THRUSTS, MELANGES, FOLDED THRUSTS AND DUPLEXES IN THE TACONIC FORELAND

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INTRODUCTION

The western margin of the allochthonous clastic rocks of the Taconic Orogen has long been recognized as a fundamental tectonic and structural feature in the geology of eastern New York. First interpreted as the trace of a major unconformity (Emmons, 1844) between fossiliferous Cambrian and supposedly older and unfossiliferous "Taconic" rocks, it soon was correctly identified as the outcropping of a surface of regional overthrusting (Logan, 1861). "Logan's Line" placed earliest Cambrian through Ordovician deep-water sedimentary rocks above the late Cambrian and Ordovician shallow water clastic and carbonate "standard" sequence of eastern New York. The actual fault contact is generally between Taconic lithologies and medial Ordovician graywackes, siltstones and shales known as the Taconic flysch. The flysch was deposited during the emplacement of the Taconic Allochthon onto the North American continental shelf in a volcanic arc-continent collision (Chapple, 1973; 1979; Rowley and Kidd, 1981). The flysch-Allochthon contact is rarely exposed, although one quarry does cross the boundary and is described below. More commonly the western Taconic thrust is seen at exposures where the contact is with Ordovician shelf carbonates. These masses of shelf carbonate are demonstrably not rooted, vary in size from kilometers to pebbles, and have been variously interpreted as olistostromes (Zen, 1961; 1967; Rodgers and Fisher, 1969) and fault slivers (Walcott, 1888; Ruedemann, 1914; Zen, 1967; Bosworth, 1980; Bosworth and Vollmer, 1981).

Sparsity of outcrops throughout much of the Taconic region has discouraged detailed structural analysis of the Taconic boundary thrusts. The authors and coworkers have completed detailed maps (1:6,000 to 1:12,000 scale) of most of the Allochthon boundary from Schaghticoke, New York, to

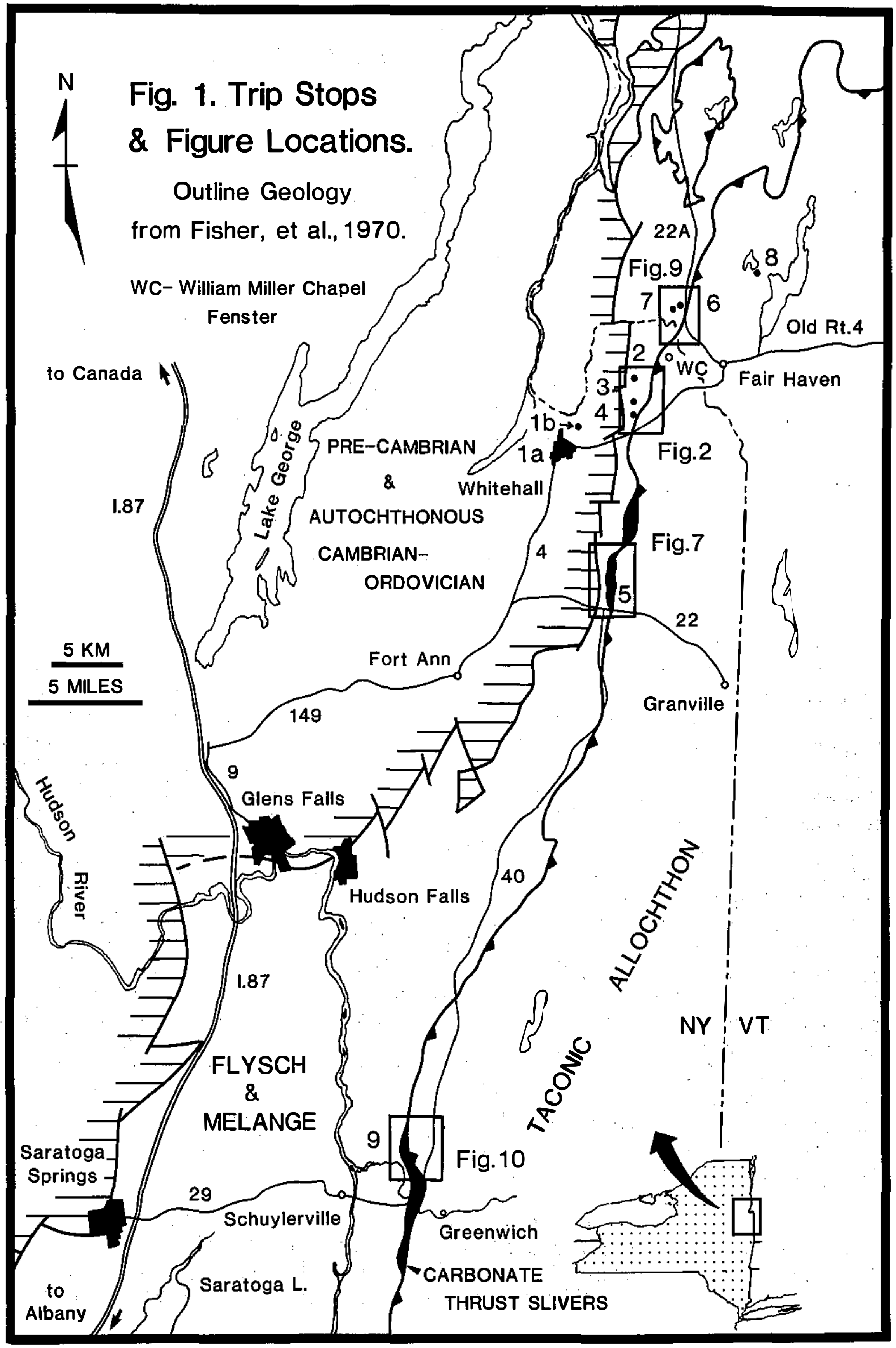
Fig. 1. Trip Stops & Figure Locations.
Outline Geology from Fisher, et al., 1970.
N
WC- William Miller Chapel Fenster
to Canada
I.87
Lake George
PRE-CAMBRIAN & AUTOCHTHONOUS CAMBRIAN-ORDOVICIAN
Whitehall
1a
1b
2
3
4
5
6
7
8
22A
Fig.9
WC
Old Rt.4
Fair Haven
Fig.2
Fig.7
4
22
Fort Ann
Granville
5 KM
5 MILES
149
9
Glens Falls
Hudson River
Hudson Falls
40
TACONIC ALLOCHTHON
I.87
NY
VT
FLYSCH & MELANGE
Saratoga Springs
9
Fig.10
29
Schuylerville
Greenwich
Saratoga L.
CARBONATE THRUST SLIVERS
to Albany

its northern limits in western Vermont (Fig. 1). These efforts have revealed several localities where the geometric details of the Allochthon boundary can be discerned, and a corresponding emplacement history proposed. Most significantly, work by Rowley at the northern extremity of the Allochthon (Rowley, 1983a, 1983b) has shown that the present western thrust of the Taconics, referred to as the "Taconic Frontal Thrust" (Rowley and Kidd, 1982), is not the surface along which the continental rise rocks of the Taconics were thrust upon the continental shelf. The initial emplacement structure, the "Taconic Basal Thrust" (Rowley and Kidd, 1982), was subsequently folded during the main generation of folding in the Taconics, as originally suggested by Zen (1961, 1964 and 1967) and Rodgers (1952 and unpubl. ms). Further shortening of the orogen produced a new thrust system including the Taconic Frontal Thrust. These structures cut the folded Basal Thrust and dominate the geometric configuration of the western Taconics and adjacent flysch terrane. Details of the obduction-emplacement history of the Taconic Orogen are discussed elsewhere (Rowley and Kidd, 1981; Bosworth and Rowley, 1984).

Some previous workers have suggested that development of the Taconic Frontal Thrust, or in general the emplacement of the Taconic rocks onto the continental shelf, was a gravity-driven, soft-sediment event (Rodgers, 1951; Zen, 1967, 1972; Bird and Dewey, 1970; Potter, 1972). The presence of olistostromes west of the Allochthon boundary (within the Taconic melange) has long been cited as evidence in favor of this interpretation (Zen, 1967). Other workers have favored a hard-rock emplacement history based on structural characteristics of the Frontal Thrust fault zone (Ruedemann, 1914; Bosworth, 1980), the internal structure and stratigraphy of the Allochthon and adjacent Taconic flysch (Rowley et al., 1979; Rowley and Kidd, 1981; Bosworth and Vollmer, 1981), and through analogy with modern convergent orogens (Rowley, 1980; 1983a; Rowley and Kidd, 1981). This latter group has depicted the Frontal Thrust as part of a large scale imbricate thrust system (see cross-sections in Rowley et al., 1979, for example), similar to that envisioned for other external fold-thrust belts (Bally et al., 1966; Dahlstrom, 1970; Price and Mountjoy, 1970). Recent geophysical studies in the Taconide Zone of Quebec (Seguin, 1982) and western New England (Brown et al., 1983) support this view.

The purpose of this trip is to examine several relatively good exposure of structures immediately below, at and above the western boundary of the Taconic Allochthon. We will attempt to illustrate the following points or opinions:

1. Movement of the Taconic Allochthon across the coeval lower Paleozoic continental shelf took place through a complex, multi-staged series of events.

2. During emplacement on the continental shelf, both the Allochthon <u>and</u> underlying shelf material were well-indurated sedimentary rocks.

3. Small- and intermediate-scale structures produced during Allochthon emplacement are typical of hard-rock, foreland-climbing thrust systems in other well-studied orogens.

4. Much of the displacement during Taconian overthrusting occurred along melange zones at the base of the Allochthon and within the Taconic flysch, but that this was a decidedly brittle, "hard-rock" event involving incorporation (overriding and imbrication) of previously soft olistostromes. The presence of olistostromes of and in itself does not indicate gravity sliding or soft rock emplacement of the Allochthon.

The Taconic Mountains were one of the first North American orogenic belts to be studied, and this trip includes localities central to many of the "Taconic Controversies". We hope that participants will freely present their own ideas about the relationships we will see in the field, as structural geology is still really only in its infancy in the Taconics. For those following this trip on their own, we would ask that hammering at outcrops be kept to an absolute minimum (in many cases, it must be completely restrained from), and that due respect be given to the friendly and helpful land owners of the area.

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STOP DESCRIPTIONS

STOP 1. Gently-inclined strata of the autochthonous Paleozoic shelf sequence, not folded or thrust-faulted. Either 1a. or 1b. will be visited, depending on the size of the group and mode of transport. Locations shown on Fig. 1.

STOP 1a. Quartzites, arenites and dolomitic micrites of the Potsdam Formation (medial Cambrian). Williams Street in Whitehall.

Grenville gneisses are exposed in the riverbed directly below this outcrop; although the unconformity is not exposed here, it is elsewhere along strike north and south. The main purpose of this stop is to see that the strata in this outcrop show no prominent signs of deformation, being part of a gently east-dipping regional homocline. Although not a main focus of this field trip, the evidence for both shallow marine to beach facies (prominently cross-bedded and rippled clean arenites and quartzites) and lagoonal supratidal-flat facies (dolomitized micrites and thin shales, laminated in places with small stromatolites and locally with sand-filled vertical burrows) are well displayed here. Some layers, with pebbles of dolomitized micrite, may well be storm deposits.

STOP 1b. Limestones of the Whitehall Formation (late Cambrian). Sciota Road 1.6 miles from Whitehall.

These strata also are part of the regional gently east-dipping homocline of autochthonous shelf strata (typically 5-10 degrees east dip). No folds or cleavage are visible in these strata, and oolites which are locally abundant in some beds do not appear strained to any significant extent. Stylolites do occur in some beds but they are bedding-parallel, presumably compactional in origin. Laminated algal micrites, locally stromatolitic, can be seen, along with micrite edgewise breccias with oolites, all evidence of shallow marine to intertidal/supratidal facies. Nodular chert layers occur locally in this outcrop. It should be emphasized that most of the volume of the pre-medial Ordovician autochthonous shelf sequence is dolostone. Limestones form an overall small proportion and this unit (part of the Whitehall Formation) is, after the medial Ordovician limestones, the most prominent limestone in the early Paleozoic shelf sequence. Dolostones occur at the east end of the quarry where the outcrop nears the road - we will not examine these.

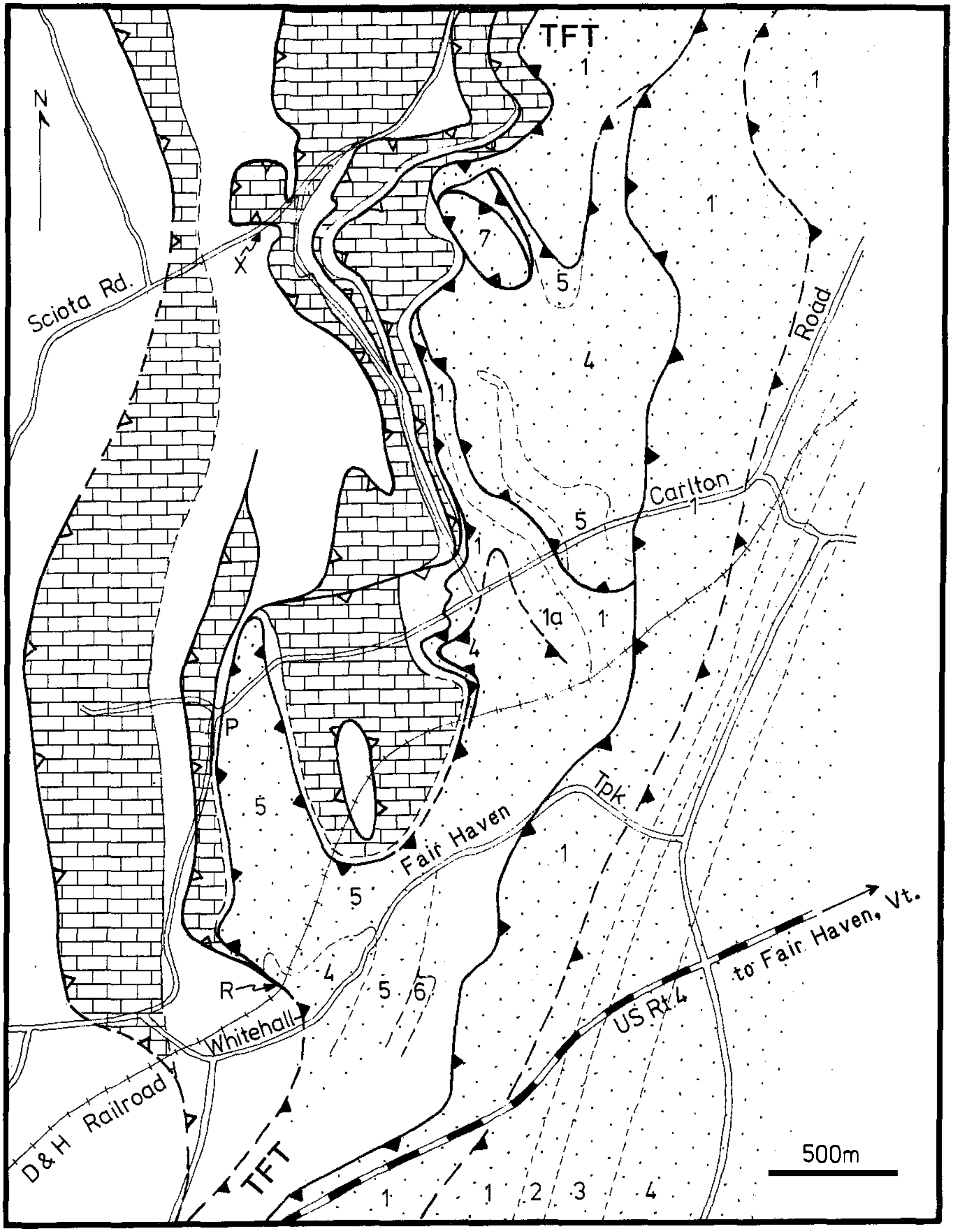
STOP 2. Thrust of medial Ordovician Isle la Motte (or Middlebury) limestones over medial Ordovician shaly melange. Locality indicated with an "X" on Fig. 2.

Carbonate exposures such as this one form lenticular belts bounded by medial Ordovician shales and fine-grained wackes (flysch) in a zone near this vicinity 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 at Stops 1a and b).

Where contacts are exposed, such as here, and Stops 6 and 9, 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 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 approximately half way along the exposure of the thrust (Fig. 3). 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

Fig. 2. Preliminary geological map of a portion of the western boundary of the Taconic Allochthon between Whitehall, N. Y., and Fairhaven, Vt. (see Fig. 1 for location). Brick pattern - carbonates, largely medial Ordovician limestones; blank areas - medial Ordovician shales, in part melange; dotted pattern - lithologies of the Taconic Allochthon: 1 - Bomoseen Formation; 1a - Truthville slate; 2 - Brown's Pond Formation; 3 - Middle Granville slate; 4 - Hatch Hill Formation; 5 - Poultney Fromation; 6 - Mt. Merino Formation; 7 - Pawlet Formation. Thrusts shown with teeth in direction of dip; teeth black for thrusts cutting Taconic Allochthon lithologies, teeth open for other thrusts.

Roadcut exposing a thrust of limestone over shale (Stop 2) is marked by "X" (see Fig. 3 for detail). A folded pre-slaty cleavage thrust surface is exposed at Stop 3, Plude's Quarry (P) - see Fig. 4 for detail. The Taconic Frontal Thrust (TFT) is interpreted to pass at the base of this exposure. The easternmost thrust shown (with a dashed line) may be the one exposed, just to the east of the area of this map, at William Miller Chapel fenster (see Fig. 1). Location of the Delaware and Hudson railroad cut, Stop 4 (Fig. 5), given by "R". Mapping by C. Steinhardt (1982), Kidd, Bosworth, M. Ross, J. Piedra and D. Wolf (1983).



TFT
N
Sciota Rd.
X
Carlton
Road
Tpk.
Fair Haven
P
R
Whitehall
D&H Railroad
US Rt 4
to Fair Haven, Vt.
TFT
500m
1
1
1
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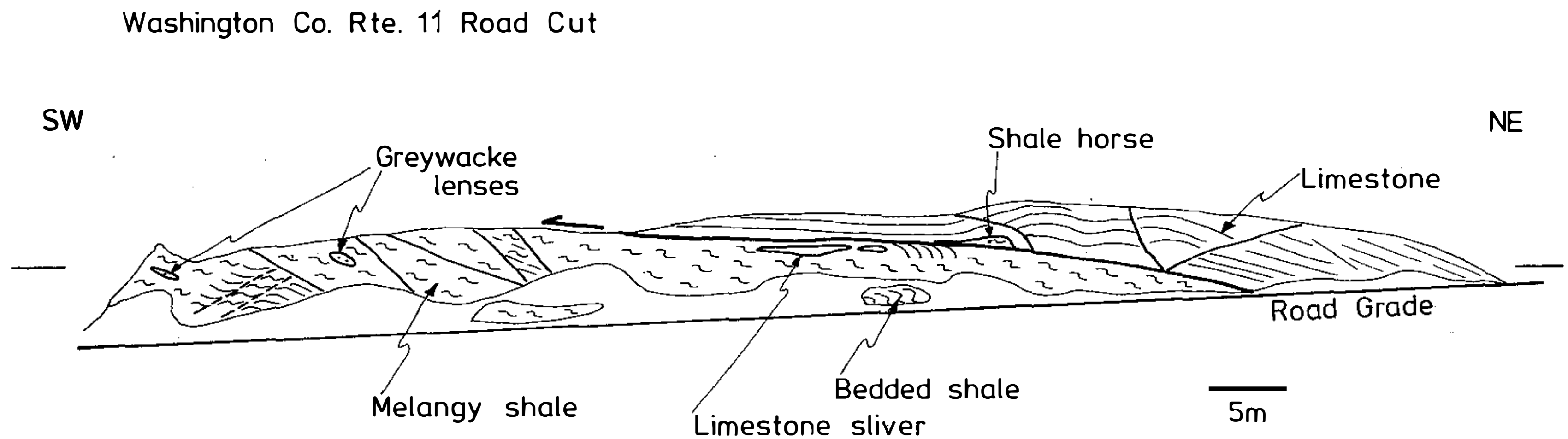


Fig. 3. Profile exposed in road cut on north side of Washington County Route 11, 0.35 mile east of intersection with Sciota Road. Location marked with "X" on Fig. 2. Medial Ordovician limestone thrust over medial Ordovician melangy shales.

western part of the cut. Slickensided surfaces suggest that they too are products of structural disruption ("structural slicing"), although an olistolithic origin 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. 2, 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 whthin them.

STOP 3. Pre- to syn-cleavage thrust of Poultney Formation over gray slates, above Taconic Frontal Thrust. Locality marked "P" on Fig. 2.

Plude's Quarry (Fig. 4) provides one of the few known exposures of Taconic continental rise rocks lying directly upon the underlying melange/flysch sequence. Several complexities of Taconic thrusting are evident at this stop. Along Carleton Road the shales and graywackes of the Taconic flysch are broken into a melange fabric, that grades up into the quarry with progressively less disruption, until a planar slaty cleavage is found. This is the Taconic Frontal Thrust, and can be mapped as in Fig. 2. Within the quarry a second, earlier fault is present, separating easily identified Lower Poultney slates and thin arenites from an underlying gray slate. The regional slaty cleavage cuts the fault, suggesting that this structure may be of the same generation as Rowley and Kidd's (1982) "Taconic Basal Thrust". The gray slates are interpreted to be a unit within the Middle Ordovician Taconic Flysch (allochthonous? parautochthonous?), and hence the fault is inferred to be a thrust.

STOP 4. Delaware and Hudson Railroad cut 300m NE of crossing Whitehall-Fairhaven Turnpike. Locality shown with "R" on Fig. 2.

At the east end of the cut (Fig. 5), both sides expose thinly laminated, brown fine-grained arenites in dark slate belonging to the upper Hatch Hill or lowermost Poultney Formations (Cambrian - earliest Ordovician) of the Taconic Allochthon. These are in contact across a steep fault with thicker bedded coarse dolomitic (locally calcareous) quartz arenites and quartzites in black slate of the middle to lower Hatch Hill Formation (early Cambrian or older). At the western end of the cut, the last exposure contains a fold in Hatch Hill slate and arenites such that bedding surfaces in the slate form the face of the exposure on one limb of the synformal fold. This western end is close to but not quite at the Frontal Thrust seen at Stop 3. On the hill to the north a southward-thinning thrust sheet of shelf limestones occurs between shaly melange below and Taconic rocks above, such as are seen in this cut and at Stop 3. A unit of shaly melange up to a few meters thick occurs between the limestone and the Taconic rocks, and was seen at Stop 3. The western part of this exposure, with the complex slicing and phacoidal cleavage in the black argillite, can be regarded as transitional, in a structural sense, to the melange. The

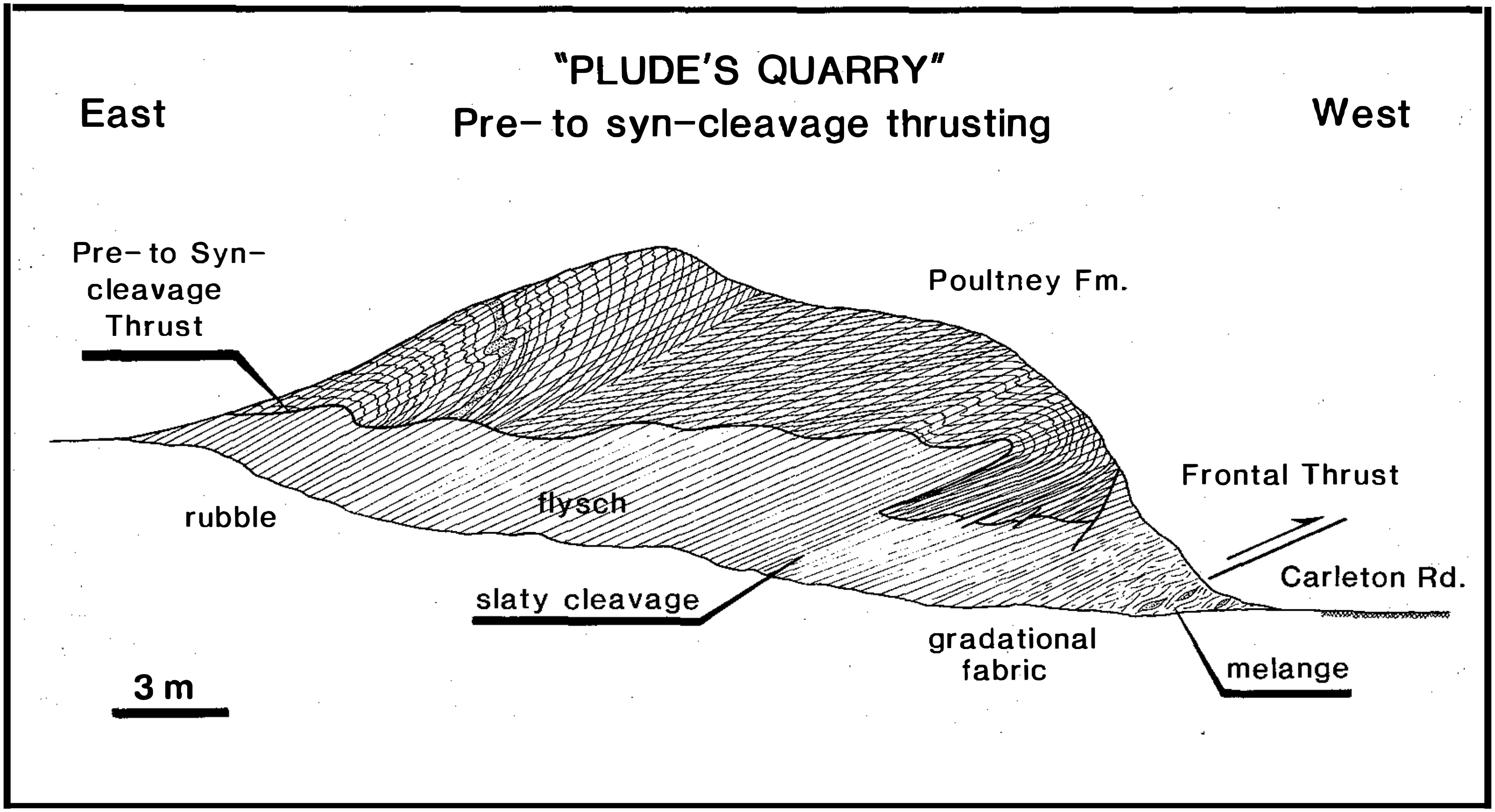


Fig. 4. Exposed pre-slaty cleavage thrust in quarry face (Plude's Quarry, Stop 3; location marked "P" on Fig. 2). Allochthonous Poultney Formation rocks were thrust over gray shales and then folded and cleaved. Thrusting and folding were apparently in part synchronous, as the amplitude of the fold in the thrust surface in the easternmost anticline is less than the amplitude in the folded Poultney. The gray slates most closely resemble a flysch lithology, although whether it is allochthonous or parautochthonous flysch cannot be demonstrated without biostratigraphic control.

disposition of the Hatch Hill and Bomoseen can be interpreted as an earlier thrust that has been folded and cut by younger, more steeply inclined thrust faults. Fig. 2 shows that the occurrence of a Bomoseen-derived slice immediately above the Taconic Frontal Thrust, followed by a Hatch Hill/Poultney-derived slice, is characteristic of much of the Taconic area bounded by the folded thrust that occurs near the Allochthon boundary in this region.

Structures in the railroad cut that we connect with the emplacement of the thrust sheet are fault-related features, particularly slickensides, summarized in Fig. 6. A Riedel and anti-Riedel fault set are interpreted to be present and are consistent with thrust movement towards the west-northwest. We emphasize the brittle nature of this deformation.

STOP 5. Parautochthonous flysch in contact with autochthonous(?) shelf carbonates. Lunch stop; location given in Fig. 7.

The Mettawee River here provides a superb series of exposures that cross from autochthonous(?) shelf carbonates (where we will stop for lunch), through alternating zones of flysch and melange, to a large sliver of Chazyan carbonate, and on into allochthonous Taconic lithologies (Fig. 7). The only area that is poorly exposed in the river is the eastern edge of the carbonate sliver, but mapping demonstrates that this fault contact (the Taconic Frontal Thrust) cuts obliquely across Taconic stratigraphy and large-scale fold axes, and is therefore a post-slaty cleavage generation structure (Figs. 7,8).

As at Stop 2, some workers are of the opinion that the allochthonous carbonate at this locality (D.W.Fisher, pers. comm.,1983) and along the western edge of the Allochthon in general (J.Rodgers, pers. comm., 1983; Rodgers and Fisher, 1969) is better interpreted as blocks-in-shale (i.e., olistoliths) than as coherent fault slivers. This locality provides an excellent means to test these two hypotheses. The carbonate/melange contact can be walked from point "X" to point "Y" (Fig. 7) with little difficulty (after wading across the Mettawee....access at "Y" is limited by buckshot). The carbonate is seen to be continuous, essentially unbroken along strike, with internal fold axes approximately parallel to the general contact trend (see Selleck and Bosworth, 1985, Plate 1A). The carbonate must be in the form of a large sheet, or composite sheet, which could be called a single "block". Minor disruption near its margins is undoubtedly present, but the structural style is dominantly detachment of underlying autochthonous shelf rocks and their imbrication at the base of the advancing allochthonous thrust pile. It is misleading to describe the geometry of the large carbonate bodies along the western edge of the Allochthon as "blocks-in-shale", and it is very unlikely that they arose as sedimentary slump features (further discussed in Rowley and Kidd, 1982).

STOP 6. Imbricated medial Ordovician carbonates, shales and melange just below the Taconic Frontal Thrust. Vermont Route 22A 6.5 km north of Fair Haven. Location shown with arrowhead on Fig. 9.

The part of this roadcut to be examined is illustrated in Fig. 9, and consists of the outcrop opposite the parking area and its continuation to the north. A thrust-repeated section of medial Ordovician strata is discernable from medium-bedded limestone (fossiliferous calcarenites to calcisiltites) without shale - Orwell Limestone, passing up abruptly into

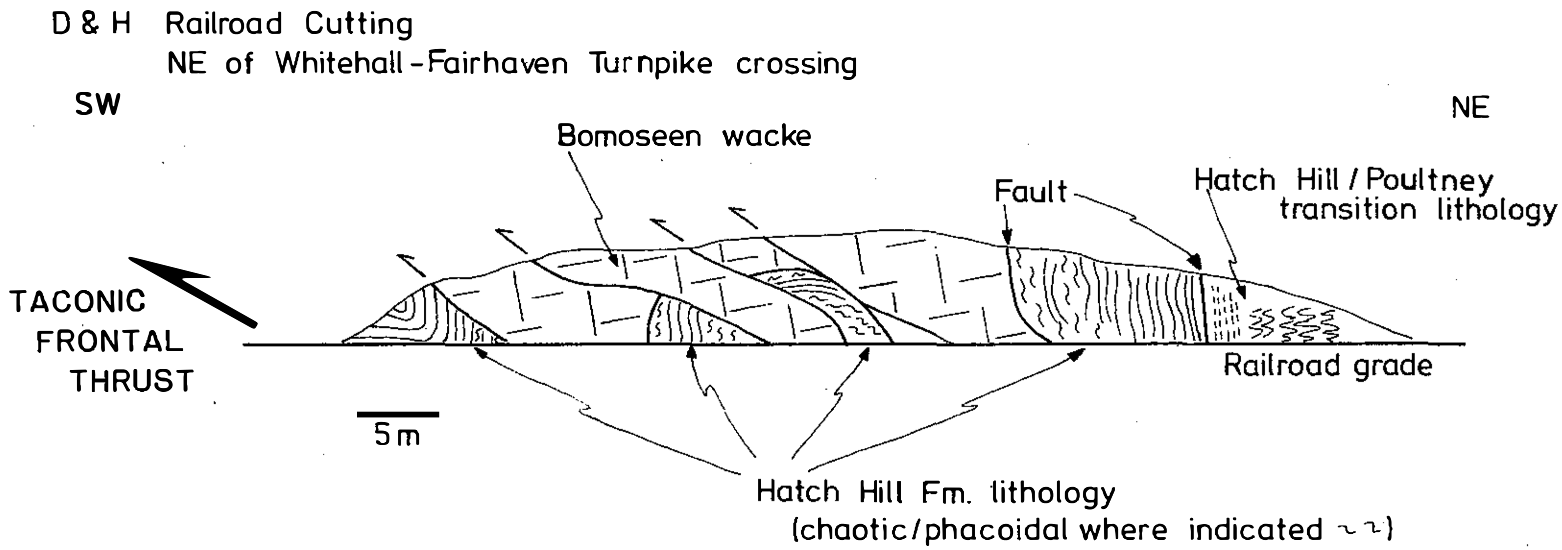


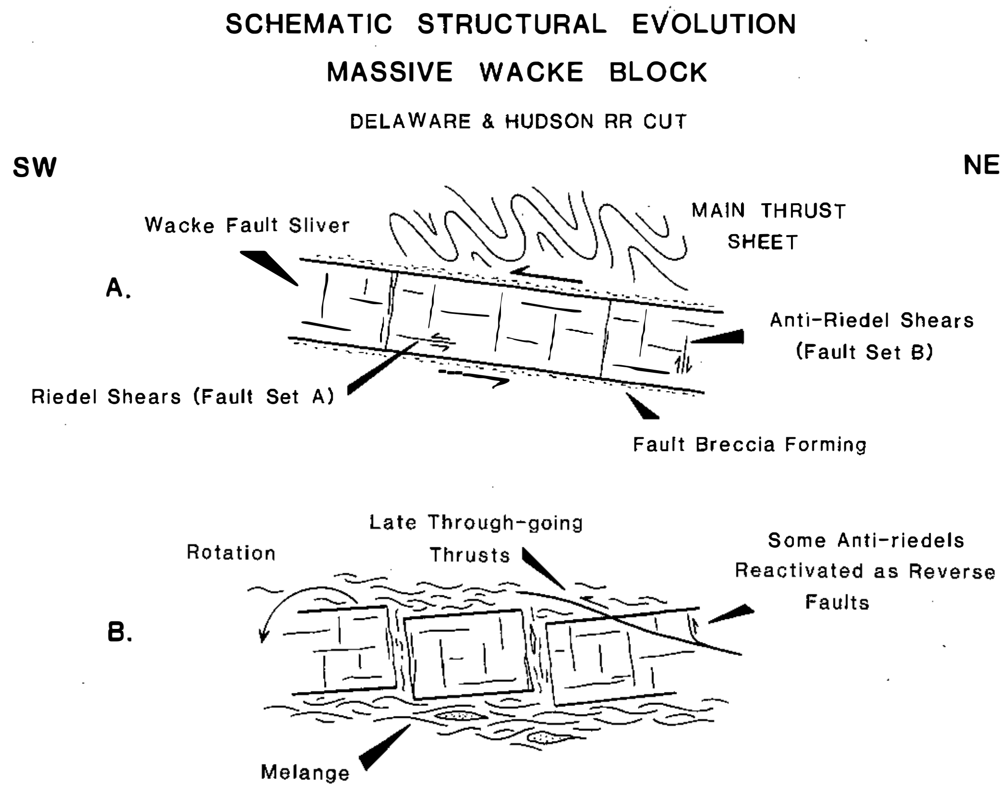
Fig. 5. Delaware and Hudson Railroad cut adjacent to the Frontal Thrust fault zone (Stop 4). Location of railroad track is given in Fig. 2; cut location indicated by "R".

thin-bedded limestones (micrites) interbedded with dark shale - Glens Falls Limestone, overlain by dark shale, in part melange - here referred to as Hortonville shale (and the melange perhaps as Forbes Hill "conglomerate"). It is important to recognize that the dark shale, in the first instance, is a stratigraphic member of this succession, just as it is in the autochthon to the west (e.g., in the Mohawk Valley). That some of it has been structurally damaged by the imbrication and duplication of the sequence is a secondary effect, reflected in the lenticular (phacoidal) cleavage visible especially in the shale closest to the base of the succeeding limestone. Two of the eight sections lack the basal Orwell Limestone, probably because of local ramping of the active thrust, or original irregularities in the depositional arrangement. It is not valid, in our view, to regard this exposure as "all melange" with blocks of limestone floating in shale. Rather, it is a thrust-imbricated repeated lithic sequence, probably forming a thrust "duplex" above more extensive shaly melange, not containing limestone clasts, that is exposed on the slope to the west of the parking lot and in the separate road cut on 22A about 100 m north of this outcrop. The duplex is below the Frontal Thrust of the Taconic Allochthon which comes to the surface about 50 m east of this road cut; wackes of the Bomoseen Formation of the Allochthon form the prominent topographic feature of "the Great Ledge" visible to the east from the parking lot. More extensive massive limestones (Orwell, and perhaps Middlebury Limestone as well) that form road cuts along 22A just to the south are thought to be larger slices in the duplex zone. Noteworthy in the narrow (less than 1 m) zones of shaly melange beneath each slice of limestone in the cut are a few blocks and cobbles of green micaceous arenite identical to the Bomoseen Formation of the Allochthon. The largest of these (approx. 1 m across) occurs at the very northern end of the outcrop, but other smaller ones occur within the outcrop near 30-40 m on the diagram. These we <u>do</u> interpret as olistolithic clasts shed from the front of the Taconic thrust sheet during its motion, and they require that the active thrust outcropped on the sea-floor, at a deep-sea trench-type feature. A similar, but larger (several m across) olistolith of Bomoseen wacke occurs in the outcrop of melange to the north. It is our observation, however, that there is a limit of a few meters to the size of these blocks that are clearly identifiable as olistoliths. Truncated bedding, slickensides and other features characteristic of ramp-flat thrust geometry can be seen in this outcrop. The present attitude inferred for the Taconic Frontal Thrust (about 10° east dip) and the steep east dip of these limestone-shale imbricate slices are consistent with their identification as duplex structures. Their attitude is not consistent with a model of tabular olistolithic slabs lying in the bedding orientation.

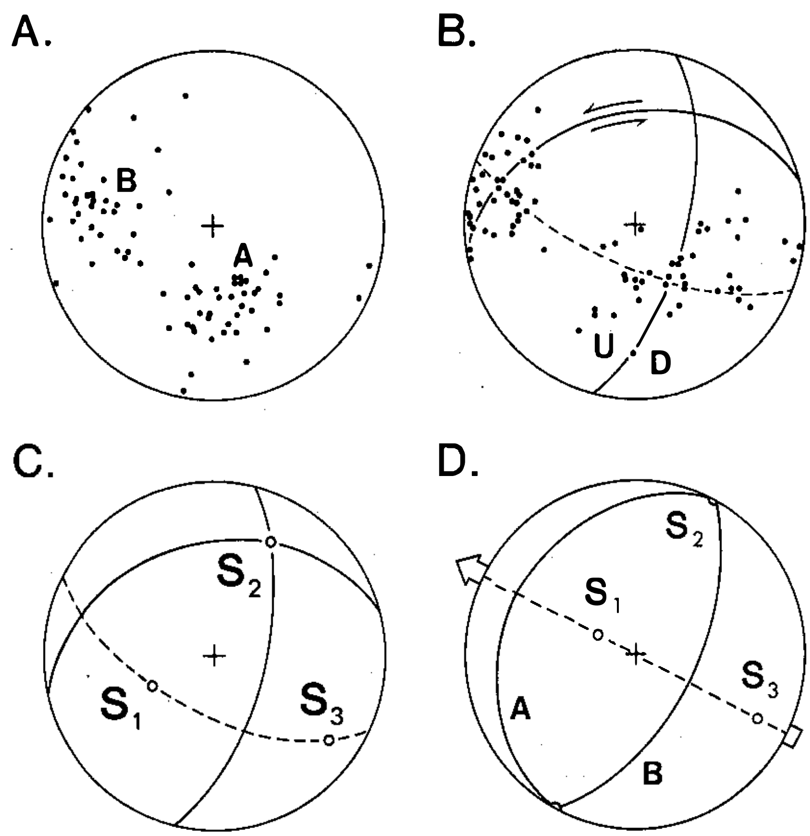
STOP 7. Boss Hogg's Quarry. Marked "H" on Fig. 9. Permission must be obtained from the owner to visit this locality.

The quarry exposes part of the early Ordovician Providence Island Formation, mainly dolostones with some limestone, not far below the overlying Middle Ordovician limestones (Middlebury) that outcrop to the east (see Fig. 9). The purpose of this stop is to see the structural condition of carbonates within the areally extensive thrust sheets that exist at this latitude between the Frontal Thrust of the Taconic Allochthon and the autochthonous shelf strata. On the south side of the entrance to

6a


SCHEMATIC STRUCTURAL EVOLUTION
MASSIVE WACKE BLOCK
DELAWARE & HUDSON RR CUT
SW
NE
A.
Wacke Fault Sliver
MAIN THRUST SHEET
Anti-Riedel Shears (Fault Set B)
Riedel Shears (Fault Set A)
Fault Breccia Forming
B.
Rotation
Late Through-going Thrusts
Some Anti-riedels Reactivated as Reverse Faults
Melange

6b


A.
B
A
B.
U
D
C.
S2
S1
S3
D.
S2
S1
S3
A
B

the quarry a close synformal fold displays well-developed solution cleavage and marked changes in thickness from the short, west-dipping limb to the long, east-dipping limb due to more homogeneously distributed ductile shape change. A complementary antiform is exposed on the north side of the entrance linked to a synform that trends along the northeast face of the quarry. A wrench fault passing through the quarry entrance must offset the fold hinges in a left-lateral sense. The contrast between the substantial ductile strain shown in this outcrop and the lack of such features at Stop 1b in the autochthon is a reflection of the thrust translation of these carbonates and deformation during active movement on lower thrusts. The cleavage at this stop is roughly parallel with that in Taconic rocks exposed to the east. However, this does not necessarily make the cleavages the same age; evidence exists to suggest that they are not, and that the Taconic rocks were cleaved and folded before emplacement over this portion of the shelf carbonate terrane.

STOP 8. Scotch Hill syncline at Glen Lake. Permission must be obtained from the owner (in the house across the road). NO HAMMERS ALLOWED. Location shown on Fig. 1.

This outcrop exposes early Ordovician strata of the Poultney Formation, probably about the same age as the carbonates of Stop 7, but a very different facies deposited in deep marine conditions on the continental

Fig. 6a. Schematic structural evolution inferred for a wacke block or sliver exposed in the Taconic Frontal Thrust fault zone at the Delaware and Hudson Railroad cut (Fig. 5).

A. block disrupted from coherent allochthonous mass, overidden and attached to base of Allochthon. Conjugate shear fractures initiated at 30 to 45° from incremental shortening direction.

B. rotation of fractures as block begins to break up and become incorporated into melange.

Fig. 6b. Stereograms of structural data collected in large wacke block at the Delaware and Hudson Railroad cut illustrated in Fig. 5. Lower hemisphere, equal area projections.

A. poles to small-scale faults (n=76). Faults in set "A" are north-dipping, left lateral, strike-slip faults; those in set "B" are east-dipping normal faults.

B. striations on small-scale faults (n=83; a few faults possessed multiple slip directions). Great circles give average fault orientations. Fault striations cluster at points roughly 90° from the intersections of fault sets A and B, the case to be expected if plane strain is dominant. Dashed great circle is plane perpendicular to A-B intersection.

C. interpretation of principal shortening directions given average fault orientations, slip directions and slip senses of shear.

D. rotation of S_2 direction to the horizontal. The trends of S_1 and S_3 now parallel the inferred west-northwest transport direction of the Taconic Allochthon. Fault set A corresponds to Riedel shear orientations, and fault set B to anti-Riedel orientations.

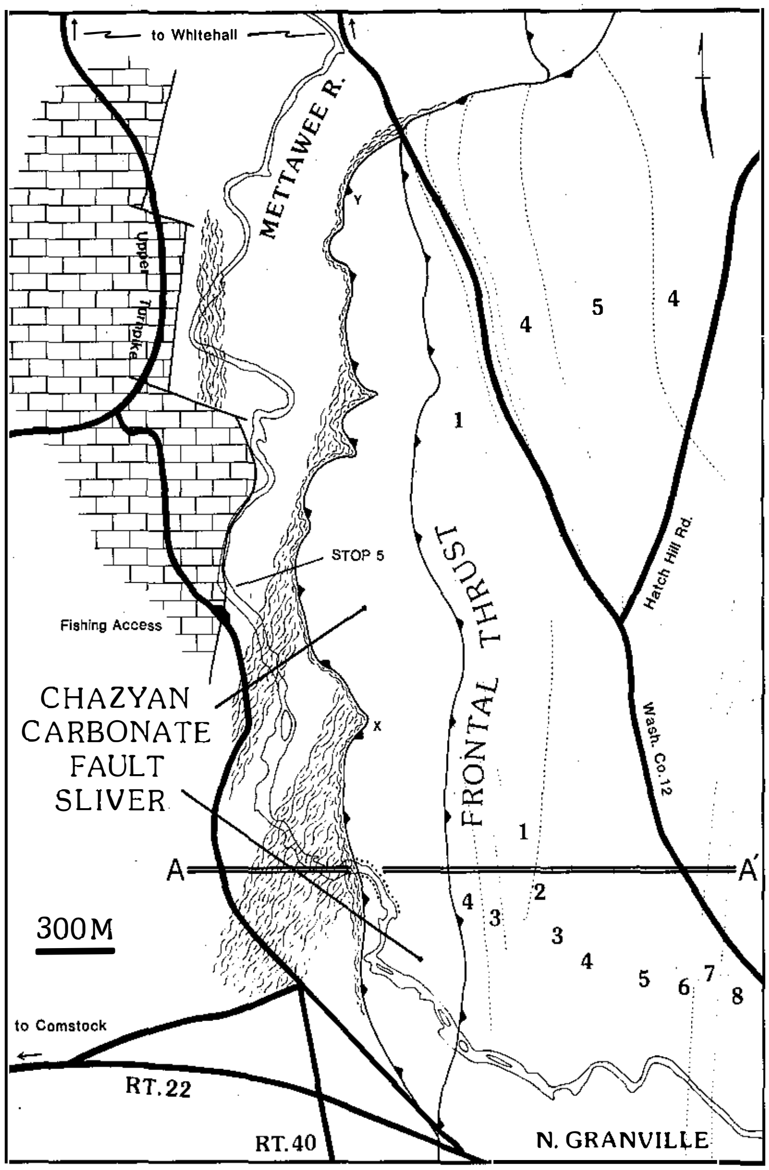


Fig. 7. Geological map of the Taconic Allochthon boundary in the vicinity of North Granville, N.Y. A large sliver of Chazyan carbonate rock lies at the contact between allochthonous Taconic sequence rocks (numbered 1-8) and parautochthonous flysch (unornamented) and melange (scaly pattern). Two generations of melange are observed in this area, one developed along the base of the carbonate fault sliver and one imbricated within the flysch. Structural relationships at the contact between autochthonous(?) shelf carbonates (limestone pattern) and the flysch are poorly constrained but believed to include both normal fault, depositional and probably thrust contacts. 1 = Bomoseen Wacke and Truthville Slate; 2 = Browns Pond Fm.; 3 = Middle Granville Slate; 4 = Hatch Hill Fm.; 5 = Poultney Fm.; 6 = Indian River Slate; 7 = Mt. Merino Fm.; 8 = Pawlet Fm. (from Selleck and Bosworth, 1985).

INTERPRETIVE
CROSS-SECTION THROUGH THE TACONIC
ALLOCHTHON BOUNDARY
FROM A TO A′

no vertical exaggeration

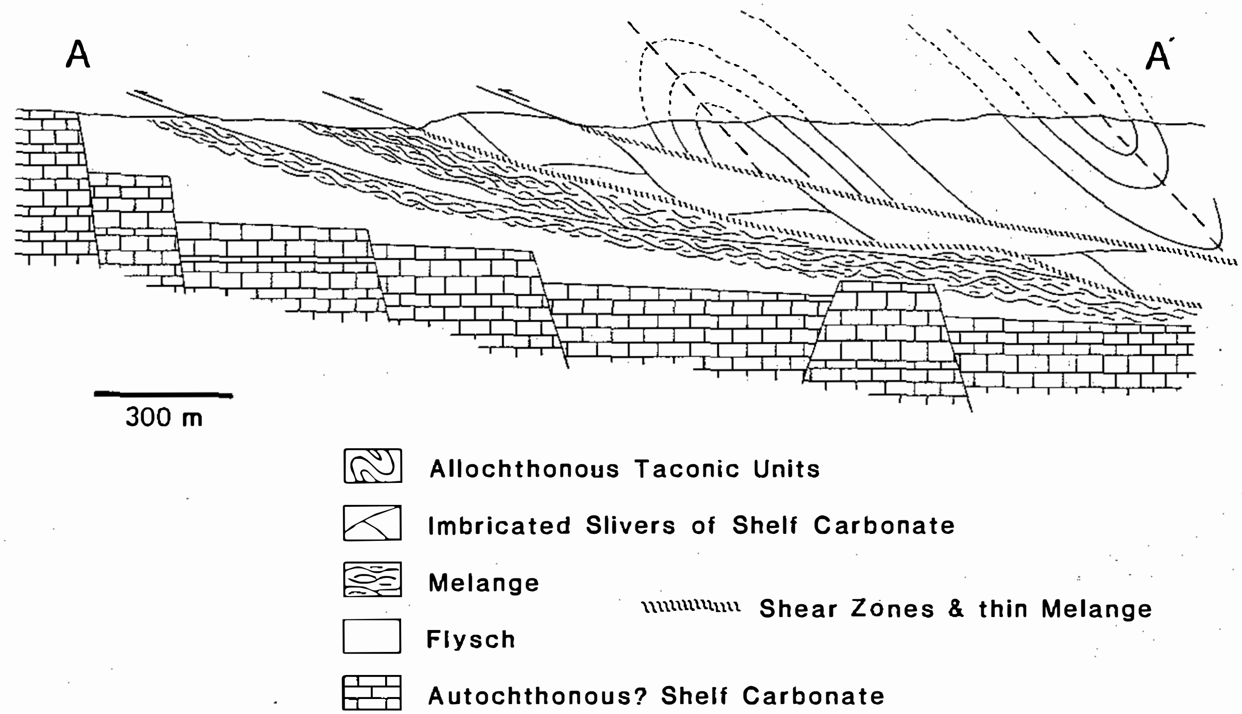
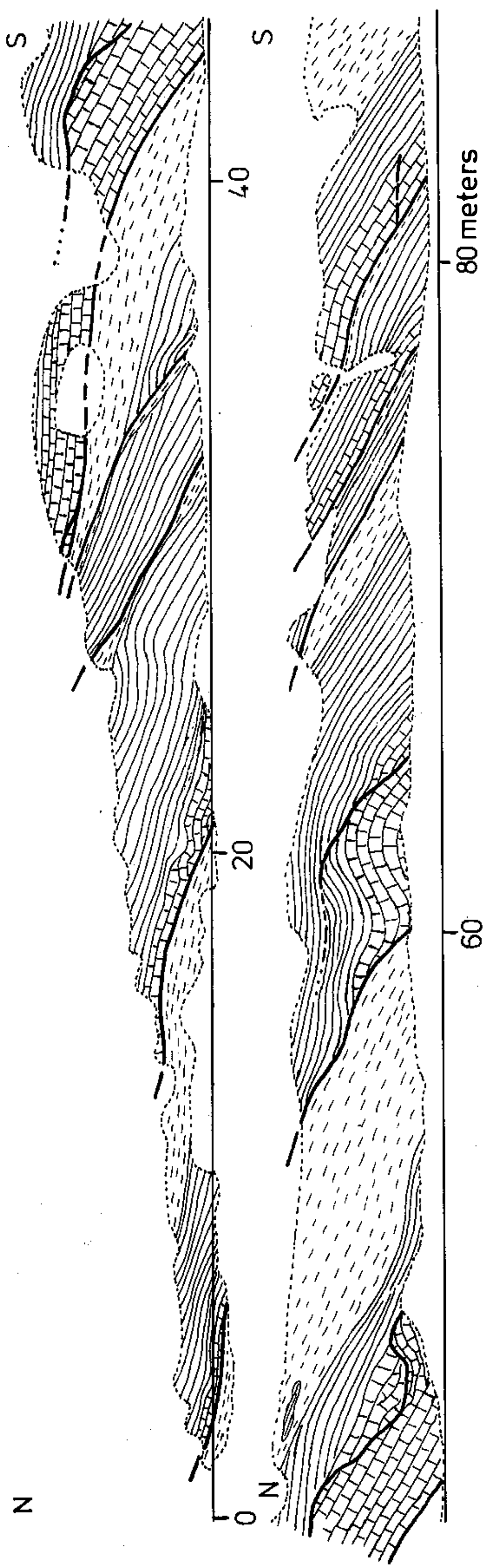
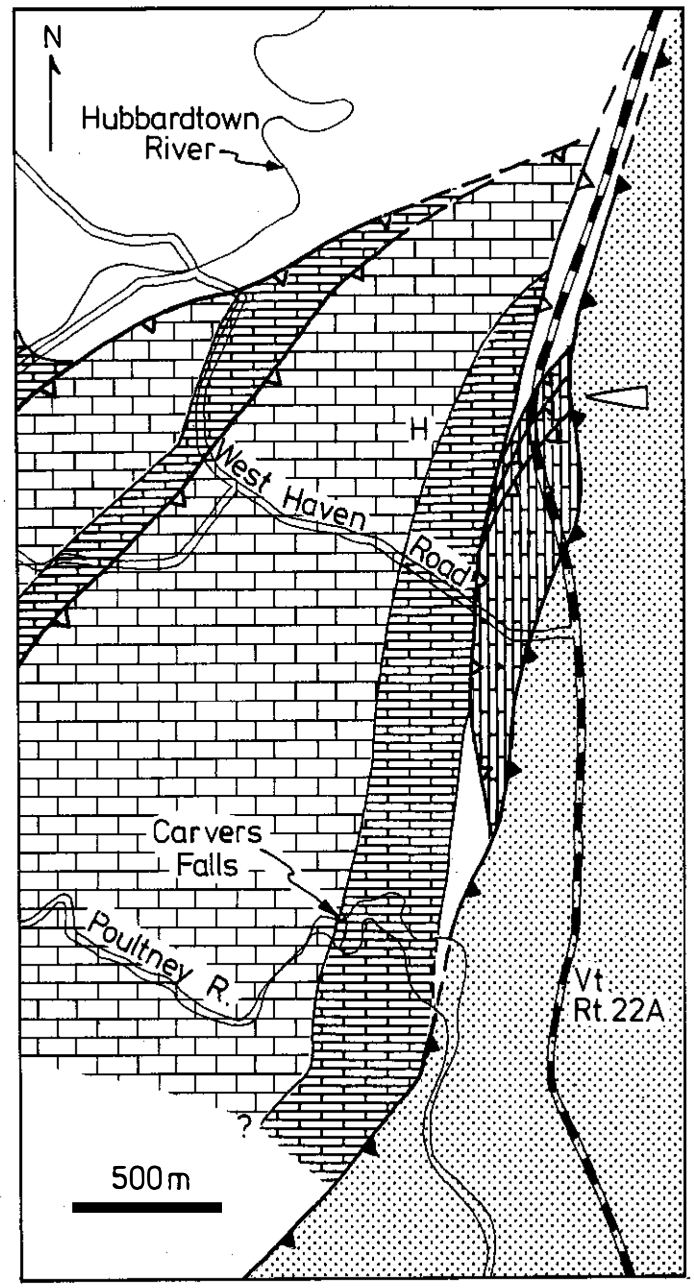


Fig. 8. Interpretive cross-section from A to A' on Fig. 7. The internal structure of the large carbonate fault sliver is schematically shown to consist of fault-bounded packets, probably defining a duplex structure of some form (internal folding of the carbonate is not diagrammed for clarity; from Selleck and Bosworth, 1985).


S
40
20
0
N
S
80 meters
60
N


N
Hubbardtown River
H
West Haven Road
Carvers Falls
Poultney R.
Vt Rt.22A
?
500 m

rise. These rocks consist of green mudrock (slate) alternating with thinner laminated layers of fine sand to silt size arenites and quartzites that are interpreted as contourite deposits, and black/gray mudrock (slate) laminae. The black mudrock layers are probably pelagic; the green are likely mud contourites. The syncline expose here is the single major hinge of a fold that is in a set with wavelengths of the order of 1 to 3 km and amplitudes of similar amount. The folds are tight to near isoclinal in form. This outcrop does not give the impression that the folds are this tight since the full transition to the fold limb bedding attitudes, particularly on the overturned limb, are not seen in this exposure. This particular fold can be traced north for 3 km and south for 8 km from this place; another single fold in this set in the northern Taconics can be traced for at least 50 km along its axis, characteristic of their subhorizontal to gentle plunges. The overturned nature of this fold, with its moderately east-dipping axial surface and near-axial planar cleavage is also typical of the structure of the low Taconics (Giddings Brook Slice). In detail, small parasitic folds in the quartzites in this outcrop can be seen to be transected by the slaty cleavage, suggesting that buckling of thin layers in response to shortening took place, as is usually the case, before thicker composite layers that generate longer wavelength folds. Thus the cleavage may be axial planar to the large-scale folds but not to the smaller ones. Examples of cleavage refraction can also be seen, and cleavage parallel quartz veins (? post-cleavage) are also present. We emphasize the coherent ductile deformation seen in this outcrop, characteristic of all the western Taconics in the northern part of the Allochthon. In our view it does not support the idea of the emplacement of the Allochthon as a gravity slide of unconsolidated sediments. Comparison of structures here with those in the thrusted carbonates (Stop 7) and at the western edge of the Allochthon (Stop 3) are consistent only with thrust emplacement of coherent, consolidated rock, undergoing related ductile deformation (folding and cleavage formation) at different times in different places during the overall assembly of the thrust sheets.

Fig. 9. Profile of roadcut (Stop 6) on east side of Vermont Route 22A, 6.5 km north of Fair Haven, Vt. (see Fig. 1 for general location). Roadcut shows imbricated sequence of middle Ordovician Orwell Limestone (bricks), overlain by Glens Falls Limestone (lines), wverlain by black shale and melange (Hortonville shale/Forbes Hill conglomerate - dashes). Two profiles shown overlap - the upper one continues to the right in the lower one. Major thrusts shown by thick lines; other faults not emphasized. Line with meter scale is road surface, which slopes to the north, and is not flat as implied by the diagram. Dips shown are those exposed at the outcrop surface - true dips are considerably steeper, typically 50-80° E. Location of roadcut (Stop 6) shown by arrowhead on map. The imbricated zone is shown schematically on the map.

Map units: coarse bricks - Providence Island dolostones; fine horizontal bricks - Middlebury limestone; fine vertical bricks - imbricated Orwell and Glens Falls limestones; blank - Hortonville shale and Forbes Hill conglomerate (melange). Taconic Frontal Thrust shown with black teeth; other thrusts with open teeth. Location of Stop 7 shown by letter "H". Mapping by C. Steinhardt.

STOP 9. Shelf carbonate duplex beneath the Taconic Frontal Thrust at Bald Mountain, N.Y. Location given in Figs. 1 and 10.

Bald Mtn. has been a perennial favorite for stops in field guide books of eastern New York, and several excellent descriptions of the locality are available in the older literature (Walcott, 1888; Ruedemann, 1914). More recent discussions can be found in Platt (1960), Sanders, et al. (1961), Zen (1967), Bosworth (1980) and Rowley and Kidd (1982).

We have intentionally placed the Bald Mtn. quarries at the end of our trip, despite their proximity to Saratoga Springs. We have been emphasizing processes related to frontal imbrication, multiple generations of thrusting and the formation of duplexes throughout the day. We feel that the examples we have presented are fairly convincing. Bald Mtn., however, is shrouded with historical overtones, and is also exceedingly complex. The general picture is quite clear: the uppermost portions of the quarries are composed of allochthonous Taconic lithologies, these overly a thin zone of phacoidally cleaved shales, which in turn overly discontinuous masses of shelf carbonate (some quite large) and more phacoidally cleaved shale. But the details are not so clear. Are the carbonate blocks fault slivers, or are they olistoliths within a large-scale sedimentary slump mass, subsequently overridden by the Taconic thrust sheets (Rodgers, 1952; Rodgers and Fisher, 1969)?

We recognize some internal order in the disposition of lithologies in the area of the Bald Mtn. carbonates, with similar lithologies aligned along strike (Fig. 10). Several of the carbonate blocks are probably hundreds of meters in length, not unlike the Chazyan sliver on the Mettawee River (Stop 5). As at Stops 5 and 6, small rounded cobbles of limestone (in this case) within the phacoidally cleaved shale zones may in fact be olistoliths, probably derived at subaqueously emergent fault scarps from the main masses of carbonate themselves (Rowley and Kidd, 1982; Bosworth and Vollmer, 1981). However, we again feel that the structure at Bald Mtn. can reasonably be interpreted as a fault duplex (Fig. 11), as was first proposed by Ruedemann (1932, p. 134). We encourage all participants to share their thoughts with the rest of the group!

A regional compilation of presently identified structures believed to be associated with the Taconic Frontal Thrust System (youngest Taconian deformation) is presented in Fig. 12.

Acknowledgements - Numerous individuals have contributed to recent structural studies of the western Taconics, and we would like to especially acknowledge collaboration with D.B.Rowley, F.W.Vollmer, S.Chisick and B.Selleck.

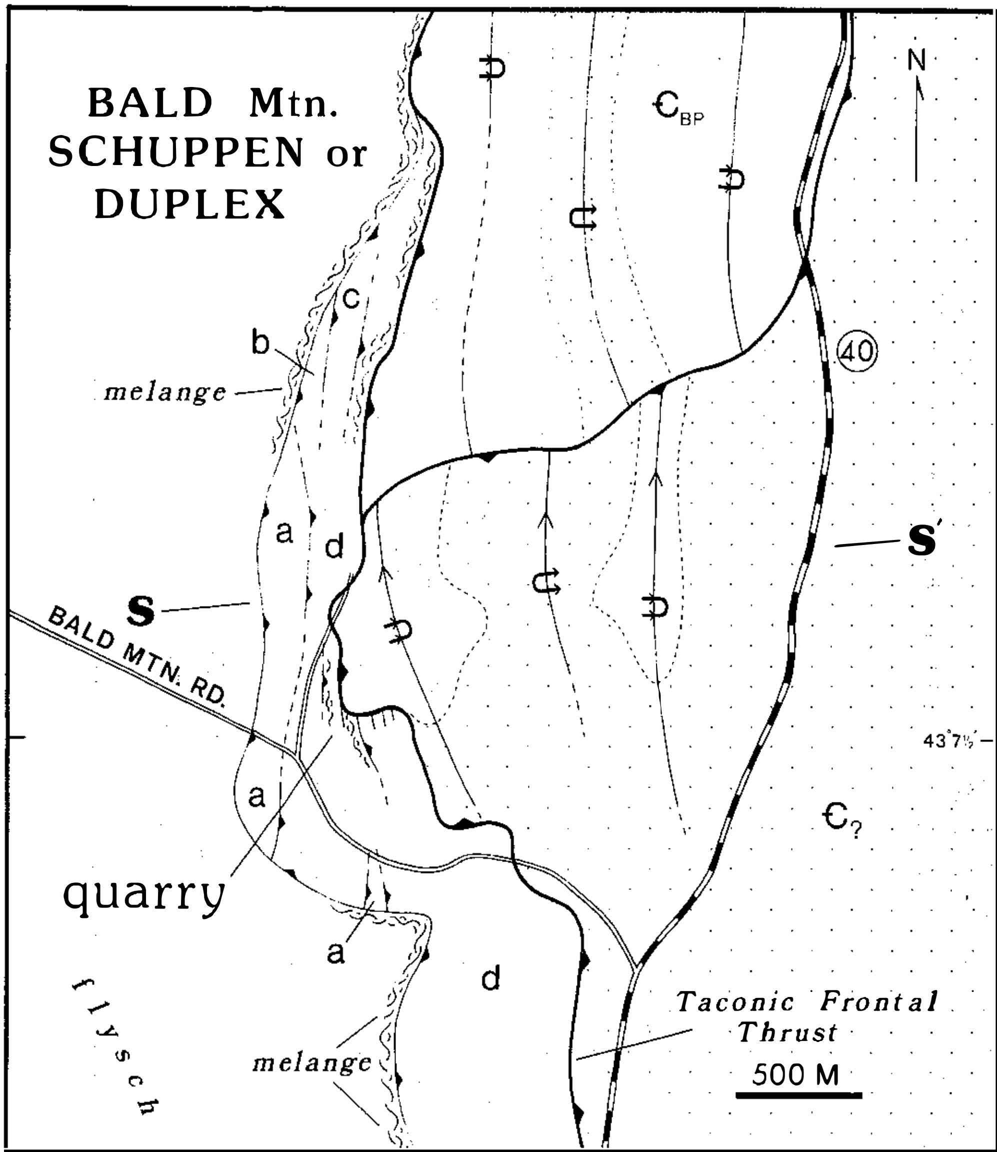


Fig. 10. Geological map of the Bald Mtn. "schuppen" or fault duplex, Washington Co., N.Y. (see Fig. 1 for location). $€_?$ = Bomoseen Wacke and Truthville Slate; $€_{BP}$ = Browns Pond and probable Hatch Hill Fms. Incomplete exposure prevents interpretation of the entire structure within the duplex itself. Duplex lithologies are identified as: a = hard quartz arenites and mica-speckled quartz wackes (in part possibly Bomoseen lithologies; Elam, 1960); b = limestone and dolostone pebble/cobble conglomerate with sandy dolomitic matrix (Rysedorph Hill Comglomerate; Ruedemann, 1914); c = thin-bedded limestone and dark gray shale; d = undifferentiated limestones and lesser dolostones, often thick-bedded or massive. Numerous melange zones are present within the duplex (anastomosing pattern) and phacoidally cleaved shale is present between most individual horses. Geology modified from Platt, 1960, and Bosworth, 1980.

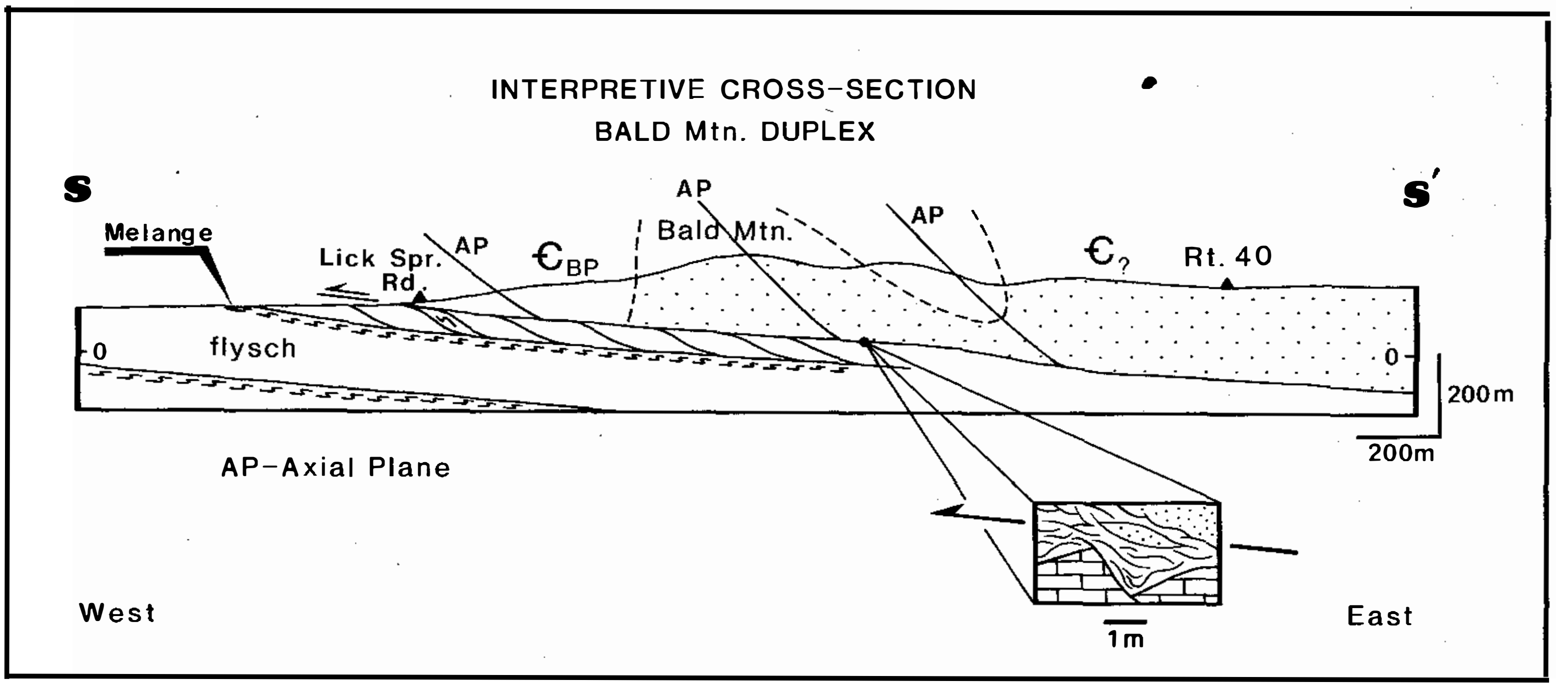


Fig. 11. Interpretive cross-section through the Bald Mtn. fault duplex (Fig. 10). Formation symbols are the same as in Fig. 10. No vertical exaggeration. Inset illustrates the complex nature of the duplex roof fault (fault zone), as exposed at the quarries (Stop 9).

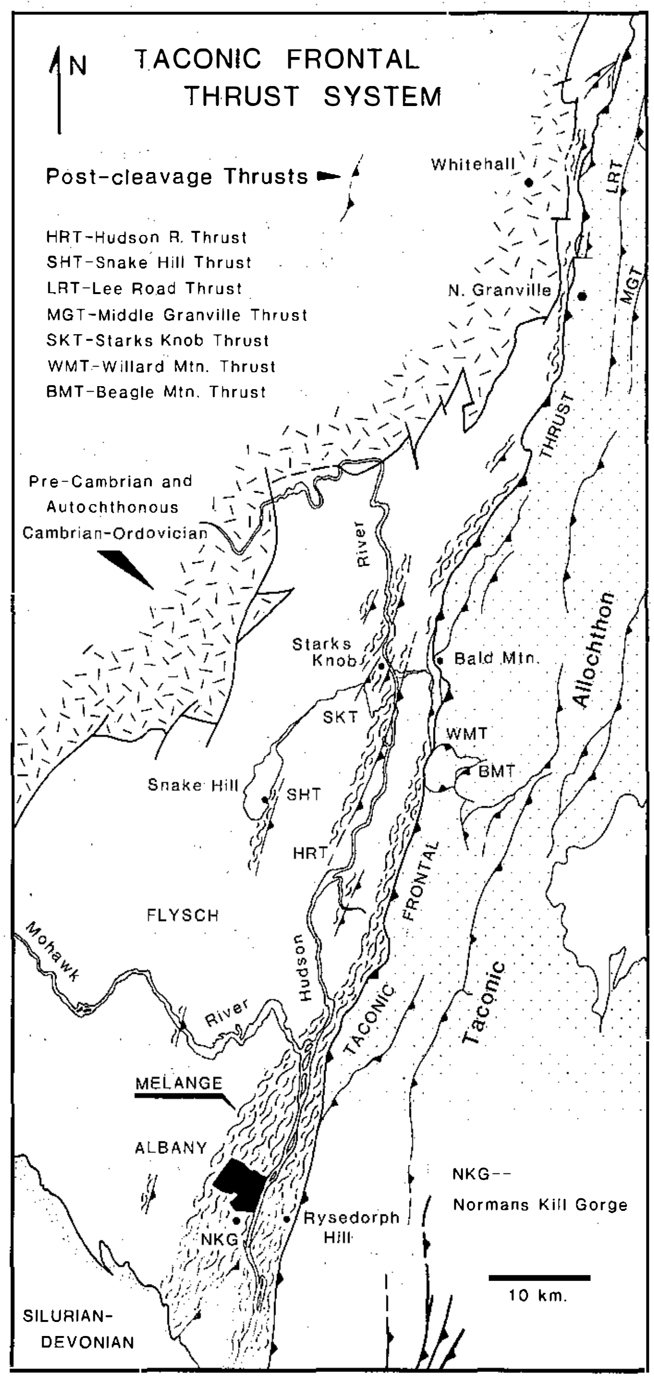


Fig. 12. Compilation of faults believed to belong to the Taconic Frontal Thrust System. These faults accommodated late horizontal shortening of the Orogen and transport of the Allochthon across the autochthonous continental shelf. Total displacement during this generation of thrusting for allochthonous rocks at the present trace of the Frontal Thrust is therefore on the order of 50 kilometers. Regional geology from Fisher, et al., 1970.

ROAD LOG FOR THRUSTS, MELANGES, FOLDED THRUSTS AND DUPLEXES IN THE TACONIC FORELAND

CUMULATIVE MILEAGE	MILES FROM LAST POINT	ROUTE DESCRIPTION
0.0		Intersection of NY Rt. 50 with I-87, Adirondack Northway. Go north from this exit (#15) on the Northway.
19.9	19.9	Take exit #20. At light at end of ramp, turn left onto NY Rt. 9.
20.4	0.5	Turn right at next light onto NY Rt. 149.
32.4	12.0	Turn left at light in Fort Ann onto US Rt. 4 going north.
43.1	10.7	Turn half right at light in Whitehall; follow US Rt. 4. Cross Hudson-Champlain canal.
43.5	0.4	At next light (Stewart's shop on right) turn left onto Williams Street. Follow Williams Street to second bridge to left over canal.
44.05	0.55	Park on Williams Street just before or after entrance to bridge.
		STOP 1A - GENTLY DIPPING QUARTZITES OF POTSDAM FORMATION.
44.65	0.6	Go north on Williams Street to intersection of Washington County Rts. 9 and 10. Turn left (north) onto Rt.10 (Doig St/Sciota Rd).
45.25	0.6	Road makes sharp right turn. Continue on Rt.10
45.65	0.4	STOP 1B - GENTLY EAST-DIPPING LIMESTONES OF WHITEHALL FORMATION. Outcrop extends from 45.6 to 45.75. At east end overlying dolostones are exposed.
47.8	2.15	Continue NE on County Rt. 10, Sciota Rd., to T-intersection where Sciota Rd. turns left (N) sharply at intersection with County Rt. 11. Go straight, following Rt. 11 up hill.
48.15	0.35	STOP 2 - THRUST OF MID-ORDOVICIAN LMS. OVER MID-ORDOVICIAN SHALY MELANGE.
48.25	0.1	Continue up hill to T-intersection. Turn

		right (south) onto Westcott Road.
49.3	1.05	T-intersection. Turn right (west) onto Carlton Road.
50.0	0.7	At next intersection (a Y), where Carlton Road curves to left (south), park just before or after intersection.
		STOP 3 - PLUDE'S QUARRY - EXPOSURE OF TACONIC THRUST.
50.7	0.7	Continue south on Carlton Road. At intersection with Whitehall-Fairhaven Turnpike (County Rte 9), shortly after sharp right turn in road, turn left.
50.8	0.1	Go down hill and park just before or after the railroad crossing. Walk northeast along the railroad tracks for about 300 meters to
		STOP 4 - D & H RAILROAD CUTTING - TACONIC LITHOLOGIES JUST ABOVE TACONIC THRUST.
		Walk back to vehicles.
50.9	0.1	Continue on County Rte 9 to intersection. Turn right (south) onto County Rte 9B (Beckwith Road).
51.45	0.55	Go to intersection with US Rte 4 at stop sign.
52.45	1.0	Cross Rte 4, continue south on Beckwith Road. At T-intersection with NY Rte 273, turn left (east).
53.2	0.75	Go east to next intersection (Beckett Road). Turn right.
54.85	1.65	Go south and west to next T-intersection. Turn right (west) onto County Rte 12.
55.95	1.1	At next intersection turn left (south) onto Upper Turnpike.
56.3	0.35	Cross Mettawee River.
56.95	0.65	Long bend to left followed over hill by sharper bend to right.
57.65	0.7	Left bend - follow paved road.
60.25	2.6	Left bend at intersection with Rathbunville

		Road. Follow Upper Turnpike, which becomes a dirt road at top of hill.
60.65	0.4	Start of steep hill down to south.
60.8	0.15	Park on left at bottom of valley.
		STOP 5 - METTAWEE RIVER SECTION AND LUNCH.
		Turn around and go back north on Upper Turnpike.
65.3	4.5	Cross Mettawee River.
65.65	0.35	Intersection with County Rte 12. Go straight, north to Whitehall.
67.25	1.6	Intersection at light with US Rte 4. Turn right. Follow Rte 4.
73.4	6.15	Cross Poultney River (NY - Vt border).
74.75	1.35	Beginning of ramp for Exit 2 (Fairhaven, Vergennes). Take this exit.
75.05	0.3	Turn left at stop sign onto Vt Rte 22A going north.
77.65	2.6	Pass junction (to left, west) with West Haven Road.
78.15	0.5	Drive into parking area on WEST side of road and park.
		STOP 6 - IMBRICATED MIDDLE ORDOVICIAN CARBONATES AND MELANGE.
		Turn and go back south on Vt 22A to West Haven Road.
78.65	0.5	Turn right onto West Haven Road.
79.0	0.35	Turn right at dirt road with saw mill sign at corner.
79.25	0.25	Drive to quarry entrance - park before entrance. (Permission REQUIRED - ask at house halfway along dirt road).
		STOP 7 - BOSS HOGG'S QUARRY - DEFORMATION IN PROVIDENCE ISLAND FORMATION CARBONATES.
79.5	0.25	Return to West Haven Road. Turn left.
79.85	0.35	Stop sign at intersection with Vt Rte 22A.

		Turn right.
82.45	2.6	Pass under US Rte 4. Continue south on Vt Rte 22A.
82.8	0.35	Turn left just before Getty gas station. Follow street east.
83.4	0.6	Stop sign at flashing red light. Turn left onto Scotch Hill Road.
83.75	0.35	Pass over US Rte 4.
87.75	4.0	Road reaches bottom of hill next to south shore of Glen Lake.
87.95	0.2	STOP 8 - SCOTCH HILL SYNCLINE - POULTNEY SLATES. PERMISSION REQUIRED. NO HAMMERS. ASK AT HOUSE DIRECTLY ACROSS THE ROAD FROM THE OUTCROP. Return to the flashing light at the end of Scotch Hill Road in Fairhaven either by retracing the route above, or by continuing along the paved road without turning around, as detailed below.
88.1	0.15	Pass entrance to Lake Bomoseen State Park.
89.55	1.45	Sharp right turn. Road runs from here along the shore of Lake Bomoseen.
91.55	2.0	Pass under US Rte 4.
92.05	0.5	T-intersection with Rte 4A (old US 4). Turn right.
93.6	1.55	Flashing red light at end of Scotch Hill Road. Turn left, following Rte 4A. Go through centre of Fairhaven.
94.35	0.75	At bottom of hill, branch onto Vt Rte 22A, which goes up a short, steep slope to a railroad crossing. Continue south on Rte 22A.
95.95	1.6	Cross Poultney River - NY-Vt border.
104.14	8.2	Cross Mettawee River.
106.3	2.15	Intersection in Middle Granville. Continue straight on Rte 22A.
106.65	0.35	Intersection at stop sign and flashing light with NY Rte 22. Turn right.

109.7	3.05	North Granville.
110.4	0.7	Follow straight onto County Rte 17 at fork in road where Rte 22 turns to right.
111.1	0.7	Intersection with NY Rte 40. Turn left. Go south on Rte 40.
128.2	17.1	Sharp left turn at stop sign and junction with NY Rte 197 in Argyle.
136.3	8.1	Pass entrance to Sprague Town Road on left (east).
136.7	0.4	Rte 40 enters a gentle curve to the right.
137.0	0.3	Turn right into Bald Mountain Road at the beginning of the next curve (to the left).
138.05	1.05	Y-intersection. Bear right onto Lick Spring Road.
138.25	0.2	Dirt track forms entrance to right into old quarry. Park on verge before or after entrance.
		STOP 9 - BALD MOUNTAIN QUARRY.
		Continue on Lick Spring Road.
138.35	0.1	Turn around at junction with dirt road. Go back past quarry entrance.
139.7	1.35	Return to NY Rte 40. Turn right.
140.65	0.95	Junction (stop sign) with NY Rte 29. Turn right.
141.65	1.0	Junction with continuation of NY Rte 40 to south. Continue straight west on NY Rte 29.
144.0	2.35	Cross Hudson River.
144.25	0.25	Pass scene of J. Burgoyne's surrender (on right).
144.45	0.2	Turn right at traffic light in Schuylerville.
144.75	0.3	Turn left at traffic light. Follow NY Rte 29.
153.55	8.8	(Entrance to I-87 North on right, to

Montreal).

153.75	0.2	Cross under Northway (I-87).
154.1	0.35	Turn left off Rte 29 to find entrance to I-87 South (or continue west on Rte 29 to reach center of Saratoga Springs).
155.0	0.9	Turn left at junction with NY Rte 9P.
155.2	0.2	Turn right onto slip road for I-87 South.