R.J., Ratcliffe, N.M., and Sutter, J.F., 1991, Petrologic, structural, and geochronologic characteristics of the Acadian metamorphic overprint on the Taconian Zone in part of southwestern New England: American Journal of Science, v. 291, 887-913.

Hayman, N.W., 1997. Pre-thrust normal faults and post-tectonic micas in the Taconic Range of west-central Vermont. Unpublished MSc. thesis, State University of New York at Albany. 179 pp., +xiii; 3 folded plates (maps); online at http://www.atmos.albany.edu/geology/webpages/nhaymana.html

Hayman, N.W., and W.S.F. Kidd, 2002a. The Champlain Thrust System in the Whitehall- Shoreham area: influence of pre- and post-thrust normal faults on the present thrust geometry and lithofacies distribution. Field trip A7, pages7-1 to 7-24 in McLelland, J.M., amd Karabinos, P., (editors) Guidebook for Fieldtrips in New York and Vermont. New England Intercollegiate Geological Conference 94th Annual meeting, and New York State Geological Association 74th Annual meeting, Lake George, NY, September 27th-29th, 2002. Skidmore College, Saratoga Springs

Hayman, N. M., and Kidd, W. S. F., 2002b, Reactivation of prethrusting, synconvergence normal faults as ramps within the Ordovician Champlain–Taconic thrust system: Geological Society of America Bulletin, v. 114, p. 476-489.

Jacobi, Louise D. 1977. Stratigraphy, Depositional Environment and Structure of the Taconic Allochthon, Central Washington County, New York. Unpublished MSc. thesis, State University of New York at Albany.193pp +ix +2p. abstract; 4 folded plates (map, sections, stratigraphy); online at http://www.atmos.albany.edu/geology/webpages/ldelano.html

Kidd, W.S.F., Plesch, A., and Vollmer, F.W., 1995, Lithofacies and structure of the Taconic flysch, mélange, and allochthon, in the New York Capital District, in Garver, J.I., and Smith, J.A., eds., Field Trip Guide for the 67th Annual Meeting of the New York State Geological Association: Union College, Schenectady, NY, p. 57–80

Lim, C., Kidd, W.S.F., and Howe, S.S., 2005. Late shortening and extensional structures and veins in the western margin of the Taconic Orogen (New York to Vermont) J. Geol., 113, 419–438.

Lim, C., and Kidd, W.S.F., 2008. Foreland zone faults and veins related to along-strike propagation of slab breakoff at the end of the Taconic orogeny. Geological Society of America Abstracts with Programs, 40 (2), 29.

MacDonald, F.A., Karabinos, P.M., Crowley, J.L., Hodgin, E.B., Crockford, P.W., and Delano, J.W, 2017. Bridging the gap between the foreland and hinterland II: geochronology and tectonic setting of Ordovician magmatism and basin formation on the Laurentian margin of New England and Newfoundland. Amer. J. Sci., 317, 555–596.

McCaffrey, R. 1996. Slip partitioning at convergent plate boundaries of southeast Asia. In: Hall, R. & Beundell, D. J. (eds) Tectonic Evolution of Southeast Asia, Geological Society of London Special Publications, 106, 3-18.

Ratcliffe, N.M., Stanley, R.S., Gale, M.H., Thompson, P.J., and Walsh, G.J., 2011, Bedrock geologic map of Vermont: U.S. Geological Survey Scientific Investigations Map 3184, 3 sheets, scale 1:100,000.

Rowley, D.B., 1980. Complex Structure and Stratigraphy of Lower Slices of the Taconic Allochthon Near Middle Granville, New York. Unpublished MSc. thesis, State University of New York at Albany. 258pp., +xv.; 3 folded plates (maps); online at http://www.atmos.albany.edu/geology/webpages/rowleyms.html

Rowley, D.B., 1983. Operation of the Wilson Cycle in western New England during the Early Paleozoic: with emphasis on the stratigraphy, structure, and emplacement of the Taconic Allochthon. Unpublished PhD dissertation, State University of New York at Albany. 602pp. (2 volumes), +xxvi; 4 folded plates (maps);online at http://www.atmos.albany.edu/geology/webpages/rowleyph.html

Rowley, D. B., 1982, New methods for estimating displacements of thrust faults affecting Atlantic type shelf sequences: with an application to the Champlain Thrust, Vermont: Tectonics, v. 1, p. 369-388.

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

Rowley, D.B. and Kidd, W.S.F., 1982. Stratigraphic relationships and detrital composition of the medial Ordovician flysch of western New England: implications for the tectonic evolution of the Taconic Orogeny: a reply to Rodgers. J. Geol., v.90, 219-226.

Rowley, D.B., Kidd, W.S.F., and Delano, L.L., 1979. Detailed stratigraphic and structural features of the Giddings Brook Slice of the Taconic Allochthon in the Granville area. pp. 186-242 in Friedman, G.M., (ed.) NY State Geol. Assoc. and NEIGC Guidebook, RPI, Troy, NY.

Schoonmaker, A., Kidd, W.S.F., and Bradley, D.C., 2005, Foreland-forearc collisional granitoid and mafic magmatism caused by lower-plate lithospheric slab breakoff: The Acadian of Maine, and other orogens: Geology, v. 33, p. 961– 964

Selleck, B. and Bosworth, W., 1985. Allochthonous Chazy (Early Medial Ordovician) Limestones in eastern New York, tectonic and paleoenvironmental interpretations. Amer. J. Sci., v.285, 1-15.

Stanley, R.S., and Ratcliffe, N.M., 1985, Tectonic synthesis of the Taconian orogeny in western New England: Geological Society of America Bulletin, v. 96, p. 1227-1250.

Steinhardt, C.K., 1983. Structure and Stratigraphy of West Haven, Vermont. Unpublished MSc. thesis, State University of New York at Albany. 167 pp., +x; 4 folded plates (maps) ; online at http://www.atmos.albany.edu/geology/webpages/steinhar.html

Zen, E.-An, 1967, Time and space relationships of the Taconic allochthon and autochthon: Geological Society of America Special Paper, v. 97, 107pp.

Zen, E.-An, 1972, Some Revisions in the Interpretation of the Taconic Allochthon in West-Central Vermont: Geological Society of America Bulletin, v. 83, p. 2573-2588.