Field trip guide - Geology of the upper Hudson River Valley
revised version of guide for SUNYA Dept. of Geological Sciences reunion
August 2017

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this guide dedicated to all the students who participated in the SUNY Albany Geological Sciences graduate programs, who contributed so much to it, and the research done there

Introduction

This trip visits outcrops showing some significant aspects of the Paleozoic geological and tectonic record to be seen in the Albany-Saratoga Springs part of the Hudson Valley, accessible during a one-day trip, using informative outcrops that are not roadcuts. The outcrops span the western edge of the Appalachian deformed zone for both the Taconic and the Acadian events. Some features from the post-glacial events (Lake Albany, and its draining) can also be seen. See Fig 0-1 for geological overview map and the stop locations.

Summary of the Paleozoic geological events and corresponding stops
Cambrian rifting/opening/spreading of the vanished ocean Tuzo Wilson (1966) first identified, seen in carbonate sedimentation on the Cambro-Ordovician passive margin; ~flat-lying still, after all these ~500 million years, **Stop 4**, and (transported in the Taconic Allochthon) rift-drift clastics at **Stop 1**.
Passive margin strata cut by mid-Ordovician normal faulting related to slab-pull from E-directed Taconic underthrusting, **Stop 3**. Local basaltic volcanism accompanying this faulting; **Stop 5**.
Deposition in the mid-Ordovician of deep marine shale and trench axis-constrained, N-flowing turbidites (materials in **Stops 1, 2, 5**; shales at **Stop 3**) in the deep marine trench caused by overthrusting of the Taconic Allochthon. The Allochthon being the front end of an accretionary stack comprised of materials picked up from the former passive margin continental rise sediments, and underlying rift/drift and rift clastics (containing elsewhere, not seen on this trip, very minor Cambrian/latest preCambrian rift volcanics) **Stop 1**.
MacDonald et al (2017) have cast doubt on the model of Rowley and Kidd (1981) for simple east-directed subduction for the origin and overthrusting of the Taconic Allochthon. Some aspects of this new scenario need discussion, especially whether eastward subduction of oceanic lithosphere occurred.
During the Taconic convergence, Ordovician turbidites and shales at and near the base of the Allochthon were converted to melange by high shear strain in clay-rich sediments, especially in the region from near Albany northwards, where these sediments are shale-dominated. **Stops 1, 2, 5**.
Late gently-east-dipping thrust faults in this melange, marked by calcite-quartz veins with slickenfibers, give fluid inclusion homogenisation temperatures of 250-290C near the present exposure of the Taconic Allochthon western bounding fault in the Albany-Troy area. **Stops 1, 2**.
The melange also contains slickenfiber veins with normal sense slip, which cut the veins with thrust slip sense, and which contain fluid inclusions with homogenisation temperatures not much lower (200-270C) than the thrust sense veins. The normal slip veins (and faults) are dominantly E side down, suggested to be from extension of the toe of the thrust pile by stress release immediately after Taconic thrusting ceased. **Stops 1, 2**. These normal faults include the Taconic Frontal Fault at **Stop 1**, and are (assumed) slightly younger than those that cut the shelf sequence. This late Ordovician extension event may explain the small volume of late Ordovician-early Silurian molasse-type shallow marine/non-marine exhumation clastics deposited in central NY and farther west.
The western extent of Taconic convergence seen in slight tilting of turbidite strata under the latest Silurian/earliest Devonian erosion surface at **Stop 6**.
Late Ordovician-early Silurian exhumation/erosion of the Taconic orogen; only seen in this area indirectly by the latest Silurian erosion surface and thin overlying arenite at **Stop 6**.
Resumption of passive margin subsidence conditions by late Silurian-earliest Devonian in eastern NY; shallow marine carbonate strata of **Stops 6, 7**.
Deformation of Devonian strata near the western edge of Acadian Orogen thrust/fold belt; **Stop 7**; more subtle/less at **Stop 6**. Thrust sense slip in calcite slickenfiber veins which contain fluid inclusions with maximum homogenisation temperatures of ~170C (near **Stop 7**).
Late Devonian orogen-derived clastics of the Catskill facies are omitted from this trip but are very well exposed in the Catskill Mountain front and vicinity (recommended for another day). For a much larger perspective on the Acadian Orogeny, see Bradley et al (2000).

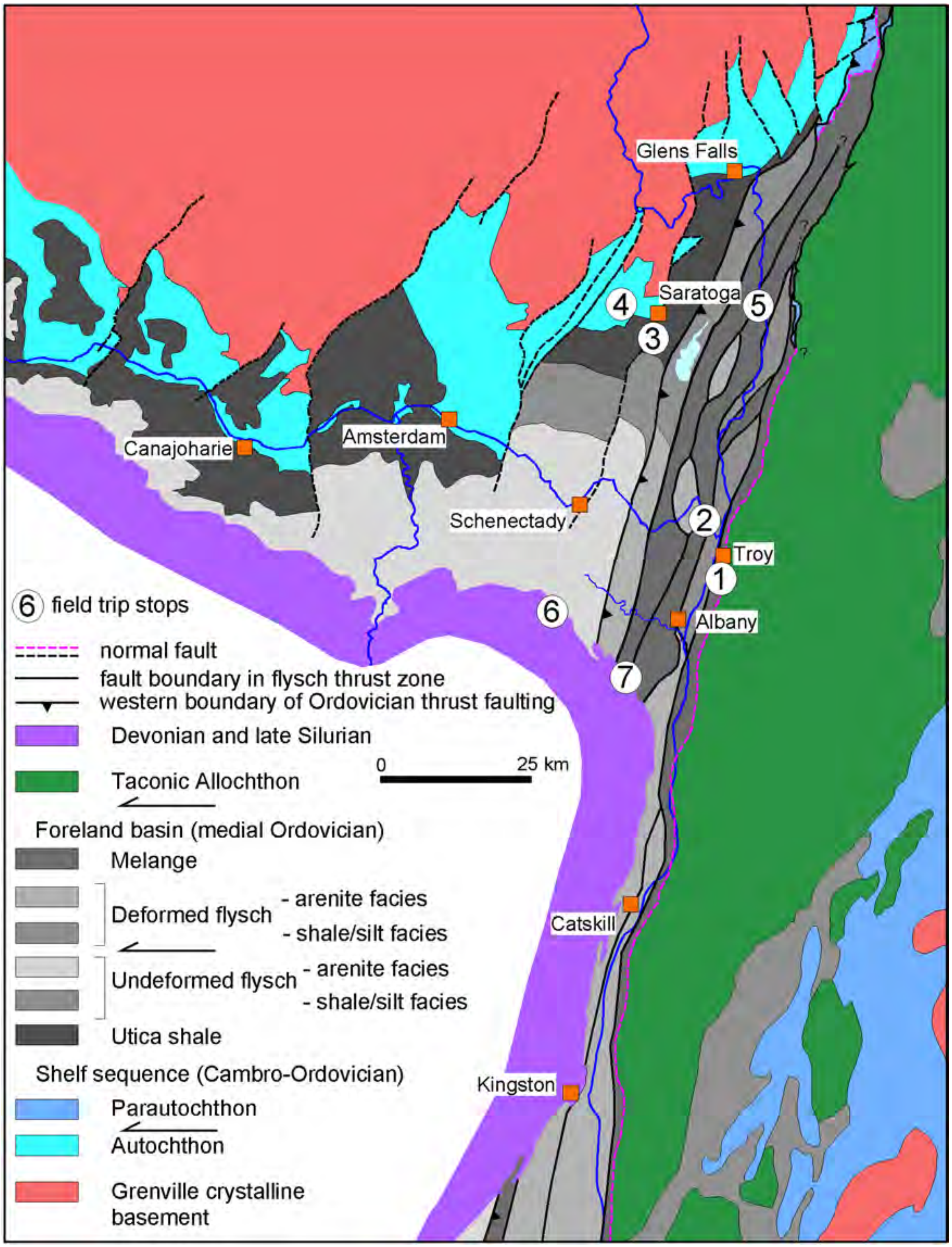


Fig 0-1. Geological overview map of the upper Hudson Valley (compiled by W. Kidd from the best available information in 2016).

Following the Devonian, a long geological ennui of slow and probably not steady denudation, with interruptions of probable but locally unrecorded deposition of distal Alleghenian orogenic clastics in the later Carboniferous, and possibly of some Jurassic faulting along the Hudson Valley, then some younger things:

Summary of the Neogene-Recent geological and historical events and corresponding stops

The Adirondack Dome; which Kevin Burke identified as identical in size (~200km diameter) and topographic anomaly (~1-2km) to African Neogene high spots (e.g see Thiessen et al, 1979), some of which are also Neogene volcanic hot spots and where the elevation is due to the lithospheric thinning above mantle thermal anomalies. Cold (surface bedrock temperature) CO_2 springs like those of Saratoga Springs (**Stop 3**) are most commonly elsewhere on the planet associated with volcanism (e.g.the Massif Central and Vichy)......we await the initial volcanic event in the Adirondacks.

And

One or more kilometers of ice on top of the bedrock, the ice starting to retreat about 18,000 years ago; a periglacial lake (Lake Albany) occupying the Hudson Valley c. 13-10,000 years ago; glacial meltwaters from adjoining areas brought sediments, of which the gravels were deposited in deltas at the stream mouths, as at the parking area at **Stop 1** for the Poestenkill. Lake Albany was rapidly drained by several events of overtopping and failure of the moraine dam(s) near New York City c. 10,000 years ago (waterfalls and bedrock incision at **Stops 1, 2**, and along I-87 between stops 2 and 3). The varved clays of the lake floor deposits are widely exposed in the Hudson Valley and provide a well-known landslip hazard in the region. More local areas of sand above the clays come from the delta of the Mohawk, and the upper Hudson and Sacandaga Rivers, and redistribution by howling periglacial winds of this material in dune fields (e.g. the Albany Pine Bush) across the drained floor of the former Lake Albany. The dunes were subsequently stablised by vegetation, until the arrival of farmers, and builders*, of European origin.

Those settlers did not take very long to resent taxation without representation, and other British aristocratic and monarchical imposts, and in 1777 they defeated and forced the surrender of Burgoyne and his nominally British, but significantly mercenary army near the place now known as Schuylerville, NY. A key part in forcing the surrender was played by General John Stark, who hauled cannon onto the top of the hill now known as Starks Knob (**Stop 5**), just north of Schuylerville, and by doing so prevented Johnny Burgoyne and his defeated army from escaping back to Canada.

*[http://www.atmos.albany.edu/geology/webpages/sunyageo.html]

pictures on the cover (credit W.S.F. Kidd)
SUNYA Earth Sciences building with azaleas; June 1997
(these azaleas and trees, and the Geological Sciences program, now entirely gone)

Cohoes Falls; 8 March 2015
(the ice has gone too, as you will see!)

Stop 1. Taconic Frontal Fault at the Falls of the Poestenkill, Troy, NY.

42.720036N 73.680361W

From the parking area, walk east down the grass slope to the path at the edge of the gorge. Go east along the path into the wooded area; find your way (on the slope above) around the wood and wire obstacles; and just beyond these scramble down the eroded path to the outcrops on the edge of and in the Poestenkill. If the stream is in flood, the outcrop may be inaccessible; normally in summer you can walk across the stream bed on the outcrop and boulders.

This outcrop is one of the very few exposures that show the fault bordering the west side of the Taconic Allochthon, the Taconic Frontal Fault (TFF). This can be seen best on the southern side of the pool that starts at the base of the waterfall.

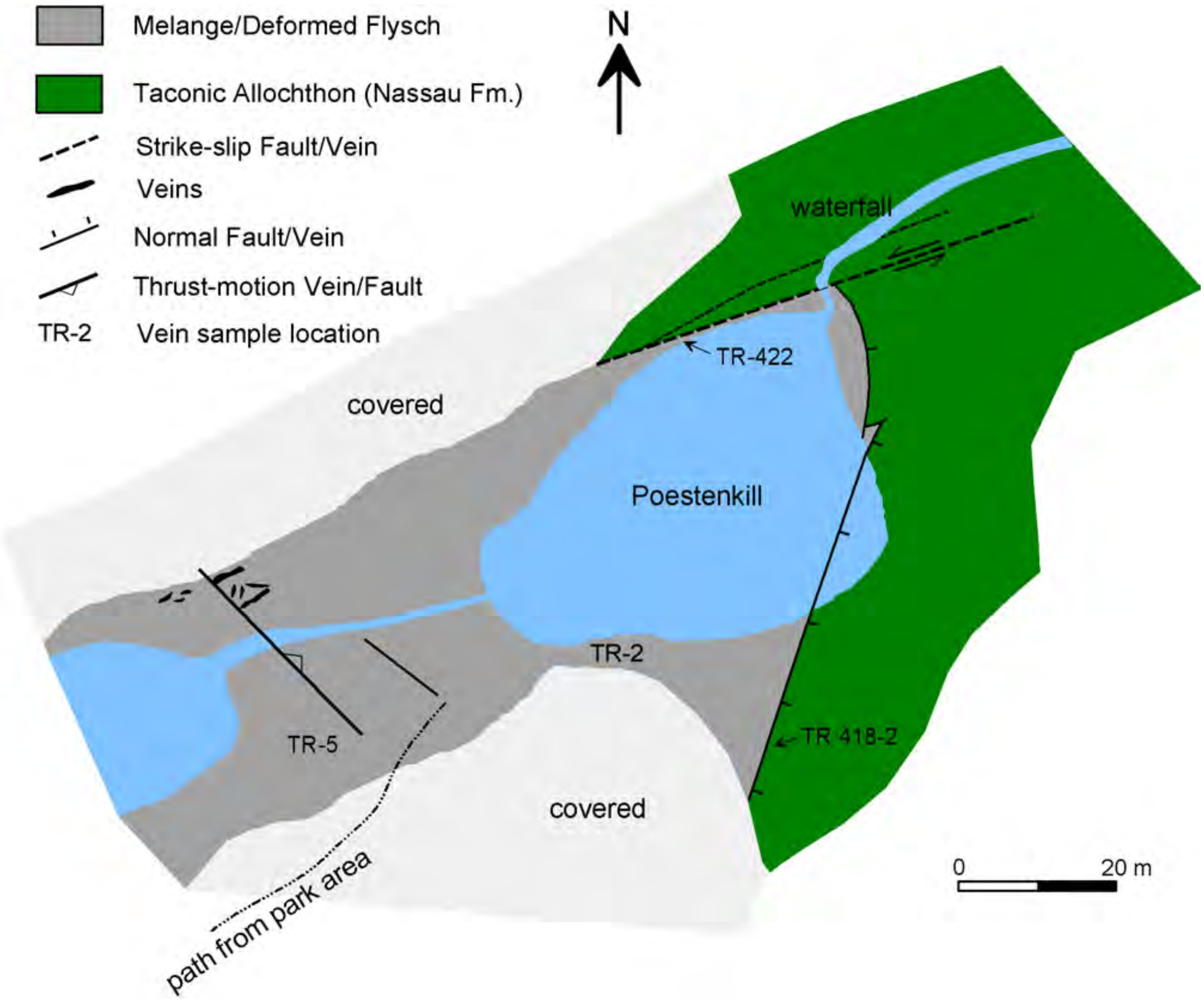


Fig 1-1. Map for Stop 1 modified after Plesch (1994), showing sample locations for vein fluid inclusion and structural information of Lim (2007); Lim et al (2005).

Strata of the Taconic Allochthon here are from somewhere within the (?)latest preCambrian to earliest Cambrian Nassau Formation, and consist mostly of greenish-grey silty to fine sandy clastics, with prominent detrital muscovite in places (rift-drift transition clastics). Based on mapping of this area by Elam (1960), the Taconic rocks are tightly folded on a large scale, but slaty cleavage is not prominently developed in the western part of the Allochthon here or farther south. This contrasts with the northern Taconic Allochthon (e.g. east of Whitehall, NY) where a prominent slaty fabric is found in rocks adjoining the Taconic Frontal Fault; this difference probably reflects slightly lower metamorphic grade (~lowest greenschist facies) and perhaps the exposure of less deeply buried and somewhat less strained material in the southern part of the Allochthon.

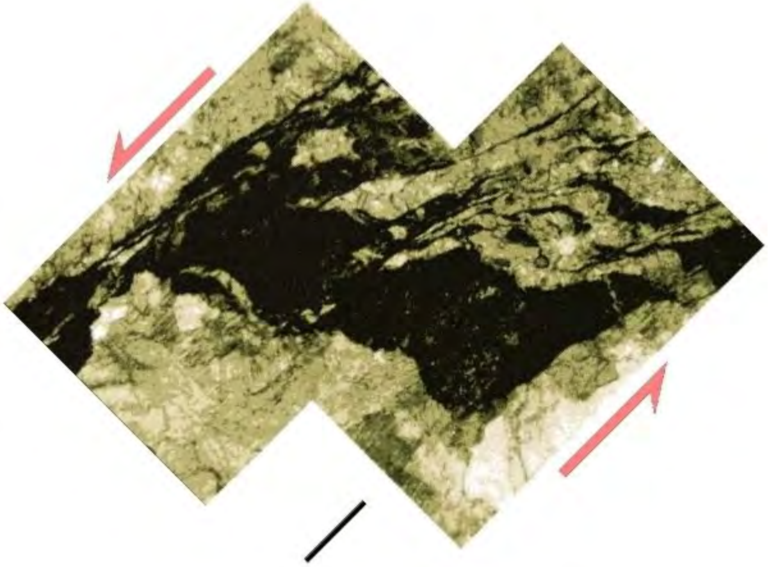
Adjoining the sharp contact of the TFF, there is about a meter of black phacoidal melangy shale with some included fragments of greywacke; beyond this grey/dark grey shale melange with abundant fragments of greywacke form the rest of the outcrop. Blocks range up to several meters across, including at the base of the access path a block preserving multiple beds of greywacke turbidites in shales. The shale and greywacke of the melange were derived from late Ordovician sediments deposited in the trench developed at the toe of the advancing Taconic accretionary thrust prism. Where these strata form intact bedded sequences, they are called Austin Glen Formation where folded and thrust, or Schenectady Formation where flat-lying and undeformed, west of the Taconic fold-thrust belt.

Melange formation probably took place under high transient shear strain rates, and high fluid pressure approaching lithostatic values, although some prior disruption by superficial submarine mass-wasting (olistostromes) was involved in places. Bosworth (1980) and Vollmer (1981) mapped large areas, thoroughly documented the structure, and in subsequent publications (Bosworth & Vollmer 1981; Vollmer & Bosworth 1984; Bosworth 1989) discussed the probable origins of the melange. Subsequent mapping in the Capital District (Plesch 1994; Kidd et al 1995) clarified that the deformed Ordovician flysch belt of the Hudson Valley south from Ravena is dominated by folded and thrust stratified packages of coarse thick turbidites (Austin Glen Fm.) with narrow melange-like thrust zones, but from Ravena north through Albany and beyond, the material is mostly shale-dominated melange, lacking large volumes of coarse greywacke even in belts like the Waterford and Stillwater zones that are less disrupted "broken formation"(Fig 0-1). This northward transition from arenite-dominated to shale-dominated facies can also be seen in the belt of mostly folded and thrust stratified material, the Vischer Ferry zone, that forms the westernmost belt of deformed materials in the New York Taconic orogen. The cause, or control of this facies change has not been determined but it appears to have been persistent, and most probably involved submarine topography. Given the coarseness and thickness of turbidites in the southern area and their consistently northward paleocurrents (Tanski, 1984), it seems improbable (c.f. the modern Aleutian Trench, with along-axis turbidite transport distances of many hundreds of kilometers) that they would be scarce to absent farther north unless there was a topographic barrier across the trench. The transition visible in the Vischer Ferry zone suggests that this was a northward shoaling of the trench axis over at most a 50km distance; perhaps a structure or structural contrast in the Grenville basement and/or mantle lithosphere (the Albany-Alabama gravity anomaly lineament is in the right position) could be responsible.

Calcite, and calcite-quartz veins, many with slickenside/slickenfiber structures, can be found commonly in the melange of this outcrop and elsewhere in the melange belts of the upper Hudson Valley. Lim (2007) showed that 1) the earliest show west-directed thrust sense slip, and that they cut the phacoidal cleavage fabric of the melange. These thrust-sense veins are faults with small displacements. Folded and/or extensively shear disrupted veins have been noted in the melange belts west of the TFF in the Capital District, but they are uncommon. However, 2) the planar thrust sense veins are in places cut by more steeply-dipping veins, and vein-free faults, with normal-sense slip, most commonly with east side-down displacement. Veins with both thrust and normal slip senses can be found in this outcrop. Additionally in this outcrop, 3) a later planar fault also with narrow calcite slickensides can be inferred to cut both, and to have oblique left-lateral slip; in particular this fault cuts and must displace the TFF by at least 50 meters (see Fig 1-1).

Lim (2007) discovered a segment of the TFF contact here has calcite vein development on it; this is up the slope on the south side of the gorge (sample site TR-418-2 on Fig. 1-1). Cutting a slab from the sample and thin sections reveal (Fig 1-2b) that this has structures showing normal sense slip on the TFF. It is probably significant that the TFF in this outcrop dips about 50 degrees east, and that in places elsewhere along strike from the Hoosick River southwards, where its trace can be adequately constrained by nearby outcrops, it maps as a linear or gently curving contact, and not as one that follows topography which it would if it had a very low dip. The next (and last) exposure of the TFF to the south, near Hudson NY, shows a vertical fault. The steep attitudes might be explained by progressive wedge thrust accretion and rotation, and the normal-sense vein as a minor superimposed later slip on a primary thrust fault. Lim et al (2005), because of the common occurrence of post-thrust normal-slip veins and faults in the melange, prefer the explanation that the present TFF, at least from the Hoosick River south, is a normal fault at the present level of exposure - see the cross sectional explanation provided in the lower diagram in Fig. 1-3. Other regional evidence of large-scale, strike-parallel east side-down normal faulting is shown by the Mettawee Fault which cuts several slices of the Champlain Thrust imbricates from near Fort Ann (Fig 0-1) northwards into Vermont (Hayman & Kidd, 2002a,b).

Fig. 1-2. (a) Exposure of the western bounding fault of the Allochthon in the Poestenkill gorge in Troy. View is to the south.



(b) Photomicrograph of a vein developed along part of the bounding fault in the exposure shown in the photo above (1-2a). Deformed host rock inclusions in the vein show normal slip on the fault. View is to the south; black scale bar is 0.5mm.

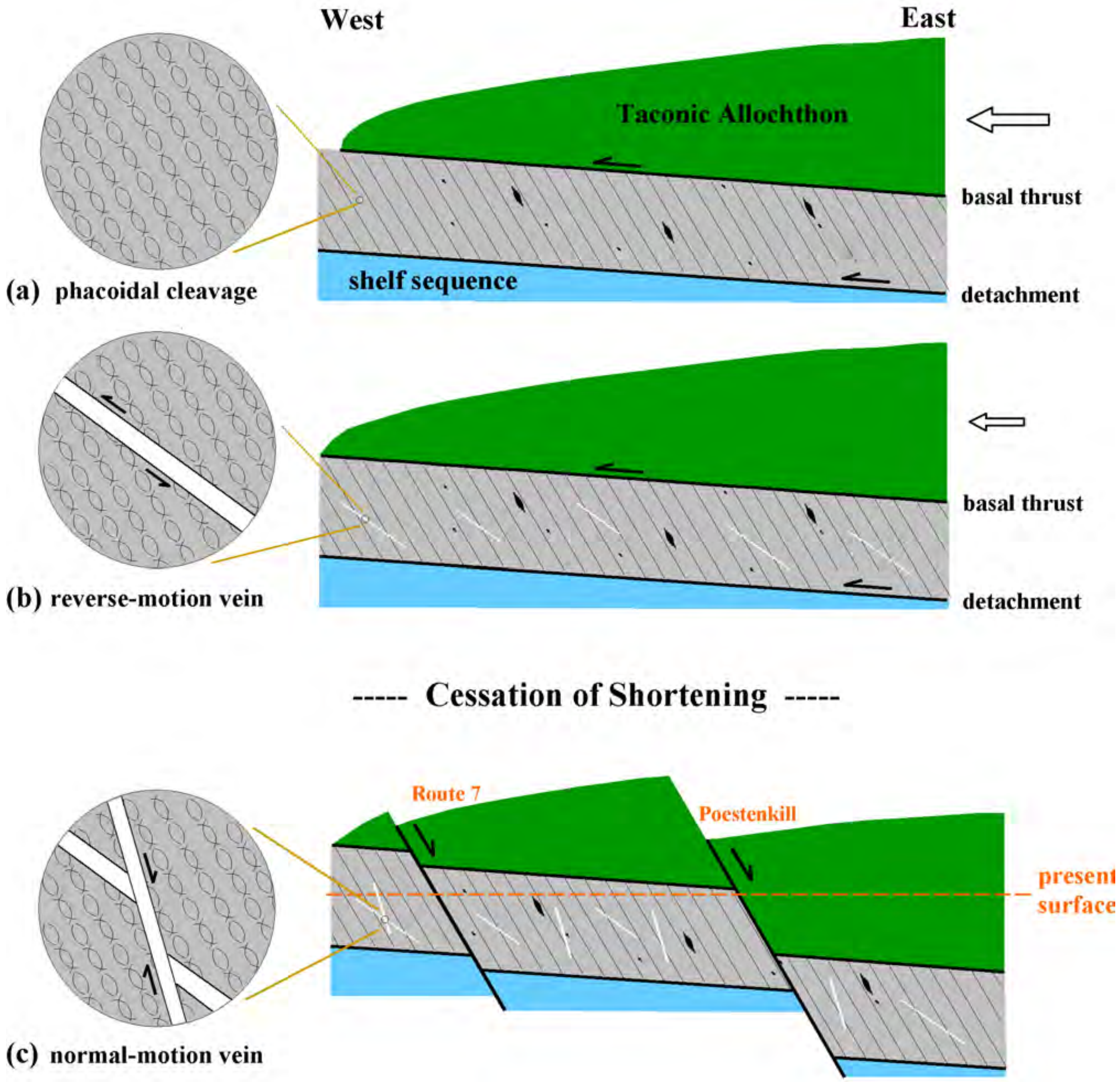


Fig. 1-3. Structural development of the Cohoes Melange with a) phacoidal cleavage under the Taconic Allochthon; b) the final thrust movements expressed by the planar thrust sense calcite veins; then c) these fabrics cut by normal sense veins and faults with mostly east side down displacements. Sections of the Taconic Frontal Fault with steep dips and normal displacement, as at Poestenkill Falls, are suggested to be where late normal faults form the boundary at the present level of erosion.

To try to constrain the age of the veins, fluid inclusion homogenization temperatures (Th) and salinities in all three structural suites of veins in the melange belt were investigated by Chul Lim, including samples from this stop, and reported in Lim et al (2005), and in Lim (2007). The results (Fig 1-4) show that almost all veins investigated, and all from this site, have low salinity inclusions and stable isotope values consistent with a metamorphic dewatering source for the fluids. Thrust-sense vein measurements from this site give elevated Th in the 295-230C range with most clustering 280-270C. Thrust-sense veins from the other Capital District sites (Cohoes Gorge Stop 2, Route 7 roadcuts, Rte 151 above Rensselaer) giveTh in the 270-230C range. Normal sense veins from the same localities give values of Th that overlap these results from as high as 265C and extend down to about 190C, with a few lower values of doubtful significance (?leakage during measurements) down to around 140C. The strike-slip vein at Poestenkill Falls only provided two measurements, with Th of about 170C obtained.

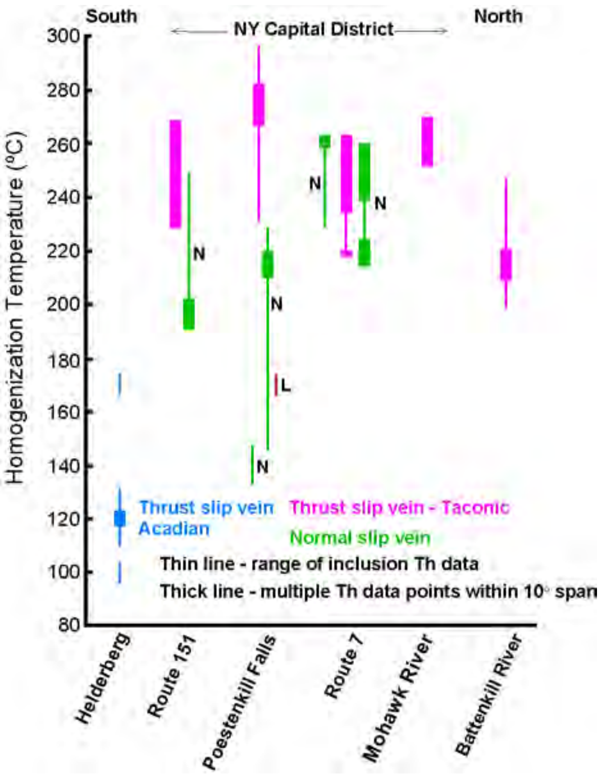


Fig 1-4. Fluid inclusion homogenization temperature measurement ranges obtained from veins in the Cohoes Melange in the Capital District (Lim, 2007; Lim et al, 2005).

These Th measurements are significant for two reasons. First, in comparison to thrust slip-sense calcite veins taken from the (Acadian) folded and thrust Helderberg carbonates nearby in south Bethlehem (near Stop 7), which give Th measurements of range 170-100C (and farther south near Catskill most are between 120-130C), they are distinguishably higher, and show that the veins in the melange, both of thrust and normal slip sense, are Ordovician-age structures, and also confirms that the phacoidal fabric cut by them also must be an Ordovician product all across the melange belt, as Vollmer (1981) originally suggested from the unconformity under the Devonian near South Bethlehem. Second, the Th measurements are consistent with the relative age of the vein sets, with introduction of hot fluids in the earlier thrust sense veins, and cooling during the development of the younger crosscutting normal-sense veins and faults. Using quartz-calcite thermometry based on the oxygen isotope compositions, estimates can be made for the trapping temperature and burial depths at that time of the vein fluids. Results reported in Lim et al (2005) for Capital District samples give plausible trapping temperatures in the range 300-340C for burial depths of ~2-5km at lithostatic pressures; ~5-9km at hydrostatic pressures.

Pebbly gravels, of well-rounded mostly Taconic-source rocks, outcrop on the slope leading north from the parking lot, and again at the top of the steep slope in the woods where the path leads down to the outcrop. These were deposited in a small delta at the eastern shore of Lake Albany when it was at or near its high stand, by the Poestenkill but when ice was still present on the high Taconics. The parking lot is approximately at the former delta top. Stand there and look west, and imagine the icy waters of Lake Albany covering most of what you can see. Bedrock incision of the Poestenkill and the falls here are consequent on the drainage of Lake Albany probably while high remnant ice-melting discharges came down the Poestenkill.

Stop 2. Cohoes Melange at Cohoes Falls and the gorge of the Mohawk River, Cohoes NY.
42.784286N 73.707402W
Park on School Street. Walk into the Cohoes Falls park. This stop is a point and talk, binoculars stop; access to the outcrop of the northern gorge wall and the top of the falls on that side is time-consuming, and quite strenuous, and tall grass with ticks poised on it has to be crossed to get there. You can't usually get to the rocks on this side of the Mohawk (because fences, safety, private property....) unless the fishing access gate near the base of the falls is open; most of the time it is shut.

Most of the bedrock exposure visible from the overlook consists of shale-matrix melange (the Cohoes Melange of Kidd et al 1995). Andreas Plesch (Albany MS 1994) mapped the whole section including the temporarily almost dry planated bedrock bed of the river (Figs 2-1, 2-2). Blocks in the melange are mostly not more than a meter or so across, commonly of Austin Glen-type greywacke, and widely dispersed. On top of the falls, and in one locality at the base of the cliff on the north side of the gorge below the falls, some black shale, mudstone and chert fragments, with early Caradocian (Sandbian) graptolites recovered, are probably from the Mt Merino Fm of the Taconic Allochthon. Other uncommon "exotic" fragments consist of meter-size clasts of carbonate breccias, and dolomitic sandstones, perhaps from the Hatch Hill Fm. of the Allochthon, and smaller 10 cm-scale fragments of sideritic mudstone, whose source is not identified, but possibly also from the Allochthon. Downstream nearer the railroad bridge, in the less-disrupted "broken formation" of the Waterford zone,some fragments of arenite have been found containing late Ordovician brachiopods and the trilobite *Cryptolithus tessalatus*; these fragments resemble the similarly fossiliferous arenites at Snake Hill on Saratoga Lake. Looking obliquely to the east across the gorge from the north side of the overlook park, a prominent eroded ledge sloping gently eastwards results from a thrust-sense calcite vein which cuts the phacoidal fabric of the shale melange, like those at Stop 1.

The Falls and the planated bedrock downstream represent the retreat of the bedrock scarp, from near the Hudson River another mile beyond the railroad bridge, by vigourous erosion immediately after one (the main) episode of drainage of Lake Albany. A slightly earlier lake drainage episode cut the smaller relief bedrock walls above the Falls, with retreat of the next waterfall scarp to the present position of the Crescent Dam, a mile upstream. There is another small bedrock scarp/waterfall in the Mohawk channel at the southern end of Peebles Island about half a mile below the railroad bridge, which represents the last drawdown and final disappearance of Lake Albany. At the time of the major drainage of the Lake, much if not all of the discharge of the Great Lakes was travelling down the Mohawk Valley because ice still blocked the St Lawrence outlet. The downcutting and retreat of the falls at Cohoes was the product of this flow, much larger than any discharge that has occurred here since the diversion to the St Lawrence.

On leaving this stop, at the other end of the one-way street, now labelled Front Street, just before it curves to rejoin N Mohawk Street, there's a blue and yellow NYS marker sign on the left, to commemorate the site where the Cohoes Mastodon was found. This complete fossil is now (again, finally) on display in the New York State Museum in Albany. It was found in peat muck filling a large pothole cut in the bedrock near the sign, when excavation for construction of the Harmony Mills was being done. Also evidence of high volume rapidly moving icy floodwater in this valley, before the local gorge and falls were cut. And a reminder to always watch your step. There's a very good diorama in the State Museum showing a mother mastodont and her calf, in a really wintery landscape; if you don't remember what Albany was like in the winter, a look at this will remind you! (However, NYS Museum is not open Mondays, "we can't afford it").

PLATE 7 - PLESCH

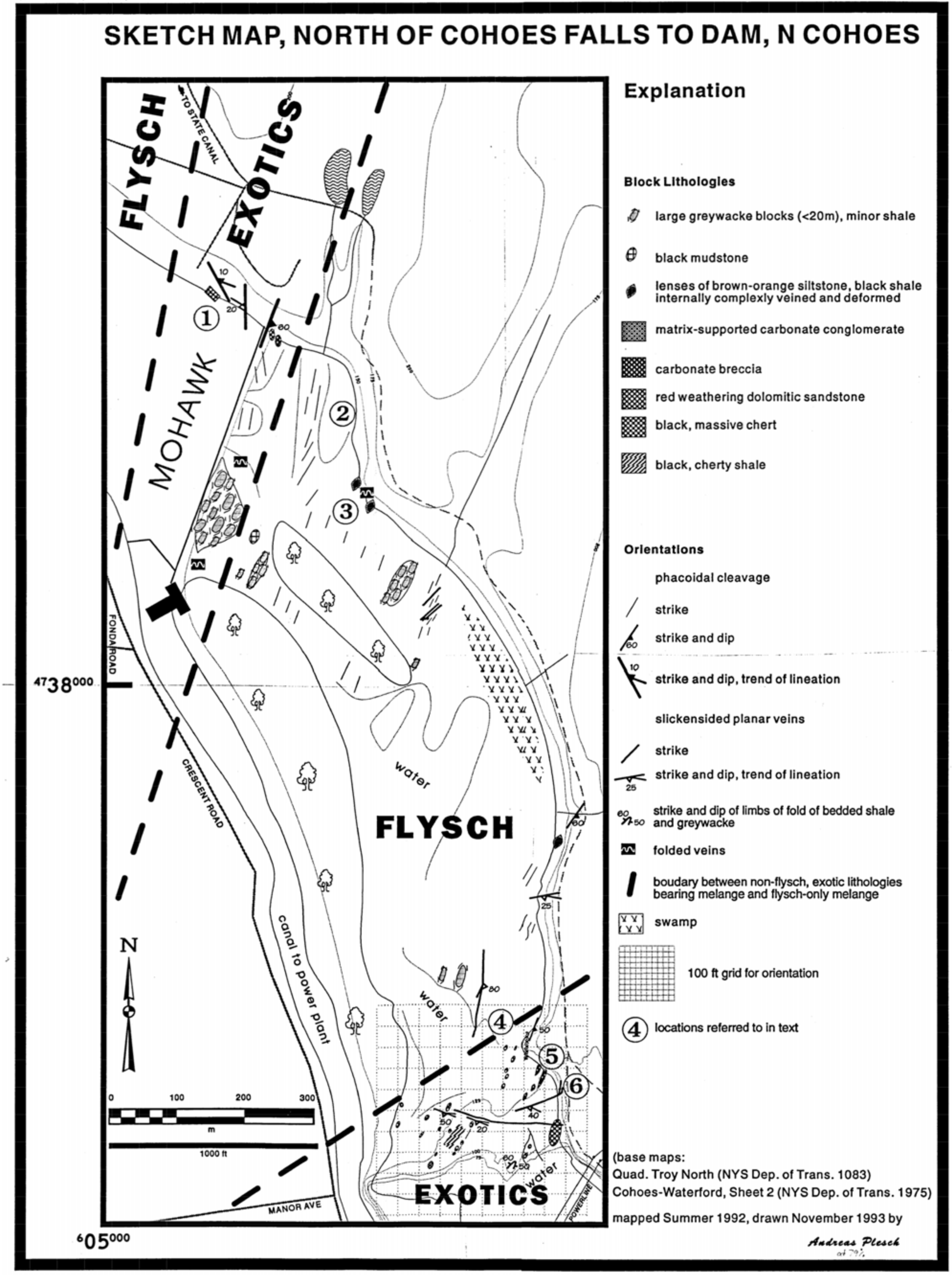


Fig 2-1. Geological map of the bed of the Mohawk River upstream from the lip of Cohoes Falls. from Plesch (1994).
Available online: [http://www.atmos.albany.edu/geology/theses/pleschpl7CoFlMap.pdf]

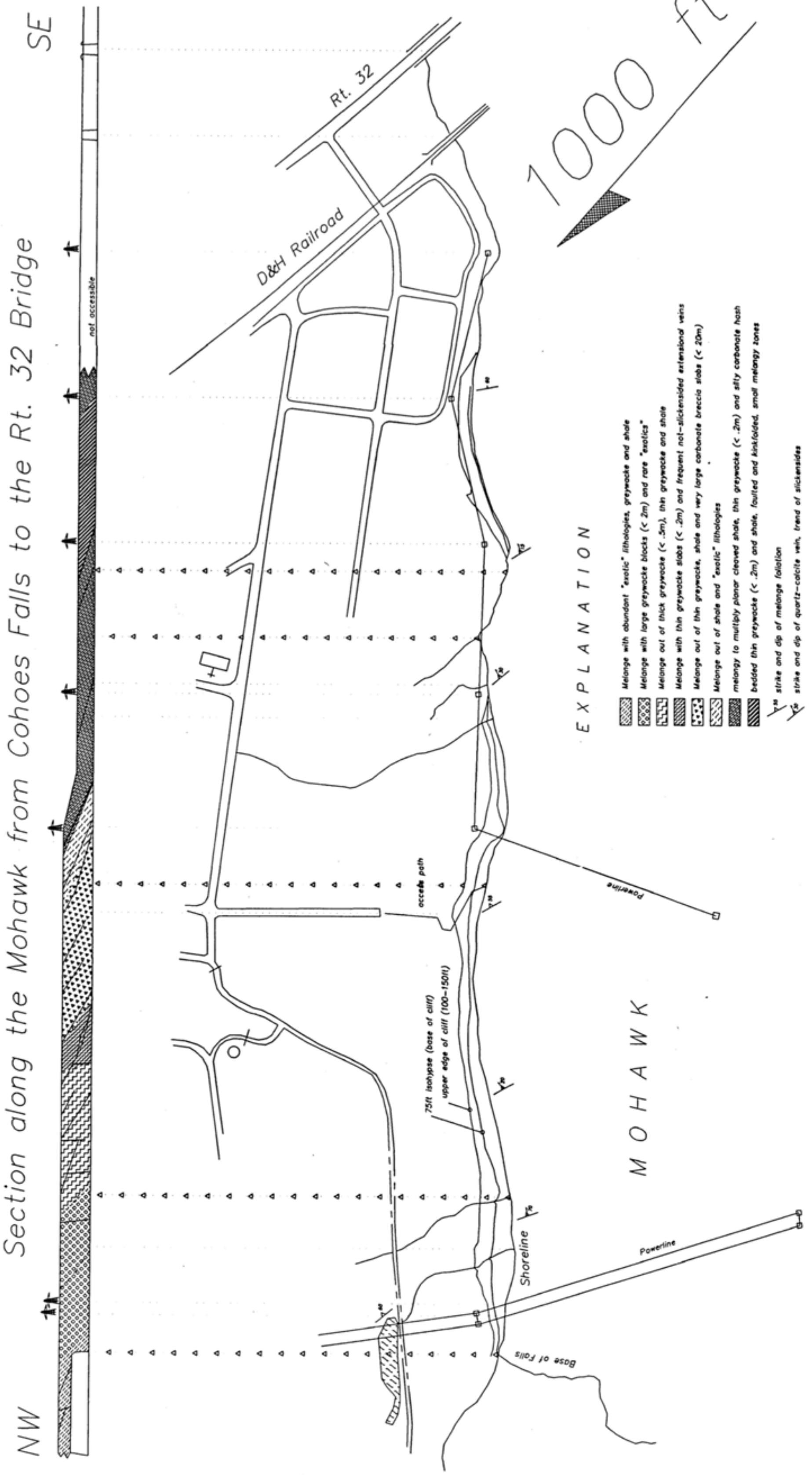


Fig 2-2. Outline map and geological section of the Mohawk River N bank cliff from Cohoes Falls to the Rte 32 Waterford bridge. From Plesch (1994).
Available online: [http://www.atmos.albany.edu/geology/theses/pleschpl9CohSc.pdf]

Stop 3. Vale of Springs, Saratoga Spa State Park

43.053871N 73.808011W

From the Saratoga Performing Arts Center parking area accessed from NY Rte 50, find the path into the trees near the northeast end of the parking area, which leads down to the paved walkway along the Vale of Springs.

On the north side of the stream coming under the pedestrian bridge to SPAC, dark shales are exposed in near flat-lying orientation. These are part of the Utica shale and lie above the Beekmantown shelf carbonates and the late Ordovician Trenton limestones (see stratigraphic section Fig 3-1). The shales form an (in most places) impermeable cap rock to the naturally carbonated waters in the fractures and other porosity of the underlying shelf carbonate rocks. The original Saratoga springs occur where the McGregor-Saratoga Fault has the carbonates exposed on its western footwall side and allows these waters to rise up the fault zone from under the shales in the hanging wall. This fault passes (under Quaternary cover) a few hundred meters west of here, just west of Rte 50. All the springs in the Vale of Springs and elsewhere in the state park, including the original spa, are from wells drilled through the shales. The runoff from the Orenda Spring just downstream of the pedestrian bridge has produced a large tufa deposit spilling down the side of the gorge wall; this is best seen from the pedestrian bridge. Downstream a few hundred yards, the Island Spouter Spring has built a substantial tufa mound in the middle of the stream. Originally touted as healthful to drink (never mind the soapy to sulphurous taste), the Saratoga waters contain quite surprisingly high levels of radon, so consuming them is now discouraged. The wells are artesian in the sense that fluid is expelled at the surface, but this is only because of the exsolution of CO_2 in the well bore; they are not artesian in the true sense (of having a static head above the ground surface).

Studies of these waters here and in the wider region by Young and Putman (Young, 1980; Young and Putman 1978, 1979; Putman & Young 1985) show that they are largely a mixture of small amounts of connate water with a large fraction of meteoric water(s). The water temperature is not anomalous; it matches the expected near-surface bedrock temperature. However the source of the large CO_2 content is not easily explained, and Putman & Young (1985) thought that aspects of the stable isotopic compositions and fluid chemistry are not compatable with the CO_2 coming from dissolution of the shelf carbonates at depth to the east. Is there a mantle source? Siegel et al (2004) analysed the Saratoga waters and concluded from elevated $^3He/^4He$ isotopic ratios that the source is from the mantle, although they raised the possibility that the original derivation was ancient, rather than modern. Their results for $\delta^{13}C$ confirm the conclusion of Putman and Young that the CO_2 source is not from the Paleozoic shelf carbonates.

Worldwide, most CO_2-rich spring waters like those of Saratoga Springs are associated with active volcanic areas (for instance Vichy, and the Massif Central). Looking to the northwest, as Kevin Burke first pointed out, the Adirondack Dome about 200km across and with anomalous relief of nearly 2km must be a Neogene feature; such relief would not persist unless it was (in geological terms) recently generated. It resembles closely, in horizontal geometry and relief, the topographic swells produced by mantle upwelling and lithospheric thinning, that are directly associated with hotspot volcanism in Africa (Thiessen et al 1979). We await the kimberlite or alkali basalt eruption in the Adirondacks! In this context, the possible evidence of young movements on the McGregor Fault (Bosworth & Putman 1986; Tice 1993) and smaller faults of this set nearby (Young 1980) could be significant.

Normal faults in the Laurentian foreland of the northern Appalachians, striking sub-parallel with the trend of the orogen, are widespread from New York to Quebec (Fig 3-2). Bradley & Kidd (1991) reviewed the evidence that they are primarily late Ordovician structures developed as the Laurentian continental margin entered the Taconic subduction/overthrust system. In particular the evidence is clear that none of these faults cut the latest Silurian-earliest Devonian strata of the Helderberg escarpment, but seismic information shows they do continue southward cutting Ordovician and older strata in the subsurface below the Devonian. The Saratoga-McGregor fault is one of these structures. The mechanism of flexural extension of an antiformal outer surface was originally proposed for the origin of such faults in the outer slope of oceanic trench systems (Ludwig et al 1966; Isacks et al 1968; Karig & Sharman 1975). Flexure of 1-2 degrees at most over a distance of 100-200 km in this tectonic position seems unlikely to produce enough extensional strain to develop the significant displacements observed in such fault arrays. Nor can flexure explain the pronounced asymmetry of the fault pattern developed, with a large majority of the faults, and most of the larger-displacement faults, facing the trench. Slab pull, and active extension of the downgoing plate, seem a more likely explanation, and this also provides a mechanism that can explain magmatism in this setting (Starks Knob, Stop 5), which flexural extension cannot (Schoonmaker et al 2005, 2016).

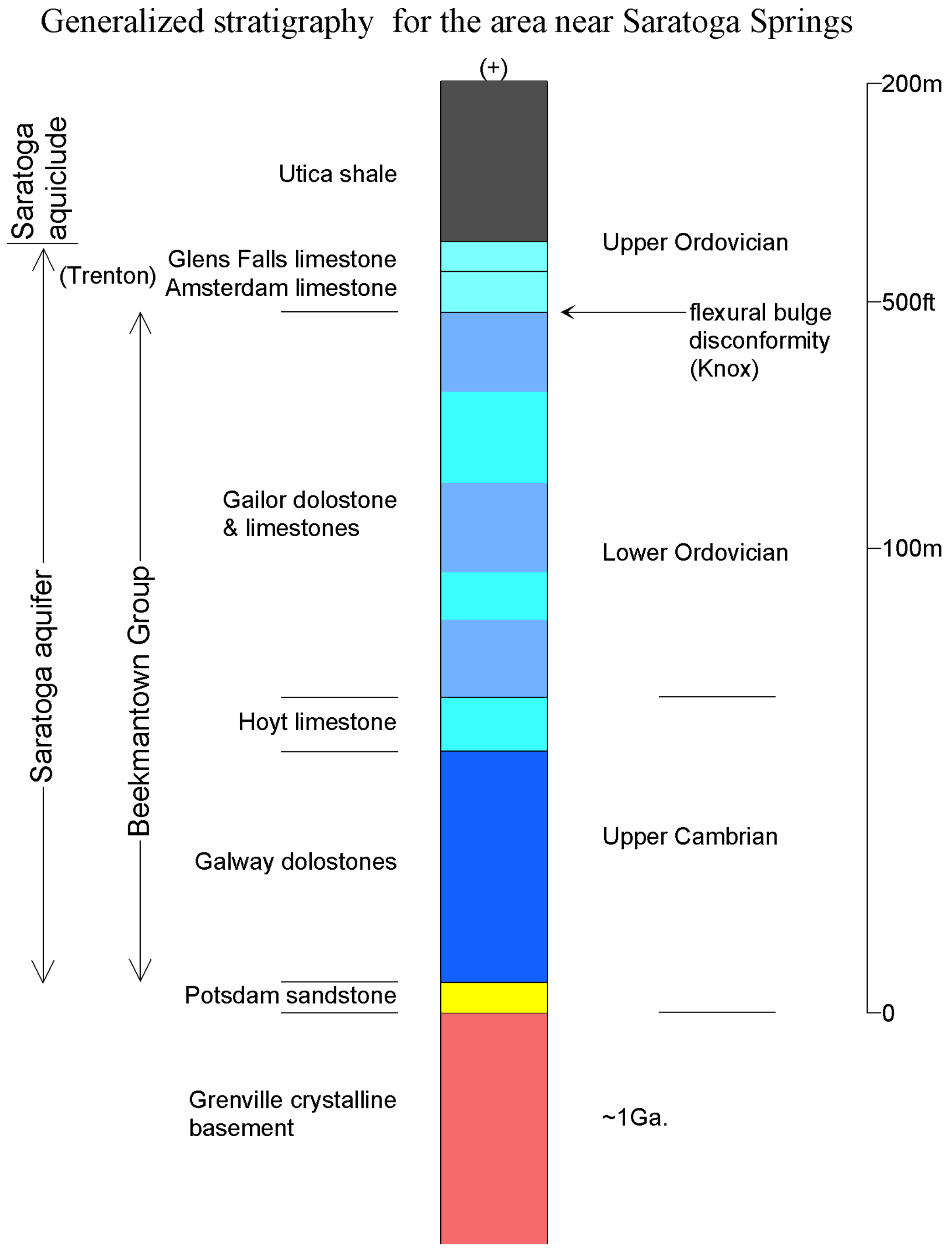


Fig 3-1. Generalized stratigraphy of the autochthonous Cambro-Ordovician shelf strata for the area near Saratoga Springs. Redrawn from figure in Putman and Young (1985).

The explanatory display board at the viewing area for the Island Spouter in 2017 contained a horrid bit of geological misinformation. Continuing complaints eventually caused replacement of the offending material.

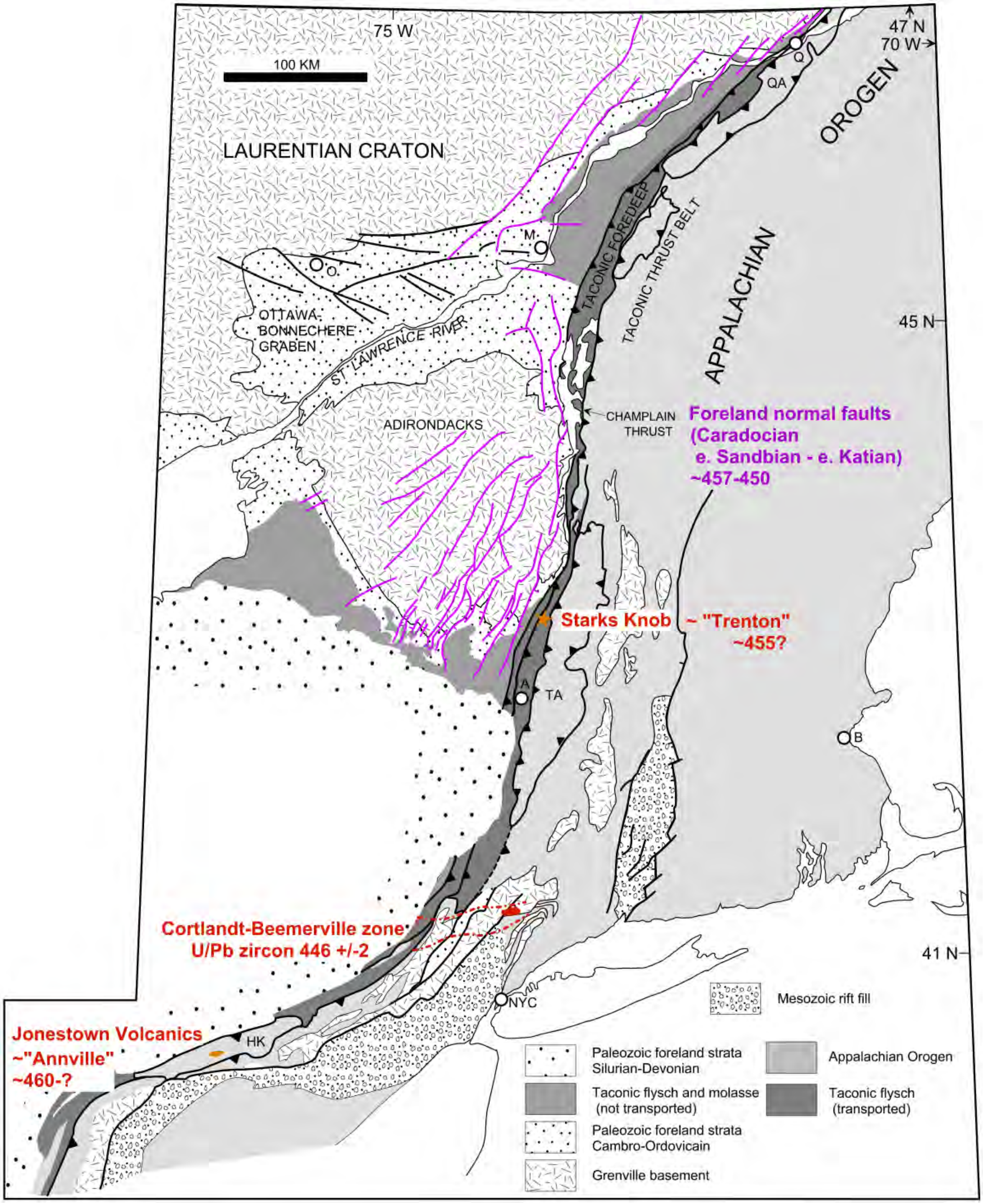


Fig 3-2. Outline tectonic map of the S. Quebec to Pennsylvania segment of the Appalachian Taconic foredeep, showing the contemporary normal faults of the outer trench slope, and the location of outcrops of transported igneous rocks related to this extension (Jonestown; Starks Knob). The Cortland-Beemerville zone is slightly younger, not transported, and suggested to be a Rhine-type "impactogen" rift structure cross-cutting part of the foredeep and related thrusts.
From Schoonmaker et al, (2016).

Stop 4. Stromatolites of the Hoyt Limestone, Lester Park, Greenfield Center NY.

43.092190N 73.848167W

Park off the roadway at the side of Petrified Gardens/Lester Park Road. The flat outcrop surface on the east side displays the spectacular stromatolite assembly. If you are interested, a limited thickness of strata above the stromatolite bed is exposed in the old overgrown quarry west of the road, and in a roadcut just to the south (be careful of traffic sweeping round the blind bend and not expecting to find pedestrians). This occurrence is sufficiently spectacular to have caught the attention of Arthur Holmes, who used a photo of it in his textbook Principles of Physical Geology (page 843 in the 2nd edition). Please do not attempt to take any samples.

The Hoyt Limestone is of latest Cambrian age, a small part of the Beekmantown carbonate platform and passive margin (Bird and Dewey 1970); see Fig 3-1 for its position in the local stratigraphy. The bedding is flat-lying here, even though there are Ordovician-age normal faults not far away both to the east and to the west (see map Fig 0-1). However, apart from local bending near faults of that set, Beekmantown passive margin strata are close to flat, and at the surface lie untransported on Grenville basement rocks west from the surface trace of the westernmost significant thrust of the the Taconic orogen. This structure, a continuation of the Champlain Thrust in Vermont, runs near Fort Ann (NE of Glens Falls on Fig 0-1) and then ramps up south into the flysch and melange and passes just west of Saratoga Lake (see map Fig 0-1). Remember that the Champlain Thrust has displacement of 80km or more (Rowley, 1982), so that the Cambro-Ordovician passive margin section of <200m total thickness seen in outcrop near Saratoga (Fig 3-1) was deposited far inboard, probably at least 150km away from the continental shelf break.

The stromatolites in the bed forming the rock pavement are exposed as truncated horizontal sections (Fig 4-1). The old NYS Museum sign that used to be here announced that this truncation was an effect of the "Great Glacier". I think evidence can be seen near the northern end of the pavement exposure that the truncation was a Cambrian event of marine erosion, because small remnants of a coarse sandy and oolitic limestone bed can be found overlying parts of the truncated stromatolites. This marine planation would represent the effect of a short-lived sea-level regression of small amplitude, perhaps....or a substantial tsunami?

Another similar exposure of this layer is located in the woods east of Petrified Gardens Road about a mile south of Lester Park. This used to be a commercial tourist site (The Petrified Sea Gardens) until the owners retired and sold the property to the nearby quarrying operation. Local residents successfully protested the plan to quarry this property and destroy the stromatolite outcrop. However, it has not generally been open to the public for more than twenty years.

Fig 4-1
Stromatolites in the Hoyt Limestone, Lester Park.

Stop 5. Starks Knob - pillow lava fragment in the Cohoes Melange, Northumberland, NY.

43.118154N 73.586723W

Park on the side of Starks Knob Road near the western of the two sets of flagpoles (to avoid a loud and unpleasant encounter with the owner, don't block the driveway just below the western flagpoles). Walk in using the access path just west of the flagpoles to the grassy area with explanatory geological display boards. The only glass to be found here is of broken bottles recently thrown from the top; be careful where you put your hands when looking at the outcrop. After looking at the outcrop accessible here in the lower part of the Knob, it is recommended, if you wish to go to the top, to return to Starks Knob road, walk up it about 50 metres, and then turn right off the road and follow the signed path up to the top of Starks Knob. If you don't like unfenced heights with a sheer drop, the top may not be for you; but there is a good view.

Because of the late 19th/early 20th century quarrying, the main basalt body is less than half the width it was in October 1777, when General John Stark hauled cannon to the top of this prominent hill only a few hundred yards west of the Hudson River. Johnny Burgoyne and his British and Hessian mercenary army, retreating from their defeat at the battle of Saratoga a few miles south of here, and following the only muddy road in the forest back to Canada, which ran between the Knob and the Hudson River, found Stark's cannons sufficiently intimidating that they surrendered, grounding their arms in the village which is now called Schuylerville (but then called Saratoga) a mile or so south of here. For geologists, it is obvious that the Knob is prominent because it is more resistant to erosion than the shale melange around it, so the geology underlies the reason why Stark put his artillery here. Ordinary enough one might think, except that this is the only occurrence of such lava in the Hudson Valley, and this hill contains all of it! And remember that this defeat and surrender was a most significant one in the removal of monarchy from the (sub-Canadian) part of North America.

Now consider the improbabilities of the geological origin and preservation of this small object.

The geological map (Fig 5-1) shows the outcrop outlines; most of what you see outcropping in the former quarry site are basaltic pillowed lavas, with phacoidal shale melange exposed structurally above the north end of the main pillow mass in the slope up to the old wire fence. A few small fragments of lava (individual pillows, and smaller fragments) can/could be found in shale melange here and in the small outcrop on the south side of Starks Knob Road, but it is important to see that their contacts and, if they can still be seen, the main shale-lava body contacts, are structural, not from lava erupted on/into muds. There are no indications of baking of the shales, and there are nowhere shales interstratified with or originally interstitial to the pillows. Material that might look like shale seen in the pillows is always found to be sheared/foliated chloritic derivatives of the originally fine-grained/glassy pillow margins, and quite distinct from the non-chloritic melangy shale. Nor are there any intrusive basalt offshoots/dikes in the shale.

The present contact of the structurally lower, western side of the volcanics is exposed west of the path to the summit (Fig 5-1). In this place melangy shales with phacoidal fabric also adjoin the lavas along a sharp contact, that dips steeply east and which runs oblique to the orientation of original stratification identified in the lavas (Fig 5-1), and is interpreted to be faulted; no calcite vein material occurs here. In contrast to this, at the base of the eastern cliff of volcanics, there are two places where a gently easterly-dipping contact can be seen structurally underneath the volcanics (Fig 5-1 cross-section). In both these places (position indicated by the slickenfiber lineation arrows on the map) a calcite vein with slickenfibers occurs between the volcanics and the underlying phacoidal shales. Thrust sense slip is given by the vein slickensides, showing that this contact too is a fault that has displaced the volcanics relative to the underlying melange. It seems likely this part of the contact is the same generation of planar gently east-dipping thrust veins seen in the Cohoes Melange at Stops 1 and 2, but we have not tried to obtain fluid inclusion data from Starks Knob. A second vein with slickensides occurs a foot or so below, within the phacoidal shale, and parallel with the vein on the basalt contact, at the southern of these two localities.

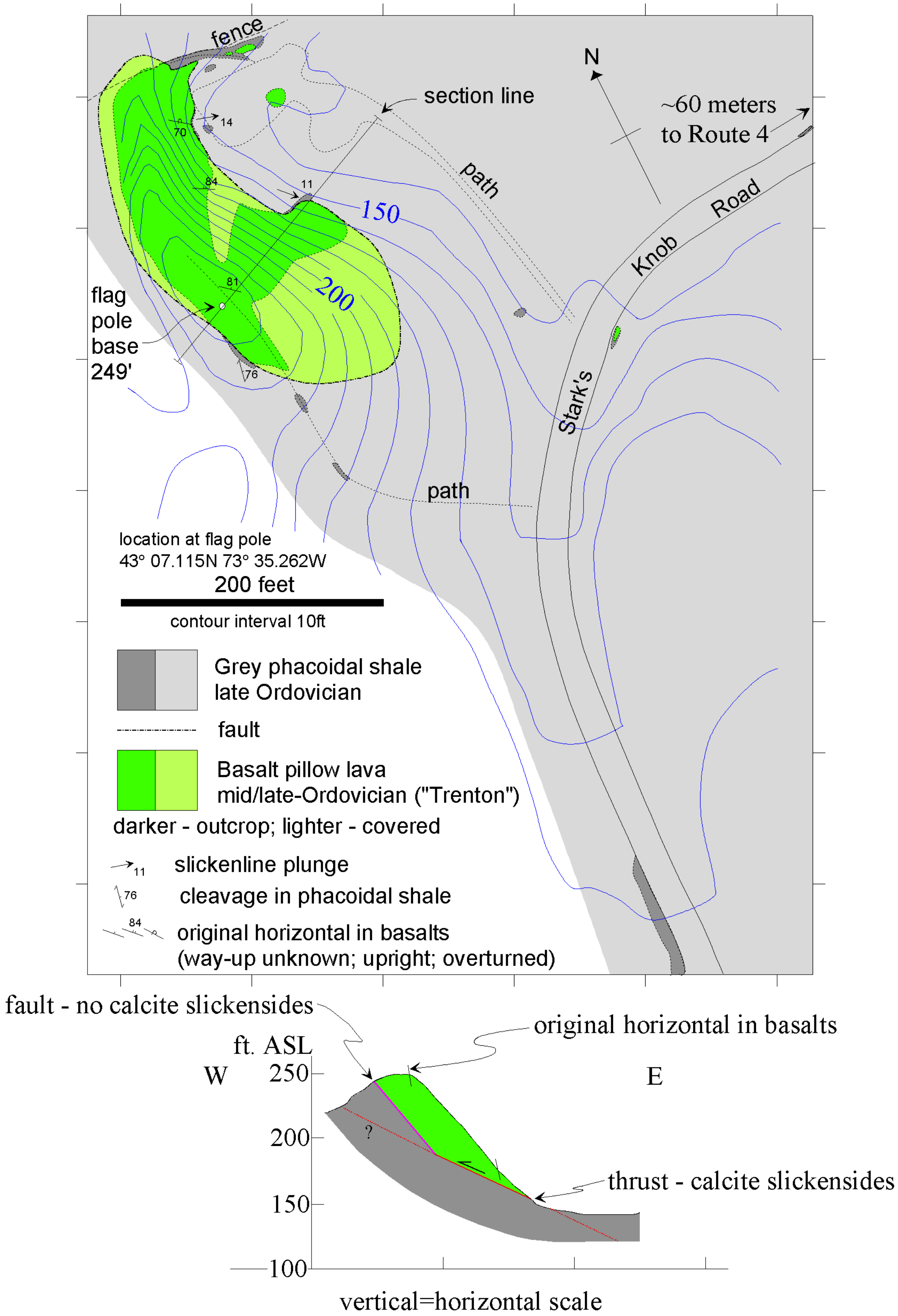

Geological Map of Stark's Knob, Schuylerville, NY

Fig 5-1. Geological outcrop map and cross-section of Starks Knob. Total station survey by W.S.F.Kidd.

The only sedimentary material found within the overall body of the pillowed lavas is a fine-grained sandy-textured (recrystallized) limestone. This occurs both interstitial, between pillows, and within pillows. Inside individual pillow sections, the limestone may form irregular-shaped blobs, but in some cases it occupies a concentric core, and in several significant occurrences, it fills cavities that were formed as successive lava tube drainage chill shelves (photo fig 5-2), as a tube extruded successive pillows from its downslope toe after magma supply to the top of the tube was cut off. These features internal to the pillows require that the precursor sediment for the limestone (probably a lime mud) infiltrated the cavities in the pillowed flow(s) exposed here after the lava had been extruded and cooled in seawater.

One fossil has been found at Starks Knob, discovered in a piece of this limestone on a SUNYA DOGS course field trip in the 1970's by a keen-eyed undergraduate (whose name, I regret to say, has been lost). This marine gastropod (mould), now in the collection of the NYS Museum, was identified by Ellis Yochelson of the Smithsonian as most similar to a late Ordovician shallow marine form *Leiospira sp.* which appears in the Trenton Group limestones (Landing et al, 2003). An attempt to find conodonts or other acid-resistant microfossils in the limestone was unsuccessful despite the collection (by WSFK) and processing (by Ed Landing) of 36kg of material.

Lime mud infiltrating the pillows, only pure limestone of similar-appearance being found in the overall pillow lava body, and the shallow marine association of the fossil strongly indicate that the basalts were erupted on a carbonate platform, or in a shallow marine part of an ocean island, above depths where turbidite clastic sediments could reach, or pelagic sediment (only radiolarian in the Ordovician) dominate infiltration.

Fig 5-2 Limestone filling chill shelves in pillow tube section at Starks Knob.
Way up is to the right (NE)! Lens cap 6cm dia.

The pillow basalts are completely altered, with chlorite-calcite-albite mineral alteration. Pseudomorphs of possible olivine, clinopyroxene, and plagioclase phenocrysts, and a few small original chrome spinel crystals were reported by Pe-Piper (in Landing et al, 2003). The pillows are everywhere infested by calcite veins of which a large number fill thermal contraction cracks radial to pillows and pillow tubes; these suggest that some quite pervasive low-temperature hydrothermal activity affected the volcanics seen in Starks Knob soon after they were erupted and before they were transported. Pe-Piper, in Landing et al (2003), reports clear petrographic and analytical data that shows such hydrothermal activity occurred and that later alteration suggests interaction with fluids from siliciclastic sediments, presumably the shale melange in which the volcanics now lie.

The less mobile trace element geochemistry of these basalts given by Landing et al (2003) shows that they resemble N-MORB, with quite elevated Cr values; a sample independently analysed by Ashcroft (2002) is consistent with those results. Schoonmaker et al (2016) include Starks Knob as an example with several others of different ages, interpreted from stratigraphic/lithological association and age as having an igneous origin in conjunction with lower plate extension and normal faulting of continental lithosphere approaching an active subduction zone. Compositions of basalts in the examples selected tend more commonly to be somewhat more enriched E-MORB types but there is a continuum into the N-MORB field; the significance of this is to show that these compositions do not necessarily require eruption at an oceanic spreading ridge.

In support of the notion that Starks Knob was erupted in a shelf/passive margin environment, over continental crust and lithosphere, we offer the observation of a thin section made by Ashcroft from a fragment of the sample he analysed, which contains a granitoid mini-xenolith, of interlocking quartz and feldspar (photo fig 5-3; Ashcroft, 2002). The things that turn up when you are looking.....

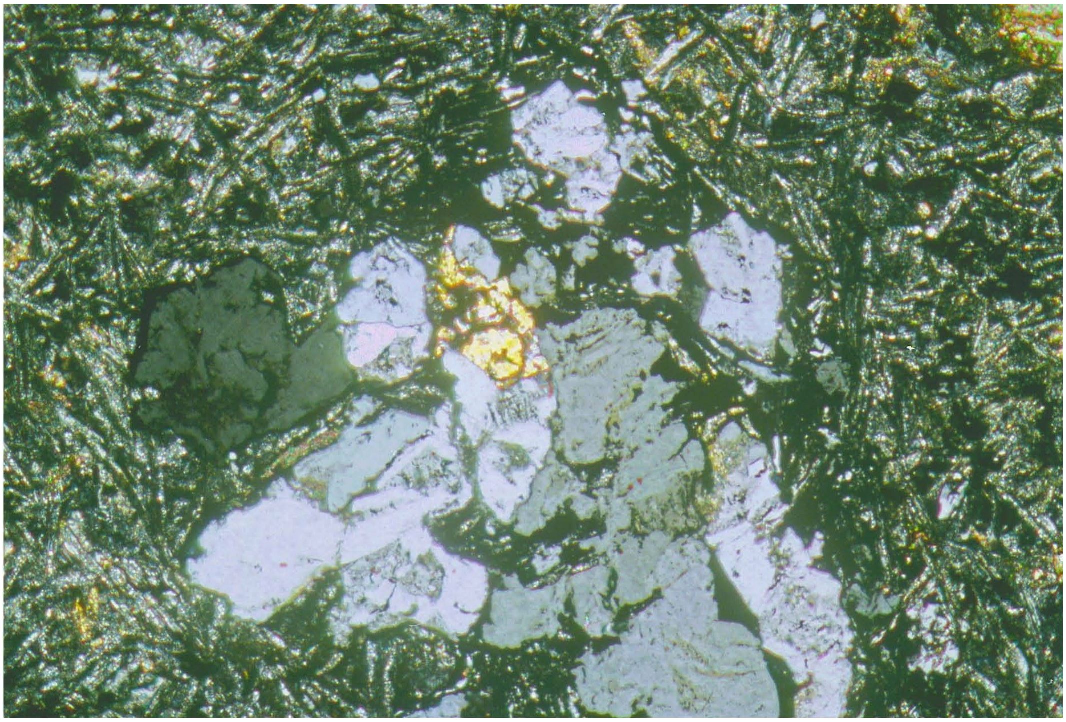


Fig 5-3 Thin section crossed polars photomicrograph of part of Starks Knob basalt sample SN-4 of Ashcroft (2002). Field of view horizontal 2.1mm. Micro-xenolith of granitoid rock (quartz-altered feldspar) in basalt.

[this last section completely revised from that in the original 2017 guide]

In Landing et al (2003), a steeply-dipping tabular limestone lens, found and sampled by Ed Landing, is described. This is exposed on the top of the outcrop at the location of the 81 degree dip symbol shown on the map. The sample shows a pinkish colour on one margin, and small basalt fragments near the other side identified by the discoverer as pebbles. The pink haematitic coloration was interpreted as resulting from baking by the adjacent lava, and the pebbles on the other side as a basal deposit in the lens, seen as a sedimentary layer. This was later illustrated in Landing & Bartholomew (2024). The way up direction obtained from this interpretation is to the southwest.

This is opposite to the way up interpreted from a pillow containing internal chilled drainage "shelves" exposed near the base of the quarry outcrop (at the dip symbol 84 degrees on the map), fully illustrated in the photo 5-2 above. Chilled drainage shelves in pillow lava tubes result from infiltration of seawater through cracks into the drained portion of a tube after the supply of molten lava to that tube has been cut off from the core of the larger overall lava flow, and as the level of magma remaining in the tube drops in successive extrusion events of individual pillows from the toe of the tube. For a significantly inclined lava tube, on a larger flow front, the shelves will extend from the upper side of the tube across towards the lower side, and it might be the case that a random section exposed through the tube could show the part near the tube base. This possibility was suggested in Landing et al (2003). Post-eruption fracturing and downslope transport in talus ramps of near flow surface tube/pillow fragments is observed in modern submarine eruptive settings, so it could perhaps be not in its original orientation. However, the pillows/tube sections in the Starks Knob outcrop, including the one displaying the drainage shelves, appear to be in their original position relative to adjacent ones, all packed together in typical pillow lava geometry. Furthermore, this geometry shows the inflated pillow/tube tops on the northeastern sides, consistent with the carbonate filled cavities between the drainage shelves being in the top of that tube. And there are another two features of the shelves that indicates that way up is to the northeast. One is the apparent chilling grain size gradient within the individual shelves, visible under a hand lens, with slightly finer-grained material at the northeastern, upper sides. The other is the detailed geometry of the shelves, with a more planar top, and a somewhat less planar base, due to immediate chilling and freezing of the meniscus top surface, and to slightly varying depths of cooling in the layer and/or incipient dripping from the base as the next drainage increment started. That feature is apparent in the photo 5-2, also indicating northeast way up.

Because there is no indication of any major fault within the quarry cliff at Starks Knob between the pillow shelves near the base and the limestone layer less than 100 feet away at the top, it is necessary to choose between one or the other as to the way up. Landing in two papers favors the interpretation of the limestone layer with red supposed baking and basal pebbles; Kidd then and now favors the several properties of the chilled shelves and the pillow/tube geometry, noting that red colouration can be of other origins than baking, particularly from low-temperature hydrothermal circulation (which process is shown to have occurred here by Landing et al, 2003). Given that carbonate sediment infiltration is required to form the limestone internal to the pillows, it seems possible that spallation of basalt fragments into and local transport by infiltrated sediment might have occurred to form the pieces interpreted as pebbles and the layer in which they occur.

Lets see what you think about this after looking at the outcrop! Agreed that it is a very secondary issue, given the evidence that the lavas of Starks Knob were transported tectonically, likely a considerable distance.

And one more remark; in a career which involved looking at altogether too much pillow lava, of both ophiolite and of volcanic arc origin, I saw just three examples of drainage shelves in pre-modern deposits. This one at Starks Knob being the best!

One other Paleozoic example, also in a block, but only a few meters across, in a melange setting, with limestone shelf infilling, in the Dunnage Melange in Newfoundland, and one in Early Archean lavas in the Barberton greenstone belt, where the lavas are in intact condition in a thick sequence, but with coarsely crystalline, probably hydrothermal calcite filling of the shelf cavities.

So these drainage shelves are a rare and a remarkable occurrence; please don't hammer or scratch this part of the outcrop.

Stop 6. Thacher State Park and Indian Ladder Trail, Voorheesville, NY.
42.654331N 74.017888W
Park near the new visitor center building, or just to the west near the Pear Orchard entrance.
Lunch Stop (outdoors but under cover at the vistor center if raining).
After lunch, the walkway to the western entrance of the Indian Ladder Trail leads down from the visitor center. Walk down the stone steps to the trail entrance gate, then down onto the wooden viewing deck beyond. There is a bronze plaque fixed to the rock face which commemorates some famous geologists from the 19th century who worked on the Helderberg Devonian (e.g. James Hall, Lardner Vanuxem, or visited it, e.g. Chuck Lyell, Louis Agassiz). Put up by the DAR!
Go down the steel stairway and walk east along the trail to the far end; up the steel stairs there and walk back to the visitor center via several scenic overlook points on the path near the cliff edge.
Some background:
Helderberg Group limestones are earliest Devonian in age and, at the base of the section at Thacher Park, latest Silurian strata (the Rondout Fm.) occur. The biostratigraphic focus in early investigations defined a separation of the Rondout Fm. from the Helderberg Group just because it contains Silurian (Pridoli) as opposed to Devonian fossils. However, it is plain that the Rondout forms the base of a transgressive marine sequence passing up into the Helderberg limestones. A basal arenite, pyritiferous here at Thacher Park, is overlain by shale and dolomitic shale; elsewhere (e.g. near Catskill) there is more dolostone in the Rondout, interpreted as an arid shore sabkha facies (Fig 6-1). The basal Rondout arenite here rests with angular unconformity on gently dipping late Ordovician turbidite arenites and shales. These Ordovician strata just under the unconformity at Thacher Park contain a younger fossil assemblage ("Maysville") than found in any of the Ordovician turbidites elsewhere in the nearby parts of the Hudson and Mohawk Valleys. Ruedemann separated them into a "Indian Ladder Beds" unit but, apart from the (scarce) fossils, they are not otherwise distinguishable from the slightly older Schenectady Fm.
In the cliff at Thacher Park, only the first two formations of the Helderberg Group are exposed, with the Manlius Fm, largely composed of thin-bedded tidal flat micrites, overlying the basal Rondout. The Coeymans Fm. overlies the Manlius, forming the upper part of the cliff, and consisting almost entirely of shell fragment debris of storm deposits, a more offshore facies (Fig 6-1). Bentonite clay layers derived from alteration of volcanic ash occur commonly in the Helderberg units, although no thick ones are seen in the cliffs along the Indian Ladder Trail. Dating of some of these ashes has provided key information to constrain the early Devonian time scale; for instance the U/Pb zircon age of 417.6 +/-1.0 Ma. obtained by Tucker et al (1998) for an ash in the New Scotland Fm. of the Helderberg Group near Cherry Valley.
The strata of the basal Helderberg Group carbonates exposed in the cliff of the Helderberg escarpment are close to flat-lying, although there are parts of the escarpment where dips of a few degrees occur locally. Above the top of the escarpment, less obviously visible until they are mapped, there are local disturbances caused by thrust movement on detachment horizons with the development of local ramps and folds and imbricate/duplex structures (Stander, pers. comm. 2017). The detachments occur in the Kalkberg (this forms the shelf at the top of the cliff at Thacher Park) with splays extending to the base of the Esopus (examples can be seen near the Hop Field parking area). Stander thinks that incipient detachment may also be present in the shale unit which forms the top of the Rondout Fm. (including breccias exposed at Mine Lot Falls along the Indian Ladder Trail); this horizon is certainly the location of a significant thrust detachment horizon farther east and south in the Hudson Valley (Marshak, 1985) and is perhaps seen at stop 7.

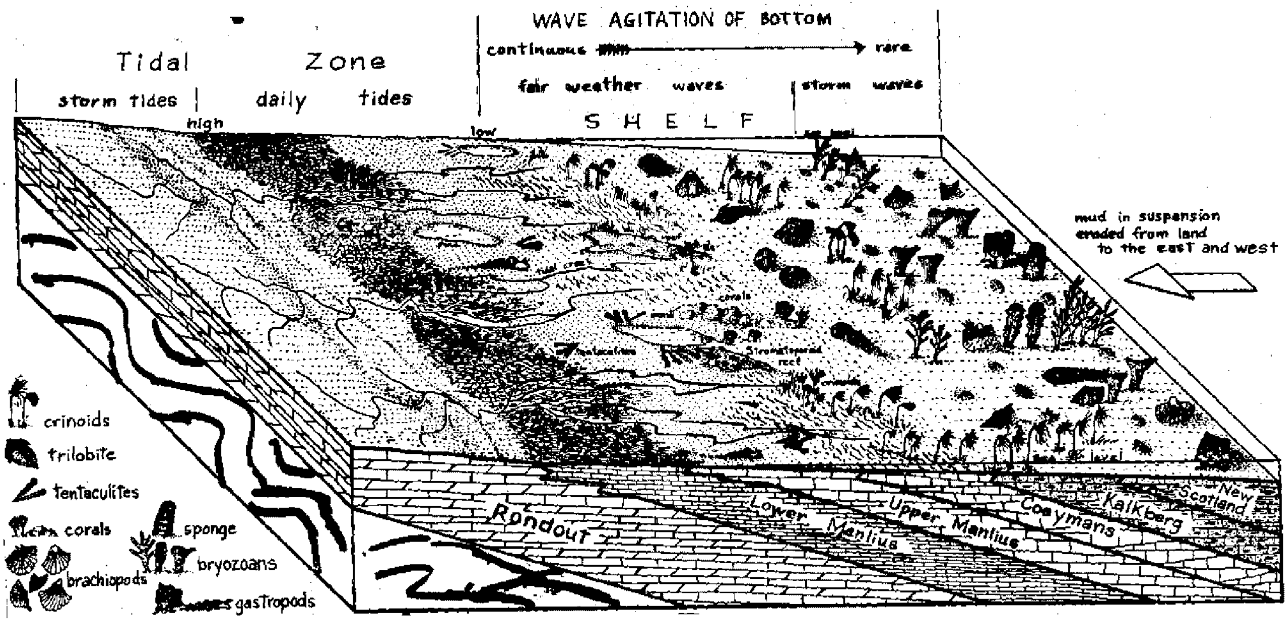


Fig 6-1. Facies diagram for the Rondout Fm and Helderberg Group limestones. (from NYS Museum Publication 14).

Some of the bedrock features that can be seen along the Indian Ladder trail (from west to east):

On the stone stairs before reaching the trail western entrance gate, in the wall of Coeymans limestone to your right, corals in apparent growth position, and overturned by storm waves; these are all storm debris deposits, so the ones in growth orientation may just have happened to finish dumped right side up.

Half way down the steel stairway, where the path angles right around an overhang, the eroded ledge on which you are walking is formed by differential erosion of the shaly and slightly dolomitic Bear Path member of the Manlius Fm. A short-lived input of clay mud to the upper part of the otherwise quite pure carbonate tidal mudflat environment which characterises most of the thin- and planar-bedded micrites of the Manlius. The overhang with thicker beds jutting out here contains stromatoporoids, which are seen more abundantly in similar thicker beds near the base of the Manlius (at the first corner beyond the base of the steel steps; also large thrombolite mounds here).

The path climbs up and passes by a solution-enhanced cavern nucleated on one of the ~N-S joint fractures, and then descends to where an underground stream emerges running out of a low cave dissolved into the lowest Manlius limestone and floored by the shale unit of the top of the Rondout. Just beyond this, at the first waterfall (Outlet Falls), the one exposure near the path of the gently dipping Ordovician greywacke and shale sequence (Schenectady Fm, or Indian Ladder Beds) is found on the east bank of the stream below the level of the path. At the path the basal Rondout pyritiferous quartz arenite outcrops.

East of this point the path is mostly below the cliff base until you approach the Minelot Falls. At the wooden ramp the path passes close to a stromatoporoid-containing bed of the lower Manlius. One of the overhanging layers behind the waterfall shows on its underside the moulds of these stromatoporoid heads. In the back of the overhanging area, the shaly beds of the Rondout occur, in part intact, but in places as breccia. Some examples can be found of pieces partly detached from the roof at the edge of breccia patches. This cemented breccia might represent filling of solution cavities, similar to modern cavities also developed here in this position. Alternatively, there might be incipient structural detachment in this shale (seen farther east in the Hudson Valley) and the breccia be of tectonic origin.

Climbing up the path east of the falls, a ledge and overhang about half way up is formed by the Bear Path member of the upper Manlius. Mudcrack forms can be seen in places on the overhang roof.

Climbing the steel stairs, the Coeymans Fm. limestones are better exposed than at the west end of the trail; similar large corals and coral fragments along with smaller broken pieces of crinoid stems, brachiopod shells, and other shallow marine invertebrates can be seen in these storm deposits.

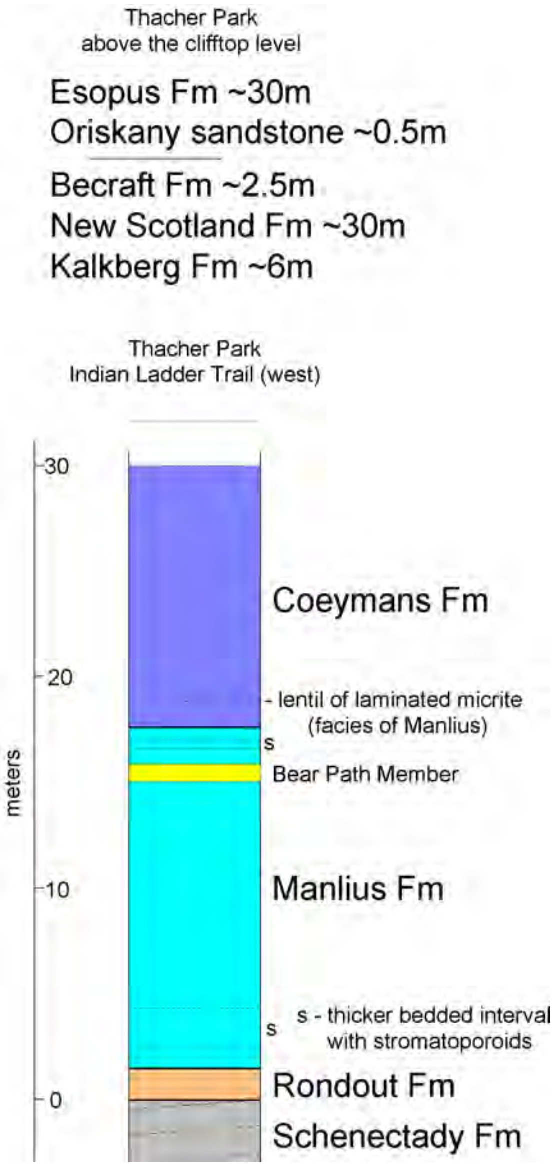


Fig 6-2. Lithostratigraphic column measured on SUNYA DOGS field class trip for the western end of the Indian Ladder trail at Thacher Park, and succession of units in and above the upper Helderberg Group, with thicknesses converted from Goldring (1933).

From the overlooks on the way back to the visitor center, if the air is clear, there are good views over the upper Hudson Valley and the site of the former Lake Albany, and including the area containing the vegetated sand dunes of the Albany Pine Bush, blown across the lake floor from the Mohawk delta near Schenectady, after the lake drained (~10,000 years ago). A view that expresses naturally-driven climate change from the kilometer or more of ice that covered this area only 18,000 years ago.....with only a modest accompanying increase in atmospheric CO_2 until quite recently. Next.....? Fully ice-free planet shoreline at ~180ft APSL (allowing for isostatic effects – Miller et al, 2005), not quite enough to reach the SUNYA podium (you can see the four dorm towers), but lapping around the base of the Empire State Plaza – also visible - “the slabs that ate Albany”.

Stop 7. Quarry in Helderberg limestones deformed by Acadian thrusting/folding, Feura Bush NY.

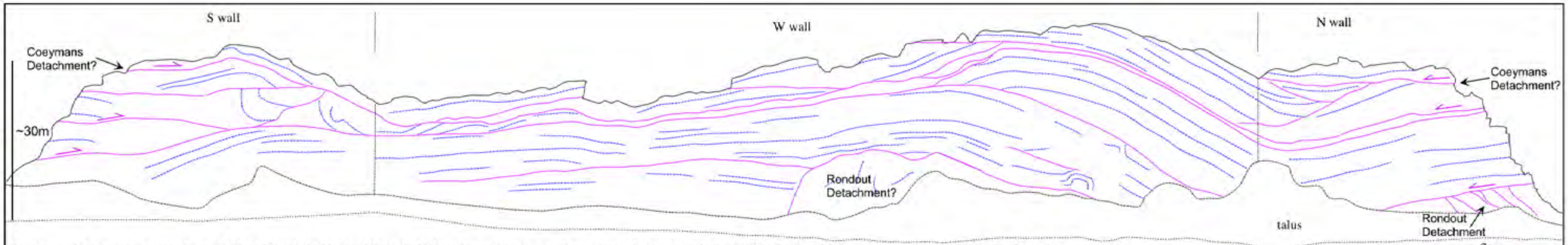
42.558063N 73.862564W
Visiting this stop requires permission in advance from the Bethlehem Police Department (be aware that it is used as a shooting range). From the parking area next to Old Quarry Road (Albany Co Rte 102), find the track at the north end of this area, which loops up into the abandoned quarry (~500 meter walk).

In the quarry walls, limestones of the Helderberg Group, and almost entirely from just the Manlius Fm, are quite spectacularly deformed in thrust ramp and duplex/imbricate structures (Fig 7-1) initiated from the Rondout Detachment localised in the shaly upper member of that Formation (perhaps visible at the north end of the quarry). Marshak (1985) originally described this detachment structure in the area around the Rte 23 roadcuts near Catskill, NY. Very similar features are seen here except (Stander, pers. comm.) the thrust transport given by calcite slickenfibers, which tends to be more nearly E-W here rather than the ~300 direction characteristic of Catskill and most places along the Helderberg escarpment in the Hudson Valley. The imbrication of the Manlius seen here appears to be between a detachment at the top of the Manlius (the base of the overlying Coeymans Fm perhaps seen near the crest of the N and S quarry walls), or alternatively in the shaly Bear Path member of the upper Manlius, and the Rondout Detachment. Detachment at the Manlius/Coeymans contact is not developed in the Rte 23 section near Catskill, but is known in some other places in the deformed Helderberg outcrop.

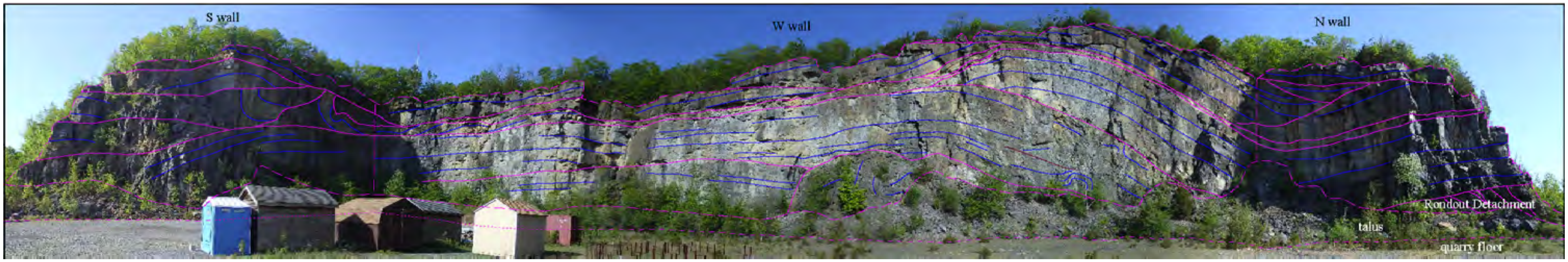
The western boundary of strong Acadian folding, produced by displacements on large ramp structures, lies a short distance west of here, although evidence of Acadian deformation and finite displacement along unfolded detachments in horizons within the upper Helderberg Group, and smaller ramp-generated/fault propagation folds, are mapped at least as far as Thacher Park, and in horizons above the Helderberg Group such detachments can be found quite far to the west, at least as far as Cherry Valley 75km away (Bosworth, 1984).

Calcite slickenfiber and associated veins in Helderberg outcrops are of thrust sense, or of original thrust sense on bedding-parallel detachment surfaces that were subsequently folded. No steep E-dipping normal sense veins have been observed cutting older thrust-sense veins, as are seen in the veins of the Ordovician Cohoes Melange (Lim et al, 2005). Samples of veins from a nearby outcrop (site next to the former Callanan quarry in South Bethlehem, 4km south of here) contain fluid inclusions that yield homogenisation temperatures (Th) of range 100-170C; samples from Catskill gave results mostly in the 120-130C interval. Lim et al point out that this range is entirely lower than that for both thrust-sense and normal sense veins observed in the Ordovician of the area not far distant along strike of the melange belt from this locality (Fig 1-4). The conclusion is that structures widespread in the Taconic melange, of which the thrust and normal sense veins are the last significant developments observed, are all Ordovician in age, and were not significantly modified, in most places, by the Acadian shortening seen here at Stop 7.

Fig 7-1 (next page)
Sketch of the structures exposed in the South Feura Bush quarry walls, and photo panorama used (low-resolution version of the original).
Imbricated panels are almost entirely comprised of Manlius limestone.
Detachments within the Rondout (the shaly upper member), and at or near the top of the Manlius (? the Bear Path member) are probably the bounding surfaces for this imbricate/duplex-type structure. The upper part of the Rondout detachment may be exposed in the northern end of this quarry.



Panorama of the quarry between Feura Bush and South Bethlehem NY, in Helderberg Group limestones. Drawn from photos, so scale is variable; the N and S walls crest at about 32m (105ft) above the quarry floor.



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Road Log for Upper Hudson Valley field trip 12 Aug 2017
mileages are from Google Maps directions; the smaller increments are significantly approximated

Directions Start point 42.651081N 73.755420W	0.0	0.0
From Eagle Street - State Street intersection outside Renaissance Hotel		0.0
Go down State Street to Broadway intersection	0.3	0.3
Turn right, follow Broadway to light	0.2	0.5
Bear left to pass under the I-787 interstate lanes	0.0	
Turn left at light into left lane; take ramp to I-787N on left	0.1	0.6
Follow I-787 to Exit 7E for South Troy (NY 378)	4.4	5.0
Cross the Hudson River on NY 378; get into the left lane before the light	0.9	5.9
Go through the light to the next light in the left lane	0.1	6.0
After the light, get to the right lane, follow US Rte 4 to next light	0.3	6.3
Bear slightly right to follow US Rte 4 to Canal Avenue junction	0.4	6.7
Turn right onto Canal Ave. (stop sign after <0.1) continue to Spring Ave	0.4	7.1
turn right on Spring Ave, go to Linden Ave junction	0.1	7.2
Turn left onto Linden Ave, go uphill to parking lot entrance on left	0.2	7.4
Turn left and park in lot for **Poestenkill Falls Park - Stop 1**		
42.720036N 73.680361W		
Turn left from the parking area; follow Linden Ave to junction with light at Pawling Ave	0.2	7.6
Turn left onto Pawling Ave (NY Rte 66); go to light at Rte 2, Congress Street	0.0	7.7
Turn left onto NY Rte 2 Congress St. Follow Rte 2 curving right then left downhill to:	0.7	8.4
Junction with 8th Street; turn right onto 8th Street; go north to intersection light at Rte 7	0.8	9.2
Turn left onto Rte 7 westbound; get into right lane; take ramp to I-787N (to Cohoes)	0.5	9.7
Go north on I-787 to end at intersection with NY Rte 32; must use left lane at end	2.6	12.3
Go straight across Rte 32 at light, follow New Courtland St then N Mohawk St up hill to:		
Junction with School Street; turn right onto School St, and park. **Stop 2 – Cohoes Falls**	0.8	13.1
42.784286N 73.707402W		
Follow one-way along School>Cataract>Front Streets to N Mohawk St intersection	0.1	13.2
Turn right onto N Mohawk St; changes to Crescent Road, follow to US Rte 9 junction	2.7	15.9
Turn right onto US Rte 9. Go north to intersection with NY Rte 146; be in left turn lane	3.8	19.7
Turn left onto NY 146; get into right lane; take ramp to I-87N	0.3	20.0
Go north on I-87 to exit 13N; take this exit ramp (not 13S just before)	11.5	31.5
Go north on US Rte 9 to left turn lane at intersection with Avenue of the Pines	3.3	34.8
Turn left onto Avenue of the Pines, go to light at intersection with NY Rte 50	1.2	36.0
Turn left onto NY 50; go in left lane to light at entrance to SPAC parking lots	0.3	36.3
Turn left into SPAC parking lot; park at east side (if possible) – **Stop 3 Vale of Springs**	0.1	36.4
43.053871N 73.808011W		
Turn right from SPAC parking lot onto NY 50; get into left turn lane at light at Geyser Road intersection	0.3	36.7
Turn left onto Geyser Road; go to junction with Adams Road	0.7	37.4
Turn right onto Adams Road; follow this round sharp left ~0.1 mile; go to junction with Rowland Street	1.6	39.0

Turn right; go north to light at NY Rte 29 intersection	0.8	39.8
Go straight across onto Petrified Gardens Road; becomes Lester Park Road; park on right at **Lester Park – Stop 4**	1.2	41.0
43.092190N 73.848167W		
Continue north on Lester Park Road to intersection with Middle Grove Road	0.3	41.3
Turn right onto Middle Grove Road; go to junction with NY Rte 9N	0.5	41.8
Turn right onto NY 9N; follow this (angles right just past Saratoga Hospital ~2.5 miles) into Saratoga Springs intersection at Broadway (US Rte 9)	2.9	44.7
Cross Broadway continuing east; road changes to NY Rte 29; go to junction with Grange Hall Road	9.7	54.4
Turn left onto Grange Hall Road; go to junction with Starks Knob Road	0.5	54.9
Turn right onto Starks Knob Road; go down this and park on left just before flagpoles at entrance to **Stop 5 – Starks Knob** (do not block the driveway just beyond the flagpoles!)	0.6	55.5
43.118154N 73.586723W		
Continue on Starks Knob Road to junction with US Rte 4	<0.1	
Turn right; go south on Rte4 to light at intersection with NY Rte 29	1.1	56.6
Turn right; follow Rte 29 back towards Saratoga Springs to junction with Henning Road	9.2	65.8
Turn left; follow Henning Rd to junction at light with NY Rte 9P	0.9	66.7
Turn left; take the ramp to I-87S	0.2	66.9
Follow I-87 south to the end at Western Avenue US Rte 20; use the one from left lane on approaching I-90 interchange and (important!) also at the US 20 intersection	29.6	96.5
Turn left into the right lane of Rte US 20; prepared to turn right at Schoolhouse Road		
Turn right at light onto Schoolhouse Road	<0.1	
Follow Schoolhouse Road to roundabout/circle intersection with Krumkill Road	1.4	97.9
Take right from circle and follow Krumkill Road to intersection with Hilton Road	3.3	101.2
Turn left on Hilton Road; follow to intersection with NY Rte 85A	1.0	102.2
Turn left; follow Rte 85A to intersection with NY Rte 85	0.9	103.1
Turn right; follow Rte 85 through New Salem and up hill to junction with NY Rte 157	4.5	107.6
Bear right onto Rte 157; follow this to Thacher Park Visitor Center entrance on right	4.0	111.6
Turn in to Visitor Center parking; if full continue to Pear Orchard parking beyond		
Thacher Park and Indian Ladder Trail – Lunch and Stop 6		
42.654331N 74.017888W		
Go back along Rte 157 southeast to junction with NY Rte 85	4.0	115.6
Bear right onto Rte 85; go to junction with Stove Pipe Road	0.3	115.9
Take part left turn onto Stove Pipe Road; continue to intersection with NY Rte 443	2.7	118.6
Turn left, go through Clarksville;go to intersection with Lower Flat Rock Road	1.5	120.1
Turn right onto Lower Flat Rock Road; go to junction with NY Rte 32	1.1	121.2
Turn left onto NY 32; go down through Feura Bush to junction with Old Quarry Road	3.1	124.3
Turn right onto Old Quarry Road (Co. Rte 102); follow to just past Bell Crossing Rd (Co.54); turn into dirt parking area on the right; **Stop 7 – S. Feura Bush Quarry**	1.7	126.0
42.558063N 73.862564W		
Go back along Old Quarry Road to Feura Bush junction with NY Rte 32	1.7	127.7
Turn right; follow NY Rte 32 to large intersection with lights	3.1	130.8

Turn/bear right to stay on NY Rte 32 (4-lanes) to US 9W junction (go in left lanes)	3.0	133.8
Keep in the left lanes to join US Rte 9W north	0.6	134.4
Go to the right lane to enter ramp to I-787	0.8	135.2
Follow I-787 to Exit 3; follow signs for Empire Plaza onto south Mall Arterial	1.3	136.5
Go up under the Empire Plaza; get into the right lane; just before the U-bend, take the exit ramp to the right for Swan Street	1.3	137.8
Go up Swan Street; get to the right before the State Street intersection	0.1	137.9
Turn right onto State Street; go down to Eagle Street	0.3	138.2
The Renaissance Hotel is across the Eagle Street intersection		

If time becomes a problem, or the weather is unpleasant, or if participants just generally wish to vote with their feet, the trip can be shortened first by cutting out stop 3 Vale of Springs (this would also save the parking fee); next by shortening the 2 hours planned at Thacher Park; and then by omitting Stop 7. This is supposed to be for your enjoyment; speak up if you would prefer it truncated. Also, if participants wish to have lunch earlier, instead of a late ~1pm lunch at Thacher Park we could stop at Fort Hardy Park in Schuylerville, next to the Hudson, the place where the British surrendered, just after visiting Starks Knob (Stop 5) ~.